Jutta Geldermann and Matthias Schumann (Eds.)

First International Conference on Resource Efficiency in Interorganizational Networks – ResEff 2013 –

November 13th –14th, 2013
Georg–August–Universität Göttingen

Universitätsdrucke Göttingen

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Foreword

While the principle of economic efficiency is omnipresent in business administration and economics, when it comes to resource efficiency, traditional methodological toolsets often fall short. Methods for configuring and optimizing resource efficient supply chains and networks for renewable resources with their varying quantities and qualities are still needed. This is because managing energy and material resources in a sustainable and responsible way can ensure long-term economic success. This includes the use of renewable resources for innovative products and processes in times of scarce resources and unstable prices for materials.

The "***International Conference on Resource Efficiency in Interorganizational Networks***" takes place from the 13-14 of November 2013 and is organized by the Research Training Group 1703 "Resource Efficiency in Interorganizational Networks - Planning Methods to Utilize Renewable Resources" of the University of Göttingen (www.ressourceneffizienz.uni-goettingen.de). The conference brings together interdisciplinary researchers developing strategies and solution concepts for efficient resource utilization and offers a forum for scientific exchange between experts and interdisciplinary groups. During the conference, 42 contributions in the fields of agricultural and forestry science, mathematical optimization, operations research, marketing, production and logistics, and business informatics will be presented in parallel sessions. The three main tracks are "Materials and Technologies", "Planning of Production and Value-Added Networks for Renewable Resources" and "Governance, Coordination, and Sales". Together, these tracks cover the entire supply chain, from wood preparation and reconditioning, to planning efficient production processes using business information, to the marketing of the products.

The track "***Materials and Technologies***" mainly focuses on the characterization and modification of renewable resources for industrial use. It is the starting point for the development of design methods of resource-efficient value-generating networks. The first session focuses on methods for the *"Characterization of Fibres and Particles"*, which comprise for example, the morphological characterization of fibre/particle size and the shape or chemical composition to gain knowledge about the chemical, physical, and mechanical properties of the raw materials used. Furthermore, the influence of modifications and processing of the fibre characteristics will be discussed. The second session examines the *"Supply Chain of*

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Renewable Resources" and the inherent uncertainty of yields and material flows of biomass from forestry and agriculture, due to seasonality and annual fluctuations. Methods for evaluating the supply chain of renewable resources are discussed, with regard to the determination of the most efficient usage options, including the recycling and cascade utilization of materials. Finally, in the session *"Usage of Cell Wall Components, esp. Hemicelluloses"*, methods of hemicellulose extraction and also the use of hemicelluloses in different kinds of industries are investigated.

The second track, "**Planning of Production and Value-Added Networks for Renewable Resources**", focuses on production planning and control of joint products within cascade utilization, i.e. the multiple utilization of a raw material before its conversion into energy. Variations in the quality and quantities of raw materials lead to specific requirements in acquisition and exchange of data, information infrastructures, software applications, and data formats. Thus, the session *"IS and IM in Value-Generating Networks for Renewable Resources"* examines how innovative information systems (IS) and information management (IM) can support supply chain management, production planning and controlling, as well as reporting of cascading materials use. The second session of this track is titled *"Mathematical Optimization in the Presence of Uncertainties"*. As decisions are often made without knowing all relevant data, mathematical applications, concepts, and solutions from the fields of robust optimization, online optimization, and stochastic optimization are sought to handle these uncertainties. The last session, *"Modeling of Production and Logistic Systems"*, deals with the planning and adaptation of production and logistics systems of renewable materials. Decision support in the context of a cascading use of resources requires appropriate quantitative methods due to multiple criteria within the production process and the supply chain.

The business relationships between companies as well as the sales potential of the products with respect to the intermediaries and consumers are examined in the track "**Governance, Coordination, and Sales**". This track focuses on ideal-typical reference models of network structures, marketing concepts, and technical systems for information supply and relationship management. The session *"Consumer Behavior towards Eco-Friendly Products"* considers the consumers' awareness of the implementation of cascade utilization and their willingness to use products from renewable resources. The session *"Distribution of Intermediate and End Products from Renewable Resources"* deals with the questions of which specific features should be considered in the distribution of products from renewable resources and how they affect the design of an efficient distribution system.

This book comprises the extensive versions of the contributions to the conference, which will also be published under Open Access terms at http://webdoc.sub.gwdg.de/univerlag/2013/ResEff.

We would like to sincerely thank all participants and invited speakers. Moreover, we thank all doctoral students, research associates and principal investigators of the Research Training Group for organizing the conference and for reviewing the articles. We are also very grateful for the financial support of the German Research Foundation (Deutsche Forschungsgemeinschaft - DFG) for our research training group and especially for this conference.

Göttingen, November 2013

Jutta Geldermann   Matthias Schumann

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Track A:
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Characterization of Fibres and Particles

Notes on Mechanical Elements in Processing Natural fibre Thermoplastic Composites: Extrusion

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Abstract

Natural fibre thermoplastic composites (NFTC) are obtained by use of standard thermoplastic processing machines. Adjusting mechanical elements of the processing machines, like the twin screw extruder, affects different aspects, namely the energy consumption, the flow-ability of the blend and the defibrillation degree of fibres and hence the mechanical properties of the produced composite.

Twin screw extruder is a common compounding method in manufacturing NFTC. The final morphology and distribution of the natural fibres present in the extruded composites is expected to have a substantial influence on the composite mechanical properties. This part of the study deals with different configurations of extruder elements in order to produce oriented, non-stacked fibres with high aspect ratio. Flax polypropylene composites at 10, 20 and 30 wt% of fibres are produced. Constant temperature profile is applied, while the shear rate effect on the fibre shape is investigated at different extruder speeds. Fibres are finally extracted from the extruded composites and studied by the dynamic image analysis equipment to measure the fibre diameter and length and hence the aspect ratio. Relations correlating fibre final morphology, screw geometry, shear rate and the corresponding mechanical properties are depicted.

Keywords

Natural fibres, flax, polypropylene, twin screw extruder

1   Introduction

In comparison to synthetic fibres; natural fibres are characterized with their low density, availability, suitability to be processed by the normal technology (i.e. extrusion, injection moulding, pulltrusion) and their low abrasion during processing in comparison with glass fibre (Bogoeva-Gaceva et al, 2007; Van de Velde & Kiekens, 2001). The main drawbacks of natural fibres are the increased water absorption and lack of adhesion between the fibre and the neighbouring matrix (Saheb & Jog, 1999). Mass production of thermoplastic polymers with natural fibres takes place most likely in extruders. Improvement of mechanical properties of the extruded composite are attained by avoiding fibre thermal damage, bad fibre-thermoplastic adhesion which affects negatively the effectiveness of polymer fibre load transfer (Gibson 1994) and finally by avoiding the inhomogeneous distribution of fibres within the host thermoplastic matrix which will result in local week areas. Increasing the aspect ratio of the fibre ; fibre length to diameter ratio; is supposed to affect the mechanical properties positively. Low aspect ratio (normally < 20) is extremely studied by the fibres reinforcing concept (Krenchel, 1964; Kelly & Tyson, 1965; Bos, 2004) as represented schematically in figure 1. Modelling of the mechanical properties of the fibre filled polymeric composites starts mainly from the rule of mixture concept. This simple rule is exposed to many modifications (Gibson, 1994; Bos, 2004; Glasser et al., 1999; Andersons et al., 2006; Baiardo et al., 2004; Alvarez et al., 2006; Garkhaili et al., 2000; Elsabbagh et al., 2009a) regarding the fibre length, orientation and coverage efficiency with the coupling agent, see equation (1).

$$\sigma_c = \sigma_m (1 - v_f) + \eta_{oE} \eta_{lE} \sigma_f v_f \tag{1}$$

'c', 'm' and 'f' stand for composite, matrix and fibre respectively, vf is the fibre volume fraction, 'σ' is strength, 'o' and 'l' stand for orientation and fibre. η_{oE} and η_{lE} are fibre orientation and length efficiency terms. η_{lE} is defined in terms of the critical length fibre 'l_c' at which the fibre loading efficiency is maximized. The failure mechanism as shown in figure 2 contains the main reasons of the fracture development in the composite.
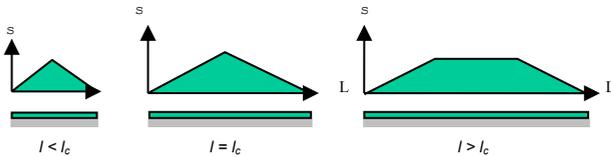
Figure 1: Effect of fibre length on fibre capacity for load transfer
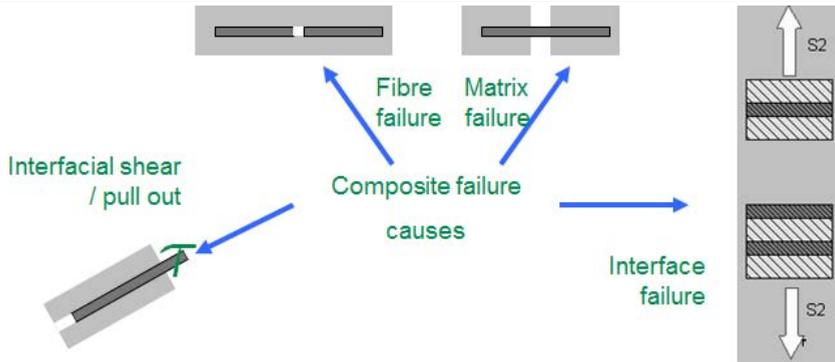
Figure 2: Modes of failure in fibre composite systems

Beaugrand & Berzin (2012) carried out experiments on low melting polymer PCL with chopped Hemp fibers using severe and light kneading configurations at different speeds, temperature and feeding rates. The effect of the fibre failure method by fragmentation in the cell wall or the decohesion in the interfibre cement was correlated with the fibre aspect ratio. Beaugrand & Berzin (2012) found that the breaking stress was surprisingly higher than that of the light kneading configuration. Beaugrand & Berzin (2012) justified his finding that L/D ratio does not give full description of stress transfer.

The current work will address the possible control of fibre geometry distribution (diameter, length and hence the aspect ratio) using different extruder layout designs and different shear rates (extruder speeds) at different fibre loadings and extrusion ratios.

2   Experimental

The materials supplied for this study is as follows: Flax fibres were supplied by Sachsenleinen- Germany in sliver form. Fibre diameter is of 68 μm in average with overall specific gravity of 1.4. Homopolymer polypropylene PP supplied by DOW company (Melting flow index = 52). Carboxylated Polypropylene (Maleic Anhydrid) MAPP as a coupling agent is supplied by Kometra with a product name of Scona TPPP 8112 FA (MFI=80 g/10 min @190°C / 2.16 kg) suitable for wood and natural fibre composites with polypropylene. Flax bundles are cut to 10 m length, then alkalinized with a solution of 2% sodium hydroxide for an overnight. The fibres are then washed with distilled water and neutralized. Drying takes place in two steps; first left in ambient air for 24 hours and secondly left at 80°C for another 24 hours. MAPP is mixed with PP bearing in mind that MAPP : Flax is 1:10 wt/wt. The sequence of compounding is the already

mixed PP/MAPP fed through input hopper and then the fibres are inserted from the extruder side feeder. The temperature pattern is 180-190-190-200-210-220-230-230 °C from the input to the output zones.

Table 1 illustrates the plan of the investigated parameters namely; speed, fibre content and extruder layout. Screw layout effect is investigated in four arrangements. Layouts (A) and (B) have different numbers of kneading elements. Only kneading elements that deal with the input fibres are considered. The kneading elements at the feed zone which deal only with the polymer granulates are not considered. One layout (A) with 8 kneading elements and another with 4 kneading blocks (B). Screw (C) contains patented Multi-Process-Elements (MPE) which allows soft incorporation of shear sensible fibres into the polymer flow. The openings in the MPE element reduce the high shear forces applied on the fibres. MPE also allows the extrusion of moist wood flour/ fibres or bast fibres. The direct processing of fibres without pre-drying also eliminates any risk of explosion. Screw (D) with teethed blocks cause fibres cutting during entry and reversed flow which in turn helps in better fibre compounding. Different fibre contents are tested namely 10, 20 and 30 wt%. Fibre content is calculated and not adjusted directly by the extruder control panel. That is because the fibres are fed as a sliver to an ingate at one third of the extruder length directly to the screw housing.

Table 1: Plan of work

Screw layout	Screw speed [rpm]/ fibre content [wt.-%]		
A	100/10 100/20 100/30	200/10 200/20 200/30	300/10 300/20 300/30
B	100/10 100/20 100/30	200/10 200/20 200/30	300/10 300/20 300/30
C	100/10 100/20 100/30	200/10 200/20 200/30	300/10 300/20 300/30
D	100/10 100/20 100/30	200/10 200/20 200/30	300/10 300/20 300/30

Mechanical properties of the extruded material are prepared by laying the extruded strands in a mould and then hot pressed at 500 bar and 200°C. To observe the fibre geometry development along the extruder processing, the extruder is stopped during the feeding process of the fibre bundle into the extruder. The screw is then withdrawn out of the extruder housing. Then samples are taken from the fibres sticking to the screw at the positions that are directly after each element within the screw. Dynamical image analysis method is a more precise way to measure the fibre length and

diameter. The fibres should be extracted from the composite by decalin solvent. The sample is weighed before and after the test to calculate the fibre content. The extracted fibres from each spot are then air pressurized at 4 bar by the dry dispersing unit (Rodos/L) using the Qicpic machine. The fibres are blown through a light beam and collected endly at the suction. The experiments are done using two types of lenses namely M8 (20-6820 µm) and M6 (5-1750 µm) according to ISO 13322-2. Each test is repeated twice because bigger lens is suitable for fibre length and the smaller lens is more accurate for the diameter measurement.

3 Results and Discussion

The mechanical properties are mainly presented to show the effect of extruder configuration on the composite. The discussion section will try to interpret the attained mechanical properties and the fibre dimensions in terms of the processing parameters and the extruder configurations.
Figure 2 shows the tensile testing results with respect to the fibre content for the different speeds. Increase of fibre content leads to an increase in E-modulus as well as for strength as shown in figures 6a and 6b. In case of strength it seems that there is a parabolic behavior where the maximum strength takes place in [20-30]wt.-% depending on the shape of the configuration. The reported strength values are less than that in literature reported (Elsabbagh et al., 2009b). This is because the kneaded composites reach higher levels of fibre distribution and adhesion with the host matrix especially under the used high injection pressure whereas the extruded/ pressed samples have more weakness points like fibre agglomeration, lack of adhesion and incomplete mould filling during hot pressing.

E-modulus and tensile strength show roughly that the ranking of the extruder configurations is from the lowest to the best as follows: B-A-D-C. The strain at break is oppositely ranked where the 'C' configuration has the least strain and 'B' has the maximum strain. The reasons of the improved strength and E-modulus in configuration 'C' can be explained by either of the following reasons: higher fibre aspect ratio because of the soft compounding profile reached by the MPE elements, or due to more available fibre surface area and hence more free hydroxyl groups that couple with PP by the help of MAPP (Xue et al., 2007). The share of each reason can be hereafter discussed and justified after measuring the geometry of the extracted fibres. Configuration (D) has the next performance. This is can be explained in terms of the openings within the teeth elements which play similar role of MPE elements. However the teethed blocks assert some damage for the fibres by shortening them mechanically and not by

decohesion as preferred. This suggests that teethed block of configuration (D) can reach that of configuration (C) only if the design of the teeth openings is justified. Thus may be useful to handle natural fibre slivers which are fed from the extruder side.

The other configurations (A) and (B) for severe and light kneading respectively show that severe kneading leads to higher mechanical properties as shown in figure 3a and 3b. It can be depicted that the severe kneading results in more fibrillation leading to more adhesion area between PP and natural fibres and hence better load transfer is achieved. Light kneading in configuration (B) is expected to result in larger fibre agglomerations and less adhesion area with the host PP matrix and thus less load capacity. However and from the other side, the elongation at break of configuration (B) is found to be the maximum. That is because the lower fibrillation grade in the light kneading case. Less fibrillation allows significant slide of fibre-to-fibre under stress. Also, local defects due to incomplete polymer impregnation would cause more discontinuities in fibre matrix contact which in turn allows only polymer and not fibre straining. It would be useful in the future to carry out some experiments on the effect of more kneading elements on the fibre length/ diameter and the corresponding mechanical properties in order to see which trend will be followed by these relations namely linear or non-linear.

Figure 4 presents the results again but with respect to the applied speed. Except configuration (A) at 20% and 30%, there is no significant effect for speed on E-modulus as presented in figure 4a. Meanwhile the effect of increasing speed on strength, figure 4b, seems significant and negative especially in the speed range [100-200] rpm. Another notice is that the 30% fibre loading is the least affected by the speed change. It is also obvious in figure 4a and 4b; that the behavior of 30% fibre loading seems superior regarding E-modulus and strength in comparison with 10% and 20% for the whole speed spectrum. 10% and 20% have overlapping behavior along the different speeds. This suggests the non-linearity between fibre content and the measured mechanical property. The results of screw speed effect on E-modulus and strength match partially with what reported by Beaugrand & Berzin (2012) where no significance is found for the range of [100-400] rpm.

Figure 4c shows the speed effect on the elongation at break. The trend appears from the first glance that it is not consistent. However thorough look shows that configurations (A) and (B) at 10% and 20% have an improvement trend in the range of [100-200] rpm. This suggests that there are two contradicting factors. More speed enhances the distribution of fibres homogeneously. But on the other side, the fibre length is shortened and hence the load transfer is weakened.
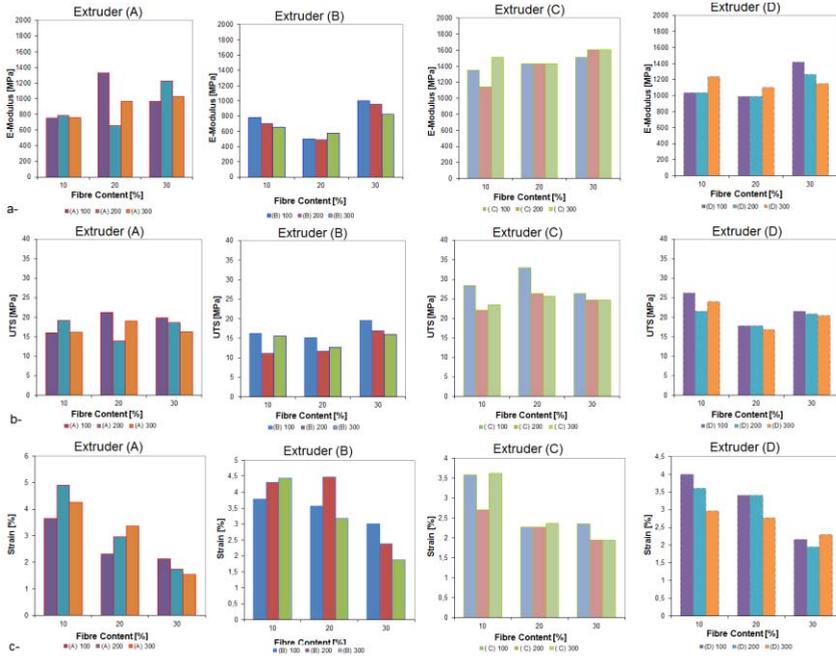
Figure 3: Tensile testing results with respect to fibre content a- E-modulus b- tensile strength c- Strain at break
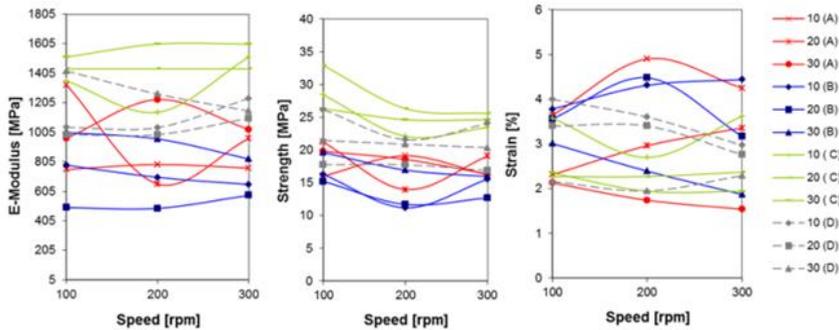
Figure 4: Tensile testing results with respect to speed a- E-modulus b- tensile strength c- Strain at break

As seen in figure 5, aspect ratios of 10% are always bigger than those of 20% and 30%. Thus indicates the effect of the rubbing between the interacting fibres during extruder and their mutual damaging on their lengths. This is explained briefly in (Nilsson, 2005) where the fibre surface length is characterised with the presence of the dislocations like kink bands. These kinks represent weak points in fibres which are prone to break up to shorter ones. The effect of speed appears significant at all fibre

contents in extruder configuration (A), where negative trend is obvious. For the 10% in case of (A), Aspect ratio decreases from almost 20 to 16 while the more fibre content of 20% shows more reduction where it drops from 19.7 at 100 rpm to 12.5 at 300 rpm. At 30% fibre content in case of (A), the aspect ratio suffers more reduction in fibre length even at 100 rpm where it is only 14.5 and then continues dropping to 12.5 at 300 rpm.

This behaviour is repeated but to a lower extent in case of configuration (B). This is expected because of the lower kneading elements which exist in this configuration. In configurations (C) and (D), the trend of aspect ratios is almost stable and independent from the fibre content. However the aspect ratios lie in the range of [10-15] values which is almost 25% less than that of extruder (A) and (B). Screw (D) shows again the dependence of fibre aspect ratio on the fibre content where higher fibre content leads to a reduction of fibre aspect ratio. The 10% has a high aspect ratio which is comparable to that of configuration (A). The speed does not play a significant role with configuration (D).

What is important in figure 5 is the fact that configuration (C) has the least aspect ratio values which are not expected due to the composite high mechanical properties. This result is also in agreement with Beagrand & Berzin (2012). The fibre aspect ratio is not the only key factor which defines the corresponding mechanical properties. Even lowest aspect ratio shows better strength. This can be understood by recalling the fact that the flexible flax fibre with high aspect ratio does not work as expected in a unidirectional load bearing behaviour. The tangled form of the flax fibre reduces the benefit of high aspect ratio as shown in figure 6. On the other way, short fibres may act better as the eficiency of load bearing in an oriented direction will be definitely increased. The miscroscopic study afterwards will check this claim.
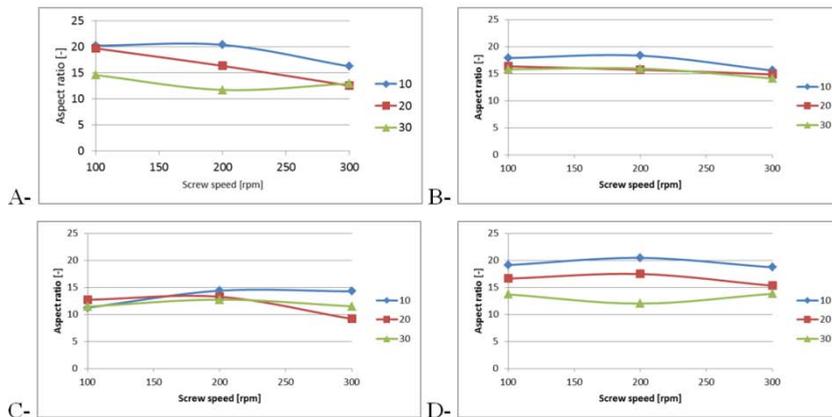
Figure 5: Aspect ratio of the extracted fibres using Qicpic M8 and M6 modes for length and diameter

a-   b-
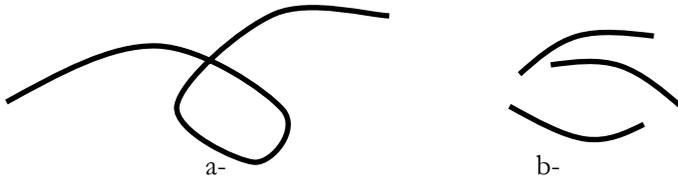
Figure 6: A sketch shows the fibre in a- tangled case with high aspect ratio   b-
relatively oriented fibres with low aspect ratio

Figure 7 shows the development of the aspect ratio for all extruders. It is
clear that aspect ratio reduces along the extruder in general but extruder 'C'
preserves the best AR. Also extruder 'A' where more kneading elements
show high AR at the beginning as better fibrillation is reached (see that
X90/X10 is more homogeneous and small for 'A' in comparison with 'B').
Also it is worth to note that the aspect ratio of extruder 'D' is always less
than those of the others specially at the beginning. This presents the effect
of the teeth elements where fibres are cut mechanically and not only due to
decohesion of fibres under temperature and shearing.

Figure 7: Fibre aspect ratio along the different extruders at 30% Wf and 200 rpm

It is interresting to see the effect of using 'Q2' modus by analysis. 'Q2' is
the second moment of the statistical analysis where the fibre of larger area
(length X diameter) has more weight than fibre of less area. Figure 8 shows
the difference between 'Q1' and 'Q2' analysis modus. As obvious, 'Q2'
modus shows aspect ratio about two to five times more than that of 'Q1'
modus. The trend lines in case of 'Q2' modus is more divergent as shown
by 'Q1' modus. The ranking (high to low) of aspect ratio by using 'Q2' has
the order of A-B-D-C. This means implicitly that the 'A', 'B' and 'D'
extruder configurations have a wide range of fibre dimensions whereas the
configuration 'C' has more convergent fibre dimensions. Hence, 'C' has

the least increase in aspect ratio from 'Q1' to 'Q2' a lower share of trivial fibres. This note represents an advantage for the 'C' configuration with its MPE elements.
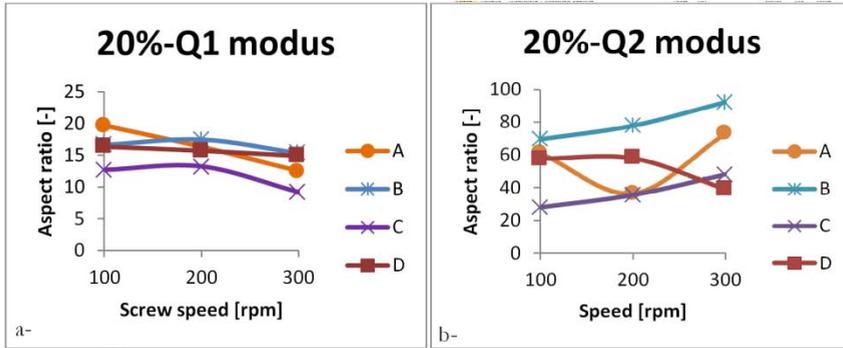
Figure 8: Effect of the statistical analysis modus on the aspect ratio of 20% flax fibre content   a- Q1 b- Q2

Statistical study. Using fitting tools of MATLAB, Weibull parameters, shown in equation (2) are calculated for the measured length distributions.

$$f(x) = b \frac{x^{b-1}}{a^b} e^{-\left(\frac{x}{a}\right)^b}$$

(2)

Table 2 lists the 'a' and 'b' parameters of the Weibull distribution. Table 2 illustrates these parameters with respect to the position in [mm] along the extruder length. This way can define models to describe the fibre dimensions development under the effect of the different extruder elements.

Table 2. Weibull parameters of the fibre length distribution along extruders (A, B, C, D) at 30% Wf and 200 rpm.

Extruder	Position [mm]	a	b	Extruder	Position [mm]	a	b
A	113,33	931,40	1,22	B	126,67	2403,90	0,79
A	140	1416,30	1,00	B	146,67	1490,10	1,00
A	200	1078,80	1,08	B	266,67	994,80	1,16
A	246,67	1490,60	0,99	B	293,3	1910,70	0,92
A	280	2145,00	1,01	B	400	787,80	1,16
A	306,67	1258,10	1,16	B	426,67	721,80	1,20
A	440	831,50	1,13	B	646	553,40	1,22
A	460	808,70	1,19				
A	473,33	806,10	1,18				
A	646	458,70	1,28				
C	113,33	1452,60	1,42	D	113,33	2069,40	1,07
C	126,67	1383,80	1,42	D	166,67	793,00	1,16
C	153,33	1192,70	1,42	D	206,67	409,90	1,31
C	166,67	1144,60	1,31	D	246,67	609,40	1,29

C	193,67	1085,40	1,21	D	380	535,30	1,23
C	206,67	1035,00	1,20	D	413,3	745,60	1,12
C	233,33	992,80	1,20	D	433,3	555,30	1,24
C	246,7	818,10	1,32	D	446,67	552,80	1,33
C	393,3	765,10	1,34	D	446,67	468,30	1,39
C	420	731,40	1,35	D	646	462,40	1,34
C	433,3	718,80	1,36				
C	453,3	691,70	1,38				
C	646	659,20	1,28				

4 Conclusion

Higher mechanical properties of the extruded samples are attained with the following descending ranking: C, D, A, B. Also it is found that the Aspect ratio is not the decisive factor of the mechanical properties in the studied type of natural fibre. Speed effect appears at low fibre content in the 100-200 rpm range. Fibre measurement along the extruder length shows that extruder 'C' shows smooth fibre transition whereas fibre 'D' shows abrupt change and longer stable dimensions. Effect of the dynamic analysis mode whether it is 'Q1' or 'Q2' is also studied. A statistical study is carried out to describe the fibre dimensions and their development along the extruder length under the effect of the different extruder elements.

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Analysis of Malaysian Bamboo Particles for Thermoplastic Composites Production

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Abstract

A study was conducted to determine the chemical attributes, thermal gravimetric and geometry of Malaysian bamboo particles for thermoplastic composites production. The bamboo species, *Bambusa vulgaris* and *Schizostachyum brachycladum*, were harvested, dried and chipped into smaller pieces, and sieved into two different particle sizes, 75 μm and 1 mm. Results indicated that *B. vulgaris* contained slightly higher hot water and ethanol extractives, while *S. brachycladum* contained slightly higher holocellulose, alphacellulose, lignin and ash. The chemical attributes will definitely affect the processing aspects of composites, especially high ash content of these species, due to the presence of inorganic materials (e.g. silica). Both bamboo species showed a similar initial thermal degradation, while *S. brachycladum* showed higher peak temperature and degradation speed. A wide distribution of particle length was measured, varying from almost 0 to 1500 μm. Both species showed increment of aspect ratio from small to large particle sizes. A higher aspect ratio was recorded from the longest particles. Reinforcement and properties of potential bamboo particles-thermoplastic composites are possibly increased due to the increment of particle aspect ratio.

Keywords

Bamboo species (*Bambusa vulgaris* and *Schizostachyum brachycladum*), sieve sizes, thermoplastic composites manufacturing

1 Introduction

Bamboo belongs to the Bambusoideae tribe of the huge family Gramineae, the grass family (Espiloy, 1992). Eichhorn, et al. (2001) stated that there are about 70 genera and over 1,500 species of bamboo all over the world. Malaysia has about 59 bamboo species (documented in Peninsular Malaysia), where about 25 species are known in cultivation and 34 are indigenous (Wong, 1995). According to Lee, et al. (1994), bamboo is considered as one of the fastest growing plant compared to woody species. Wahab, et al. (1997) stated that maturation period of bamboo is shorter, which requires about 3 to 5 years to mature. Properties of bamboo generally vary by species, maturing age, relative density, position along and across culms, node characteristics, form or size of test specimens and growth condition (Siopongco & Munandar, 1987). Bamboo is generally recognized as a promising resource for wood-based industries in the future due to its special characteristics. Based on a report by Rana, et al. (2010), bamboo enterprises are continuously sustaining the economic development in Asia especially in harvesting, manufacturing and marketing activities. About 35% of bamboo species in China are widely used in wood-based industries for house-making, furniture, composite boards, flooring, formwork, etc. (Hua & Kobayashi, 2004). The demand for bamboo materials increased (in the case of China), therefore boost up the bamboo plantation sector to meet market demand. This will definitely contribute to the high utilization of bamboo as a raw material in wood-based industries and at the same time will generate more bamboo waste materials as well (e.g. bamboo chips, bamboo particles, bamboo saw dust, etc.), which are possible to be exploited as raw material for wood-based composite industries.

Recently, bamboo has attracted attention as a potential material for thermoplastic composites production. Properties of bamboo particles-thermoplastic composites have been recorded (Ke & Jyh, 2010; Wang, et al., 2009). The properties of thermoplastic composites based on bamboo particles were compatible (Wang, et al., 2009), while the microstructure of the composites surface exhibited that bamboo particles and polymer matrix were also well mixed together (Wang, et al., 2010). However, the information on the capability of bamboo particle itself for thermoplastic composites is quite limited. Some properties such as chemical attributes, thermal gravimetric and geometry of bamboo particles are essential to be identified for the purpose of thermoplastic composites production. In general, chemical compositions of bamboo are comparatively similar to wood. As reported by Othman, et al. (1995), the main chemical components of bamboo are holocellulose (60 – 70 %), pentosans (20 – 25 %), cellulose, hemicelluloses and lignin (each amounted to about 20 – 30 %).

Minor constituents are slimes, tannins, waxes and inorganic salt (Tomalang, et al., 1980). Compared to wood, however, bamboo has higher alkaline extractives, ash and silica contents (Othman, et al., 1995). Mengeloglu & Karakus (2012) stated that some thermal gravimetric aspects such as initial and maximum degradation temperature are crucial in determining processing temperature. Apart from chemical attributes and thermal gravimetric, particle geometry is also important for thermoplastic composites based on natural particles (Kociszewski, et al., 2012). One of the challenges is how to answer the particle geometry behaviour (such as distribution, size and aspect ratio) for the suitability in bamboo particles-thermoplastic composites production. According to Oksman & Clemons (1998), the optimization of particle size and aspect ratio should be studied thoroughly for the purpose of thermoplastic composites toughness and interface/interphase reaction.

In this study, chemical attributes (hot water and ethanol extractive, holocellulose, alphacellulose, lignin and ash contents), thermal gravimetric (thermal degradation and degradation speed) and particle geometry (distribution, size and aspect ratio) of Malaysian bamboo particles (*B. vulgaris* and *S. brachycladum* species) were determined and analyzed. The potential use of these bamboo particles as reinforcement for thermoplastic composite products was also discussed.

2   Materials and Methodology

The matured *B. vulgaris* and *S. brachycladum* species were selected and harvested from natural bamboo stand in Raub, Malaysia, and transferred to Bio-Composite Laboratory, Universiti Teknologi MARA, Shah Alam, Malaysia, for further processing. The whole bamboo culm (includes bamboo epidermis) was utilized in this study. The culms were chipped into smaller pieces (10 to 30 mm in length and 1 to 3 mm in thickness), air-dried for several weeks and transported to Department of Wood Biology and Wood Products, Faculty of Forest Sciences and Forest Ecology, University of Göttingen, Germany, for further assessments. The dried chips were milled using hammer mill machine to produce two groups of small particles using different sieve sizes; 75 μm and 1 mm. The particles were dried in a drying oven at 103 °C for 24 hours to minimize their moisture contents.

The chemical attributes analysis, such as hot water extractive content was conducted by adding 13 g of particles into the extraction thimbles (TAPPI T264, 1997). The samples were put into the heated Soxhlets apparatus over 200 ml distilled water, boiled for 6 hours, cooled in a fume hood for 24 hours and dried in a drying oven (Temperature = 103 °C, time = 48

hours) for hot-water extractive content determination. The extracted samples were put again into the Soxhlet apparatus over the 200 ml ethanol-cyclohexane solvent, boiled up again for 6 hours, cooled in a fume hood for 96 hours before oven dried for ethanol extractive determination.

2 g of extracted sample was put into a 250 ml Erlenmeyer flask with 0.75 g natrium chloride, 0.25 g acetic acid and 80 ml distilled water for holocellulose determination (Wise, et al., 1946). The flask was put into heated water bath (80 °C), shaken for 3 hours, while the natrium chloride, acetic acid and distilled water were added for each hour in between. The mixture was left to cool down, filtered and washed with 100 ml distilled water followed by 25 ml acetic acid and oven dried for holocellulose determination. Alpha-cellulose was determined from the holocellulose extraction (TAPPI T203, 1993). The extracted sample was put together with 75 ml natrium chloride into 100 ml Erlenmeyer flask, left at room temperature for 2 hours, shaken every 15 minutes, filtered and washed using 25 ml natrium hydroxide, 150 ml distilled water, 25 ml acetic acid and 25 ml aceton before oven dried for alpha-cellulose determination.

The extracted samples were also used for lignin content determination (TAPPI T222, 1998). 5 g of samples were put into 100 ml beakers while 15 ml of 72 % acid sulphuric were added and stirred for 2 hours. The mixture was transferred into 1000 ml Erlenmeyer flask, diluted with 200 ml distilled water and boiled for 4 hours. The mixture residue (lignin) was filtered and washed with hot distilled water before oven dried for lignin determination. The ash content was determined based on TAPPI T211 (1993). 10 g of extracted particle was placed in porcelain crucible, heated over a low flame of Bunsen burner to carbonize the sample without flaming (char) and placed in a furnace at 525 ± 25 °C for 4 to 5 hours. The furnace was switched off and the sample was cooled overnight. After the completion of cooling, the sample was transferred into desiccator and cooled again to room temperature for ash determination.

Thermal gravimetric analysis of particles was done in a thermal analyzer, Netsch TG209 F1 IRIS, using a scanning of 20 K/min heating rate under nitrogen with 20 ml/min flow rate, from room temperature until 800 °C. Approximately 12 mg of dried particle was used to measure the thermal degradation. For each particle group the mass loss (TG)/thermal degradation (T_d) curve (%) and the degradation speed (DTG) curve (%/min) were generated and calculated using Netsch Proteus Thermal Analysis software. The initial T_d was set to 5 % mass loss of the samples.

The particle geometry analysis for both species and sieve groups was carried out using the optical dynamic image analysis (DIA) system with QICPIC Sympatec (Germany) sensor machine (Witt, et al., 2007). The dried particles were air-conditioned at 22 °C and 65 % humidity for

one week. The range of measurement area was M6 (from 5 to 5120 μm). The dispersion of the particle through the scanning optic was performed by a dry dispersion unit in DIA system with 1 bar air pressure. The particles were separated from each other by the transportation of air pressure from this dispersion unit. Typically, more than 1,000,000 particles are needed to reach the maximum error value below 1 % (ISO 14488, 2007). The particles were oriented randomly and captured with the highest possible contrast in order to detect the precise images. The bamboo particle geometry was analyzed based on their distribution, size and aspect ratio (proportion between length and diameter).

3   Results and Discussion

Table 1 shows the results of the chemical attributes of *B. vulgaris* and *S. brachycladum*. The results were also compared with other bamboo species from different authors. In general, *B. vulgaris* in this study contained slightly higher hot water and ethanol extractive compared to *S. brachycladum*. The hot water extractive of bamboo or any woody material indicates tannins, gums, sugar, starches and coloring matter, while ethanol extractive indicates the presence of waxes, fats, resins and possible wood gum (TAPPI T264, 1997). All of these materials are soluble materials and generally not considered as part of bamboo substances. The presence of natural extractives can possibly prevent the bonding performance of natural particles for composite products (Frihart & Hunt, 2010). Both species showed dark green color after ethanol extraction due to the extractive process of chlorophyll in bamboo epidermis. *S. brachycladum* was found to contain relatively higher holocellulose, alphacellulose and ash compared to *B. vulgaris*. Janssen (1981) stated that alphacellulose is the main function of mechanical properties of bamboo. In general, chemical attributes of *B. vulgaris* and *S. brachycladum* in this study did not vary much with *Gigantochloa scortechinii* (Kassim, 1999) and *Phyllostachys pubescens* (Li, 2004). However, the high ash content of *B. vulgaris* and *S. brachycladum* in this study may potentially decrease the processing performance of thermoplastic composites due to the presence of inorganic materials (e.g. silica) in epidermis, especially when related to thermal stability of particles during composites processing. The ash content in both bamboo species in this study (especially *S. brachycladum*) was greatly higher when compared to wood species; e. g. loblolly pine = 0.2 %, red maple = 0.4 %, ponderosa pine = 0.5 % (Petterson, 1984) and Malaysian hardwoods = 0.1 – 2.5 % (Khoo & Peh, 1982). According to Li (2004), bamboo epidermis contained the significantly highest amount of ash compared to middle and inner layer due to the presence of

high silica in the epidermis layer of a culm. Since ash was previously referred to these inorganic materials such as silicates, sulfates, carbonates or metal ions (Rydholm, 1965), the consideration of processing parameters (e.g. temperature and rotating screw speed) have to be undertaken. Both bamboo species in this study contained a quite similar amount of lignin. Scurlock, et al. (2000) stated that bamboo lignin contributes to its high heating value during processing of bamboo-based materials, while its rigidity is suitable for building material.

Table 1: Chemical attributes of *B. vulgaris* (Bv) and *S. brachycladum* (Sb) in comparison to *Gigantochloa scortechinii* (Gs) and *Phyllostachys pubescens* (Pp).

Chemical attributes	Bv	Sb	Gs[1]	Pp[2]
Hot water extraction (%)	6.4	5.4	7.3	5.2
Ethanol extraction (%)	4.3	2.8	3.3	6.8
Lignin (%)	24.5	24.7	25.8	23
Holocellulose (%)	64.8	66.7	65.8	72.5
Alpha-cellulose (%)	39.8	44.1	-	47.7
Ash (%)	2.3	3.1	1.3	1.3

1 = Data from Kassim (1999)
2 = Data from Li (2004)

Figure 1 shows the T_d and DTG curves of particles, while Table 2 summarizes the T_d and DTG data. Due to the evaporation of moisture, the mass loses before 100 °C were neglected. While the maximum DTG peak of moisture loss was found at 66 °C, the degradation speed was stabilized until 100 °C. Therefore, 100 °C served as starting curves of TG and DTG. Based on the figure, the masses for both species and particle size were stable up to 200 °C. Generally, T_d of both species was ranged from 235.7 up to 254.6 °C. Based on the previous statement by Saheb & Jog (1999), T_d of natural materials is associated to low (220 – 280 °C) and high temperature degradation (280 – 300 °C), with the former one was for hemicelluloses and cellulose degradation, the later was for lignin degradation. In term of processing point of view, Mengeloglu & Karakus (2012) in their study described that the extruder temperature during thermoplastic composites extrusion should be set less than the thermal degradation temperature of natural particle in order to prevent these particles from degrading. From Table 2, *S. brachycladum* exhibited relatively higher peak temperature and peak DTG compared to *B. vulgaris*.
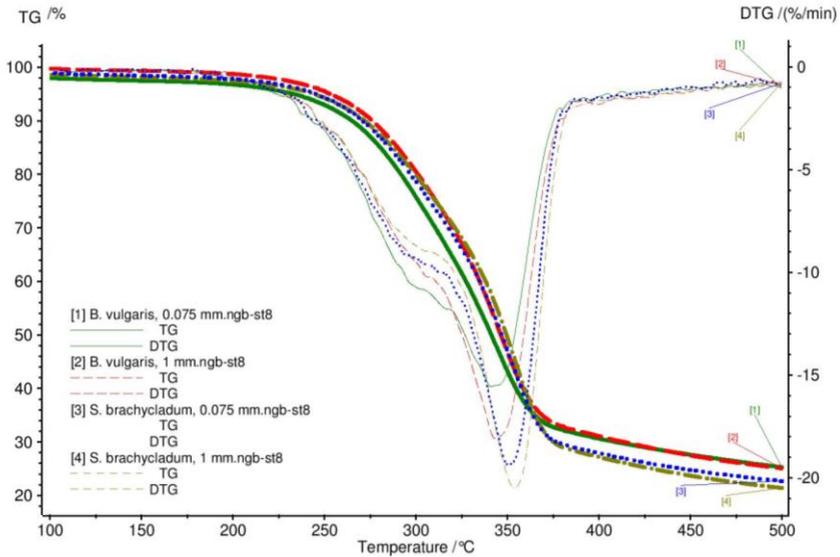
Figure 1: T_d [%] and DTG [%/min] curves of *B. vulgaris* and *S. brachycladum* particles.

Table 2: T_d and DTG data for *B. vulgaris* and *S. brachycladum* particles.

Particles	T_d [°C]	Peak Temperature [°C]	Peak DTG [%/min]
B. vulgaris /75 μm	235.7	341.2	15.6
B. vulgaris /1 mm	254.6	343.4	18.1
S. brachycladum/75 μm	246.7	350.5	19.4
S. brachycladum/1 mm	246.2	353.9	20.5

Figure 2 shows the particle length cumulative distribution from different sieve size groups (75 μm and 1 mm), while Table 3 shows the number of analysed particles, cumulative distribution and aspect ratio of some particle length. A total number of up to 24.8 million particles were measured for each sieve size group. A wide distribution of particle length was measured (Figure 2), varying from almost 0 to 1500 μm. About 99 % of particles from *B. vulgaris*/75 μm and *S. brachycladum*/75 μm sieve groups were smaller than 500 μm in length, whereas 90 % of particles from *B. vulgaris*/1 mm and 83 % of particles from *S. brachycladum*/1 mm were smaller than 500 μm in length. Both species show increment of aspect ratio from small to large particle sizes for both sieve size groups. A higher aspect ratio was recorded from the longest particles. For all groups, only 5.9 to 7.6 % of particles had an aspect ratio of less than 1.7. About 99 % of particles from *B. vulgaris*/75 μm group had an aspect ratio of less than 4.2. According to Kociszewski, et al. (2012), the large-sized particles with high aspect ratio

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provided better wood polymer composites (WPC) properties than the small-sized particles. Transfer efficiency of load from matrix to wood fiber was increased with increasing fiber length/diameter ratio (Migneault, et al., 2008). Although the reinforcing potential for thermoplastic composites production is seemed to be quite limited, higher reinforcement and properties of bamboo particles-thermoplastic composites in this study are possibly increased.
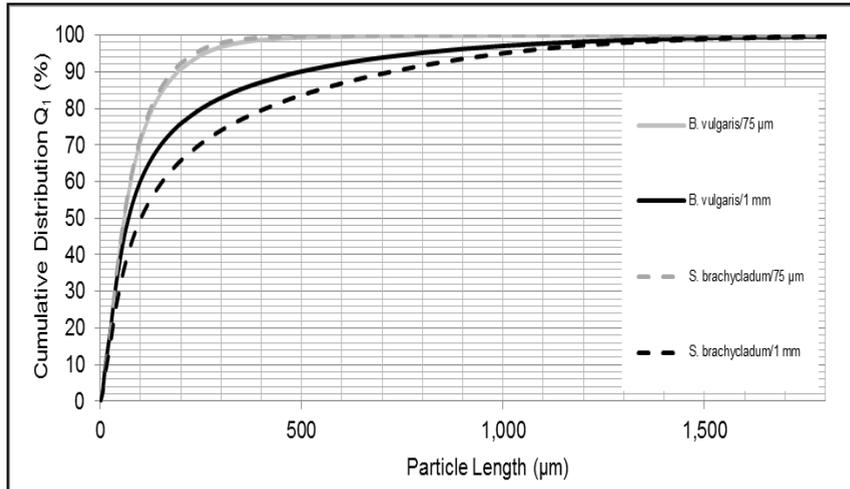
Figure 2: Particle length cumulative distribution from different sieve sizes (75 μm and 1 mm).

Table 3: Number of analyzed particles, cumulative distribution and aspect ratio of some particle length (Bv = *B. vulgaris*, Sb = *S. brachycladum*).

Species	Sieve Size	No. of Analyzed Particles (Million)	Length (μm)	Cumulative Distribution (%)	Aspect Ratio
Bv	75 μm	24.06	10	6. 7	1.7
			100	71.1	2.1
			500	99.4	4.2
	1 mm	13.26	10	7.5	1.7
			100	60.3	2.1
			500	90.1	4.0
Sb	75 μm	24.81	10	6.6	1.7
			100	72.2	2.1
			500	99.7	3.3
	1 mm	9.33	10	5.9	1.7
			100	49.9	2.2
			500	83.6	3.4

4 Conclusions

The analysis of Malaysian bamboo particles showed that different species contained different chemical attributes which will definitely influence the processing performance of thermoplastic composites. T_d value was generally ranged from 235.7 to 254.6 °C, while the peak temperature and DTG of *S. brachycladum* were higher than *B. vulgaris*. A wide particle sizes cumulative distribution (length) of Malaysian bamboo species was also recorded. Although limited, the aspect ratio of particles from small to large sizes was increased, thus provide possible reinforcement for thermoplastic composite products.

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Green Composites

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Abstract

Composites from polymers (rubbers and plastics) and reinforcing fibers provide best properties of each. They replace conventional materials in many structural and non-structural applications. Both fibers and plastics are light, on combination they give composites of very high strength to weight ratio. In recent years composites made from natural (cellulosic) fibers and organic polymers have gained a lot of interest in construction and automobile industry. Unlike synthetic fibers, natural fibers are abundant, renewable, cheap and of low density. Composites made from natural fibers are cost effective and environment friendly. However, lack of interfacial adhesion and poor resistance to moisture absorption makes the use of natural fibers less attractive for critical applications. However, these problems can be successfully alleviated by suitable chemical treatments. This presentation deals with the use of natural fibers such as pineapple leaf fiber, coir fiber, sisal fiber, oil palm fiber and banana fiber as reinforcing material for various thermoplastics, thermosets and rubbers. The fiber surface modifications via various chemical treatments to improve the fiber-matrix interface adhesion on mechanical, viscoelastic, dielectric rheological ageing and thermal properties. The use of these composites as building materials will be discussed. Finally recent developments in cellulose nano-composites will also be presented.

Keywords

Natural fibers, green composites, cellulose

1 Introduction

The material scientists all over the world focused their attention on polymer composites reinforced with various natural fibres, primarily to cut down the cost of raw materials. Several natural fibres have been detected

to be effective as reinforcement in various forms (as short fibres, as long fibres and also as textile). The interest in using natural fibres as reinforcement in polymer matrices has grown rapidly in recent years for making low cost building materials, automobile components and other biomedical applications. Natural fibres and biopolymers have been found to show a pronounced impact on environmental protection Natural fibers have gained increasing attention due to its high strength, stiffness, biodegradability, renewability and their application in development of composites. A lot of research works have been performed all over the world on the use of natural fibers as reinforcing material for the preparation of various types of bio-composites (Valentini, 2013; Gabr, 2013; Shi., 2013; Cheng, 2013; Koga, 2013; Sambo, 2012; Savadekar, 2012; Abraham, 2013). A combination of natural fibres as reinforcing agent and bio-based polymers as matrix should enable the production of truly green composite materials possessing specific properties comparable favorably with those of glass fiber-based composites. However, there is still limited information in the literature about the best conditions for obtaining nanofibres from several vegetable sources and the impact of these conditions on the properties of bio-composites. Cellulosic materials have a great potential as nanomaterials because they are abundant, renewable, presents low density, have a nanofibrillar structure, and can be made multifunctional and self-assemble into well-defined architectures.

2 Experimental

The main process for the isolation of cellulose nanofibres (CNs) from cellulose fibers is based on acid hydrolysis. The nature of the acid and the acid-to-cellulosic fiber ratio are also important parameters that affect the preparation of CNs. Nanofibres can also be obtained by applying a simple laboratory technique like Steam explosion. The geometrical dimensions (length, L, and width, w) of CNs are found to vary widely, depending on the source of the cellulosic material and the conditions under which the hydrolysis is performed. Such variations are due, in part, to the diffusion controlled nature of the acid hydrolysis. The heterogeneity in size in CNs obtained from hydrolysis, for a given source type, can be reduced by incorporating filtration, differential centrifugation, or ultracentrifugation steps.

The preparation of nanocellulose executed along 3 phases as shown in Figure 1 and described below.
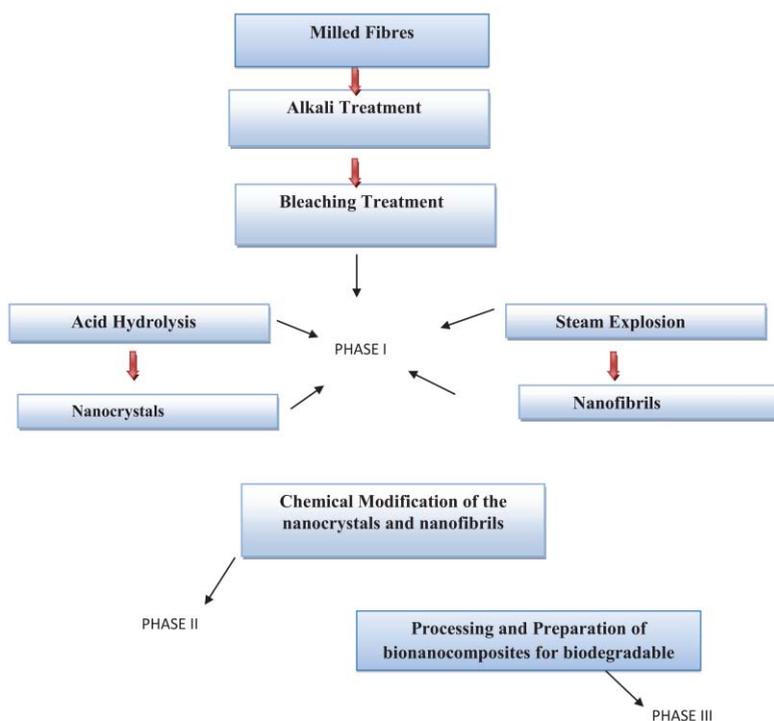
Figure 1: The preparation of nanocellulose

Phase I–Pre-treatment of the fibres and preparation of cellulose nanofibres

The first phase of the work involves separation of the cellulose nanocrystals and nanofibrils and their characterisation. The natural fibres will be extracted with 1% of NaOH at 80 °C for or 2.5 h. This process allows the solubilisation of pectin and hemicelluloses, which will be removed by filtration. The resulting insoluble material will be bleached with NaClO2 solution.

In acid hydrolysis the cellulose nanofibres obtained from native fibres are highly crystalline and rigid nanoparticles known as nanocrystalline cellulose (NCC) or whiskers. In this technique aqueous suspension of cellulose nanocrystals can be obtained by hydrolysis of chemically purified cellulose by 60%(w/w) and sulphuric acid for 5 h at 50 °C under strong agitation.

In the steam explosion method, a laboratory autoclave, which can work with 137 Pa pressure, will be used for steam treatment. Steam explosion technique will be applied on the alkali treated fibre for one hour and

steam pre-treatment will be performed by loading the lignocellulosic material directly into the steam gun and treating it with high pressure steam at temperatures within 100 to 150 ºC. The steam explosion generates semi-crystalline nanofibrils (Pasquini, 2008; Mehta, 2006; Lin, 2012; Kvien, 2005).

Phase II – Chemical modification of cellulose nanofibres

In the second phase of the work, the acid hydrolysed and steam exploded nanofibres will be collected and particle size evaluated. After that these nanofibres obtained from acid hydrolysis and steam explosion processes will be chemically modified to obtain a their good dispersion into the non-polar polymer matrix. Different chemical modifications of the different cellulose nanofibres will be attempted, including: esterification, catonization,acetylation, oxidation (TEMPO), silylation and polymer grafting.

Detailed evaluation of the surface of the chemically modified nanofibres will be done by techniques like scanning electron microscopy (SEM) and atomic force microscopy (AFM)

Phase III – Preparation and characterization of the bionano-composites

In the third phase of the work, bionanocomposites will be prepared by (i) casting(solvent evaporation) and (ii) extrusion(iii) Two roll milling etc. with polymer matrix.

The production of nano-scale cellulose fibres and their application in polymer composite reinforcement is a relatively new research field. Natural fibres, the most abundant bio polymers and nano materials serve as very good source for cellulose. Nanocelluloses and their unique properties such as high stiffness, strength, high specific surface area, low coefficient of thermal expansion, optical transparency and self-assembly behavior make it very good candidate for utilizing them in the making of bio/nanocomposites (Rosa, 2010; Zimmermann, 2010; Cherian, 2008; Wang, 2007; Roohani, 2008; Alemdar, 2008 ; Mora´n, 2008). Nanofibre reinforced polymer composites give improved properties compared to neat polymer and micro composites based on the same fibres.

Taking advantage of the large number of hydroxyl groups at the surface of nanocellulose substrates, different chemical modifications have been attempted, including esterification, etherification, oxidation, silylation, amidation, polymer grafting, etc.(Wei, 2013; Pasquini, 2008; Pothan, 2006; Mehta, 2006; Ganan, 2005; Abraham, 2013)Non-covalent surface modification, including the use of adsorbing surfactants and coupling agents has been also studied. All chemical functionalization have been mainly conducted (i) to tune the surface characteristics of nanocelluloses to promote their dispersion in nonpolar organic media and/or to improve their com-

patibility with hydrophobic matrices in nanocomposites; (ii) to introduce stable negative or positive charges on the surface of nanocellulose mainly CNs to obtain better electrostatic repulsion-induced dispersion especially when exploring their self-assembly properties. The main challenge for the chemical functionalization of the different nanocellulose substrates is to conduct it in such a way that it only changes their surface while preserving their original morphology, avoiding any polymorphic conversion and maintaining the integrity of their native crystalline structure (Habibi, 2010; Gabr, 2013; Dufresne, 2008; Cao, 2012).

3 Results

3.1 Characterizations nanowhiskers
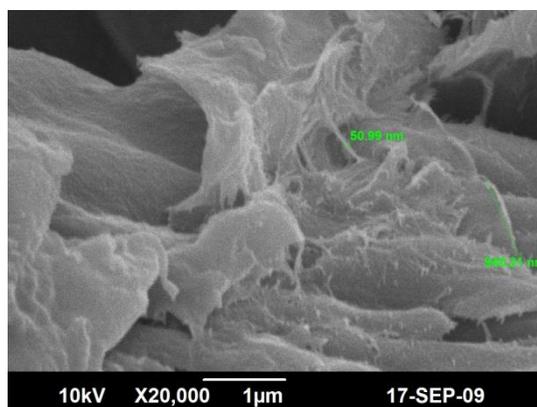
Figure 2: SEM image of nanocellulose whisker (Thomas, 2010)
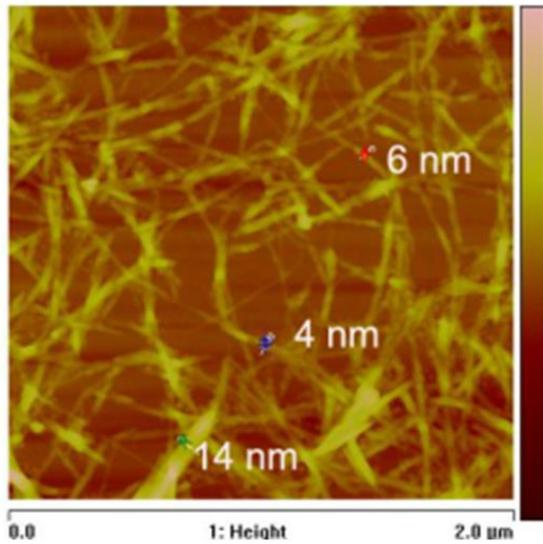
Figure 3: AFM image of nanocellulose whisker (Thomas, 2010)

3.2 Characterizations NR/Cellulose nanocomposites
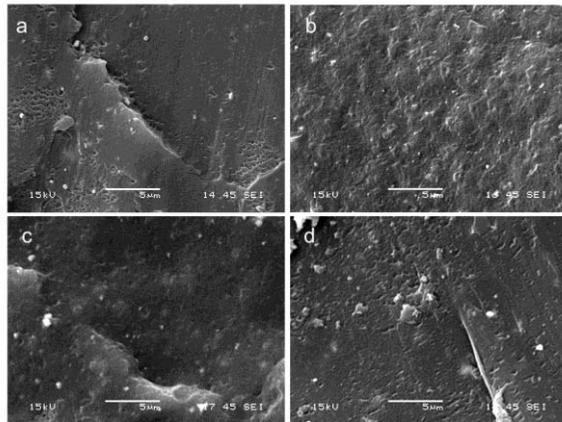
Figure 4: SEM image of cellulose nanowhiskers/NR nanocomposites
(Thomas, 2010)
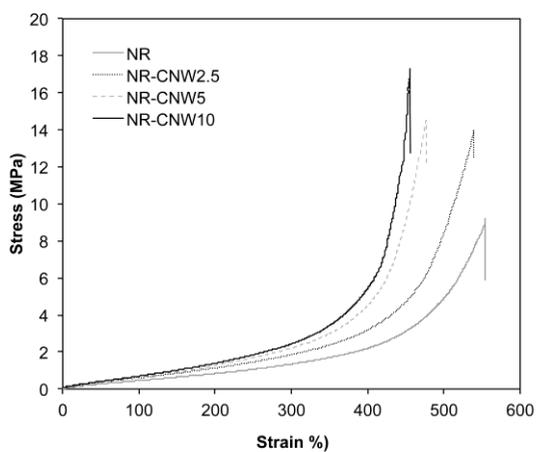
Figure 5: Stress –strain curve of cellulose nanowhiskers/NR nanocomposites (Thomas, 2010)
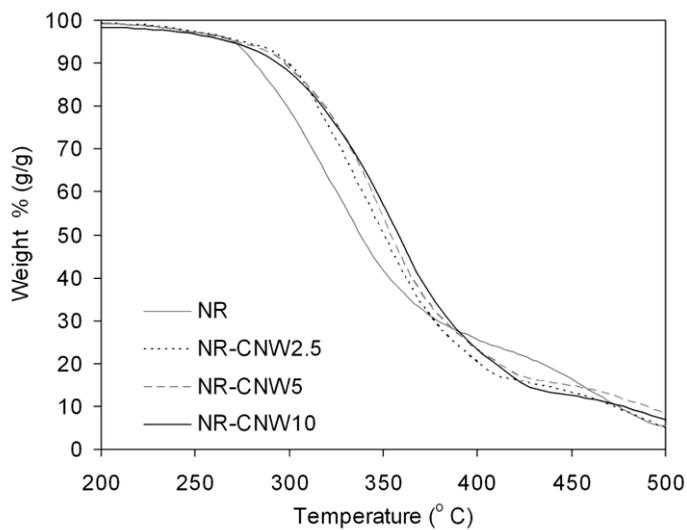
Figure 6: TGA result of cellulose nanowhiskers/NR nanocomposites (Thomas, 2010)
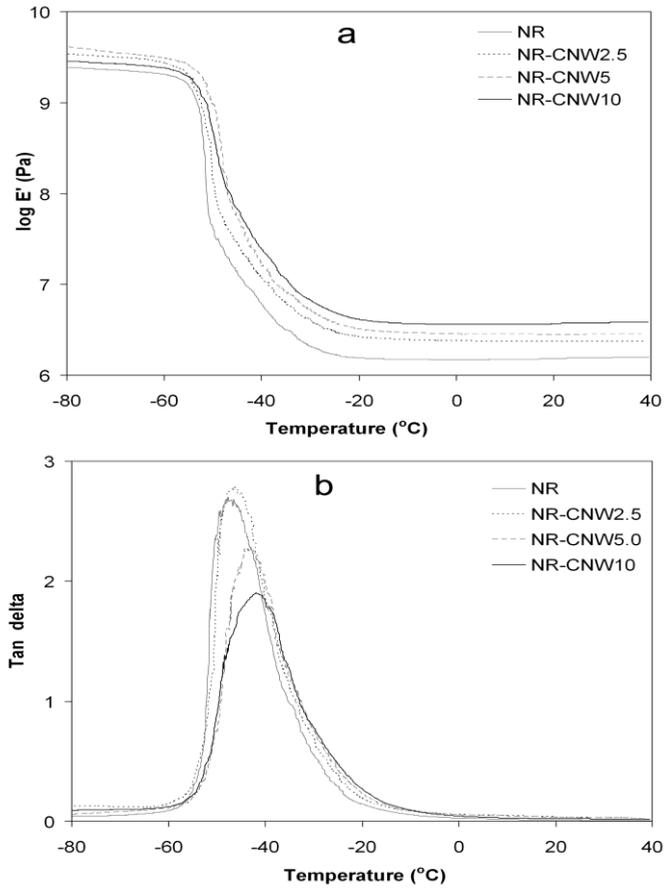
Figure 7: DMA result of cellulose nanowhiskers/NR Nanocomposites
(Thomas, 2010)

4   Conclusions

Nanocomposites based on natural fibres are practical materials that have a promising future because of their eco-friendly nature, their low cost, low density, ease of separation, with acceptable mechanical properties, their lightweight, carbon dioxide sequestration, biodegradability, the simplicity of the manufacturing process, and their properties that make them suitable for use in a wide range of conventional applications. The use of cellulose nanofibres as reinforcing elements in the polymer matrix has been predicted to create the next generation of value-added novel eco-friendly nano-composites.

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Influence of Compounding and Injection Moulding on the Fibre Morphology

A visual Fibre Analysis via FibreShape

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Keywords

FibreShape, compounding, injection moulding, natural fibres

1   Introduction

In times of growing environmental concerns the interest towards the use of renewable resources increases, particularly also in the automotive industry. Natural fibre reinforced, form-pressed composites (NFRC) are already used for interior panels. A new interest is now growing in the field of natural fibre-reinforced injection moulded parts. To guarantee the crash-safety, numerical simulations of the natural fibre-reinforced, injection moulded components are essential. Therefore it is necessary to characterise the fibres in the component to evaluate the simulation. In this study within the overall project NFC-Simulation, the morphology of natural fibres, like hemp, flax and kenaf, and regenerated cellulose fibres like Cordenka® were visually analysed due to the influence of compounding and injection moulding.

2   Material and Methods

Granulates of 30mass% fibres in a polypropylene matrix were produced for each fibre (hemp, flax, kenaf and Cordenka®) with a twin screw extruder at the Institute for Bioplastics and Biocomposites at the University of Applied Science and Arts, Hanover. Furthermore, plates (30 x 16 x 3.2 mm³) of each granulate were injection moulded in Hanover. A schematic drawing of the compounding process and the injection

moulding process is shown in figure 1 and 2. The natural fibres were extracted with an organic solver, xylene, from the granulates and on four positions of the plates (figure 3). Therefore circa 1 g of the granulate and the injection moulded plate, respectively, was cooked in a xylene bath in a filter crucible till the polymer was melted and could be sucked into a flask. This procedure is done several times till the xylene was clear and only the fibres were left in the filter crucible. Before and after the extraction procedure, the samples were conditioned for at least 24 h at 20 °C and 65 % relative humidity according to DIN EN ISO 139 and the mass was determined to an accuracy of 0.01 mg on a type ABT 120-5DM scale (Kern & Sohn GmbH, Balingen-Frommern, Germany) to analyse the fibre mass content of the samples.
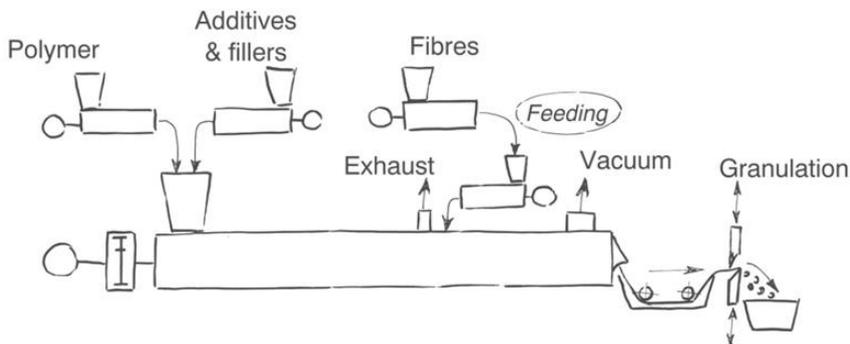
Figure 1: Process design for the production of natural fibre-reinforced thermoplastics granules with a classical extrusion process (Müssig, 2013).
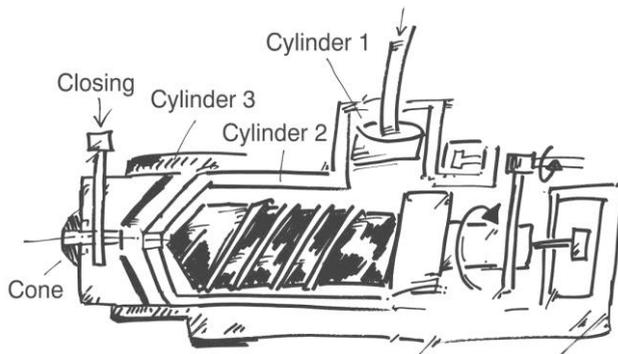
Figure 2: Schematic drawing of the injection moulding process with natural reinforced granulates (Huber, Graupner & Müssig, 2010).

The extracted fibres and the original Cordenka® fibres were prepared on slide frames (40 x 40 mm², glass width 2 mm; Gepe, Zug, Switzerland). The slide frames were scanned with a Canonscan scanner CS 4000 (Canon, New York, USA) with a resolution of 4000 dpi. The original hemp and flax fibres were scanned with an Epson Perfection V700 Photo scanner (Seiko Epson Cooperation, Japan) with a resolution of 1200 dpi. Before scanning, all fibres were conditioned for 24 h at 20 °C and 65 % relative humidity according to DIN EN ISO 139. For the analysis of the object length and width, the image analysis software FibreShape 5.03 (IST AG, Vilters, Switzerland) was used. Standard long-fibre measuring masks, calibrated at 4000 dpi and 1200 dpi, respectively, with 8 IWTO wool standards, were adapted to each type of fibre. Especially for the semi-transparent Cordenka® fibres, modifications, regarding the grey value, had to be done to measure the complete fibres instead of single fragments.
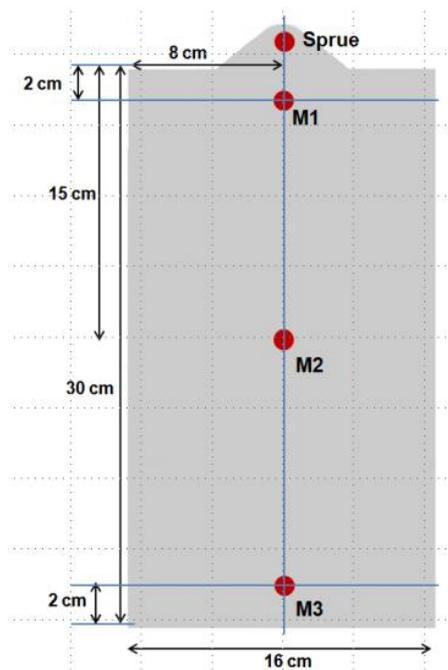
Figure 3: Natural fibres were extracted from four positions (Sprue, M1, M2, and M3) of the injection moulded plates.

3 Results and Discussion

The influence of the compounding and injection moulding process on the fibre / fibre bundle length and width is shown, here exemplarily for the hemp fibres / fibre bundles, in figure 4. The width and the length of the fibre bundles were decreased during the compounding process significantly, whereas the injection moulding does not seem to damage the fibres a lot further (figure 4). A similar behavior could be observed for the other natural fibres (flax and kenaf). The Cordenka® fibres were only reduced in their length during compounding (figure 5), while the width was not decreased (data not shown).
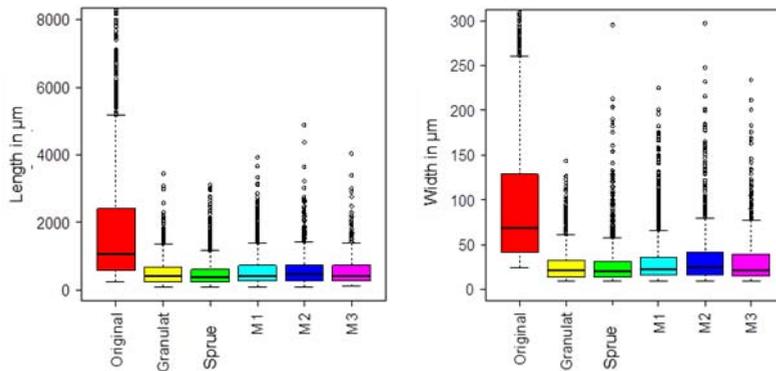
Figure 4: Box-and-whisker plots (whiskers with maximum 1.5 IQR, outliers shown as circles) of the length (left) and width (right) of the hemp fibres / fibre bundles, originally and extracted from the granulate and the plate.
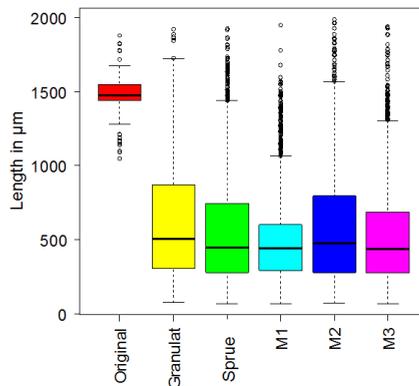
Figure 5: Box-and-whisker plots (whiskers with maximum 1.5 IQR, outliers shown as circles) of the length of the Cordenka® fibres, originally and extracted from the granulate and the plate.

During the compounding process the fibre bundles of hemp, flax and kenaf were split and broken due to the shear force in the twin screw extruder. Therefore their lengths and widths were decreased significantly. However, during the injection moulding process no further reduction of the fibre size could be seen. Steuernagel et al. (2013) observed during a recycling process of natural fibre-reinforced polypropylene a significant reduction of the fibre width after the first recycling step; whereas no further reduction could be observed in the following three recycling steps.

The Cordenka® fibres, which only consist of single fibres, were only reduced in their length; no fibrilation of fibres was observed. Comparable results could be shown during a recycling process for glass fibre-reinforced polypropylene by Steuernagel et al. (2013); the width of the glass fibres remained over four recycling steps, whereas the aspect ratio decreased from 40 down to 30.

The length of the natural fibres was already reduced so far during the compounding, that a further reduction of the fibre length could not be seen during the injection moulding process. Within the project NFC-Simulation, the influence of the manufacturing processes on the fibre morphology are simulated in close cooperation between the working group of Prof. Dr. Tim Osswald at the University of Madison (USA) and M-Base Engineering + Software GmbH (Aachen, Germany). Those injection moulding simulations showed the same results for short fibres (circa 500 μm). However, the simulation also showed that longer fibres (> 2000 μm) would break and reduce their lengths during the injection moulding process.

4   Conclusion

Manufacturing processes have a great influence on the morphology of natural fibres. To evaluate the results of the numerical simulation it is essential to analyse the fibre morphology during the different process steps. The experiments presented in this work show, that the compounding process had a stronger influence on the decrease of the fibre and fibre bundle length and width then the injection moulding. This is most probably due to the fact, that the natural fibres were already shorten during the compounding to a specific length (circa 500 μm) that the forces on the fibre induced by shear or bending during the injection moulding process will not reduce the fibre and fibre bundle length any further. Numerical simulation (at the University of Madison and M-Base) of the injection moulding process showed qualitatively the same results for short natural fibres. Whereas, for longer natural fibres the simulation showed a length reduction during

the injection moulding process. With the presented method – fibre extraction in combination with scanner based image analyse – the influence of manufacturing processes on the natural fibre morphology is well describable. The experimental results show a very good accordance with the simulation results. The project NFC-Simulation represents an important step in order to simulate the complex process of natural fibre-reinforced polymers. The results can possibly be used for crash simulation for complete car components. In order to develop the natural fibre-reinforced injection moulded market, simulation tools are required to enable also injection moulded NFRCs to enter crash relevant components in the automotive industry.

Acknowledgement

Project partners are: Ford Forschungszentrum Aachen GmbH, Aachen; IAC (International Automotive Components), Ebersberg; LyondellBasell, Frankfurt; Kunststoffwerk Voerde Hueck & Schade GmbH & Co. KG, Ennepetal; Simcon Kunststofftechnische Software GmbH, Würselen; M-Base Engineering + Software GmbH, Aachen; University of Wisconsin-Madison, Madison; Fachhochschule Hannover, Institut für Biokunststoffe und Bioverbundwerkstoffe; Hannover; Hochschule Bremen, Bremen; Technische Universität Clausthal, Institut f. Polymerwerkstoffe u. Kunststofftechnik, Clausthal and Fraunhofer LBF, Darmstadt.

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Characterisation of the wood component of WPC via dynamic image analysis

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Abstract

The wood component of WPC is a decisive factor influencing the material properties of the WPC. Dynamic image analysis can help to characterise the morphological constitution of the wood particles or fibres at every processing step. As an example of use, different WPC granulate materials with varying wood content have been produced via extrusion with varying screw speeds and throughputs. After separating the wood particles from the polymer via Soxhlet extraction, the processed particles have been characterised via dynamic image analysis concerning their particle size and shape distributions. The wood content during processing has the strongest effect on particle size resulting in smaller particles at higher wood content. Low screw speeds impose higher degradation on the wood component especially at a low wood content. No influence of the level of throughput on the wood particle size and shape could be detected.

Keywords

Particle size distribution, particle shape, wood plastic composites, WPC processing

1   Introduction

Wood plastic composites (WPC) are a group of innovative new materials which are mainly used for deckings and claddings but as well for window frames, furniture, other consumer goods, and conversion parts for the automotive industry. Raw materials for the production of WPC are beside different polymers and additives wood particles, wood fibres, and wood shavings (Carus et al., 2008). The variable shape variants of the wood that can potentially be used in WPC could help towards an enhanced cascade use in wood industry and hence an increased resource efficiency. By- and waste products of wood industry could be applied to WPC production before using them for the production of energy.

It has to be evaluated beforehand which properties those by-products require to be a suitable raw material for the production of WPC with a performance that matches the application. One factor that influences the performance of WPC is the morphological constitution of the wood component. For example, the tensile and flexural strength of wood-fibre-filled WPC is improved compared to wood-flour-filled WPC (Stark 1999). But shorter particles are easier to disperse in the polymer matrix and result in a more homogenous material (Yam et al., 1990; Shahi et al., 2012).

One way to gain information on the constitution of the wood component is to characterise the wood fibres or particles by means of dynamic image analysis. The dynamic image analysis delivers particle size and shape distributions by calculation of several size and shape descriptors from binary 2D pictures, allowing detailed description of the particle material.

Particle characterisation enables to study the changes of the wood component of WPC in every processing step. It permits to study the milling behaviour and particle formation of different wood species (Plinke et al., 2012). A comparison of different processing methods for WPC – i.e. extrusion, injection moulding, and compression moulding – as to the changes the wood component undergoes being exposed to shear forces, friction, and high temperature is possible (Stark et al., 2004). Even more, particle analysis allows for the possibility to examine the relation between particle size and shape of the wood component and the mechanical properties of WPC (Ashori et al., 2011; Stark & Rowlands, 2003).

As an example of use of dynamic image analysis the present work focuses on the characterisation of wood particles extracted from WPC granulate material having been processed under different conditions. The aim is to identify relevant processing parameters influencing the wood particle change during WPC processing.

2   Materials & Methods

2.1   WPC production

Norway spruce (*Picea abies*) was ground with a cutting mill (FDR 112M/8A (SM 2000), Retsch GmbH, Germany) with an aperture size of 4 mm. To obtain a medium particle size fraction, sieve separation was done with two sieves of aperture size 1 mm and 2 mm. The shavings were then washed in water between two sieves of aperture size 0.71 mm and 1.6 mm to remove dust. Afterwards, the washed wood particles were dried in a hot air oven to a moisture content of < 3 %.

The dried wood particles were compounded with polypropylene (PP) (Sabic PP 575P, Saudi Basic Industries Corporation, Saudi Arabia) in a Leistritz MICRO27GL/GG40D co-rotating twin-screw extruder (Leistritz Extrusionstechnik GmbH, Germany) with gravimetric feeders and a hot-cut pelletizer. The temperature profile was ranging from 150 °C to 180 °C and the nozzle temperature was at 136 °C. Seven WPC granulates were produced at different screw speeds, throughputs and with varying wood content (see Table 1).

Table 1: Setting of the WPC granulates produced in this study.

wood content [%]	screw speed [rpm]	throughput [kg]	sample
30	80	4	30%-80-4
30	160	8	30%-160-8
50	80	4	50%-80-4
50	160	8	50%-160-8
70	80	4	70%-80-4
70	160	8	70%-160-8
70	160	4	70%-160-4

2.2   Soxhlet extraction

For separating the polymer from the wood particles the WPC granulate was subjected to a Soxhlet extraction with xylene (technical grade from AppliChem, Darmstadt, Germany) for 8 h. After extraction the particles were dried at 103 °C to remove excess solvent and moisture.

2.3 Particle characterisation

The change of particle size and shape of the dried wood particles due to different process settings during granulation was characterised using the optical dynamic image analysis sensor QICPIC with dry dispersion unit VIBRI (Sympatec GmbH, Germany). The size and shape of each single particle were calculated from binary 2D images taken at a frame rate of 450 fps at a resolution of 10 μm. The extracted particles have been analysed as to the length-based size distribution (Q_1) and the elongation with the particle length and the particle width as equivalent diameters. As described in Witt et al. (2007) the particle length is calculated as the shortest path between the most distant endpoints of the particle after skeletonising its binary image via a complex evaluation algorithm. The width is calculated as the projected particle area divided by the added length of all skeleton paths. The particle elongation represents the ratio of width to length. The number of particles examined per sample varied between 1 million and 5 million. As a reference the length-based size distribution of the raw material particles before processing as been determined at a resolution of 20 μm.

3 Results

Figure 1 shows the length-based cumulative distribution of the particle width of the extracted particle material after granulation at varying wood content, screw speed and throughput compared to the width distribution of the raw material particles. The displayed size range comprises only 50 % of the raw material's particle width whereas it comprises 100 % of the processed particles' width. This indicates a strong degradation of the particle size during granulation. In addition, the varying processing parameters have a more or less distinctive influence on the distribution. The strongest effect is related to the wood content of the WPC. Processed at a wood content of 30 %, ca. 55 % of the particle width is smaller than 30 μm. Processed at 50 % content this number rises to 63 % and processed at 70 % it rises up to 70 % indicating a decreasing particle width with increasing wood content during processing. The screw speed and the throughput show no distinctive influence on the particle width.

Figure 2 presents the length-based cumulative distribution of the particle length of the different wood particle samples. The size range displayed covers only 17 % of the particle length of the raw material while it comprises 100 % of the particle length of the processed particles revealing a great shortening of the particles during granulation. Similar to the width distribution, the length distribution is distinctively influenced by

the wood content during processing. Processed at 30 % wood content 75 % to 79 % of the particle length is smaller than 300 μm. At 50 % wood content it is 85 % and at 70 % wood content it is 88 % to 89 %. At constant wood content also a slight effect of the screw speed is visible in a shift of the distribution to smaller particle lengths for the lower screw speed. This is especially obvious for a wood content of 30 %.

Figure 3 displays the particle elongation of the processed wood particles depending on the particle length. For all particle samples bigger particles are more elongated than smaller particles. A distinctive influence of the varying processing conditions on the elongation cannot be observed.
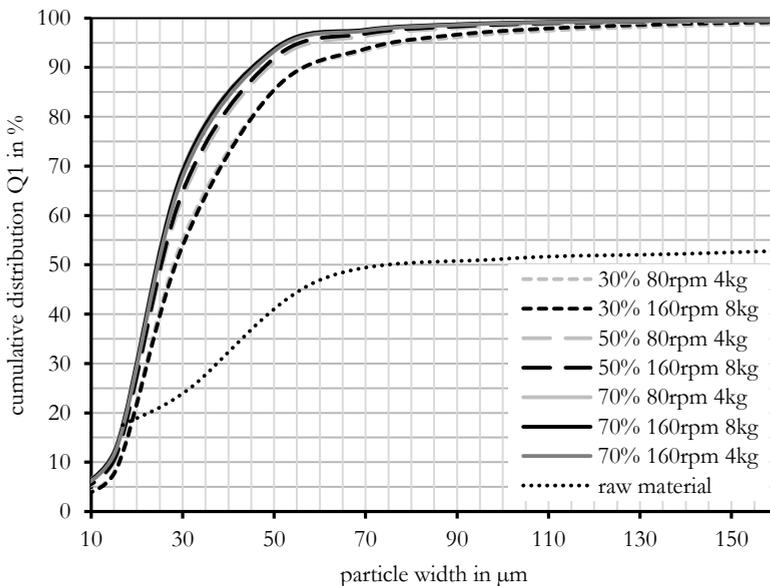
Figure 1: Length-based cumulative distribution (Q_1) of spruce wood particle width after granulation with varying wood content, screw speed, and throughput.
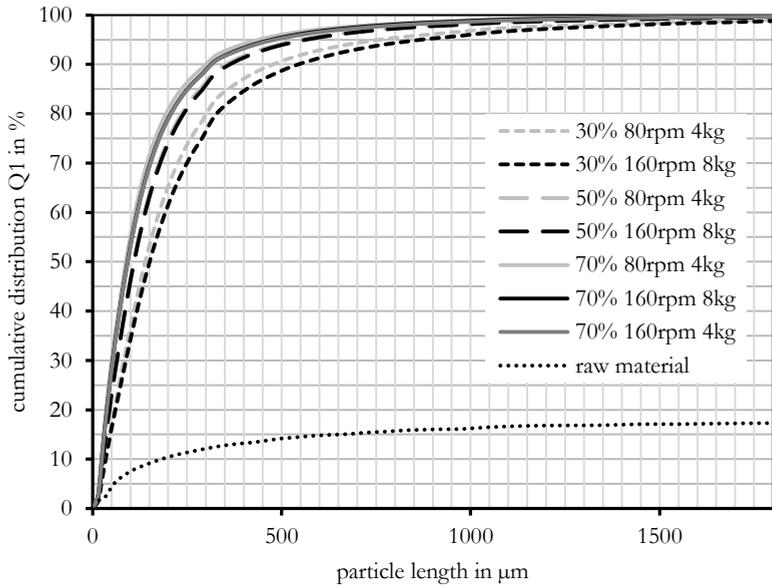
Figure 2: Length-based cumulative distribution (Q_1) of spruce wood particle length after granulation with varying wood content, screw speed, and throughput.
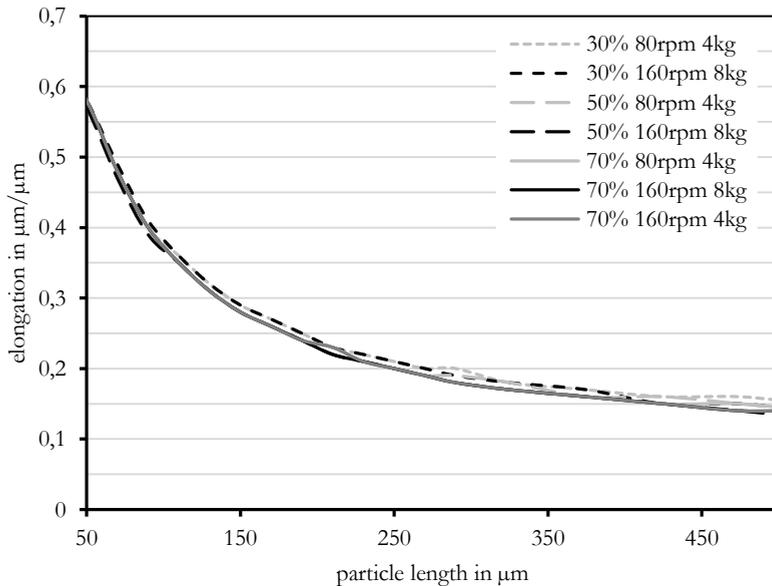
Figure 3: Particle elongation depending on particle length of spruce wood particles after granulation with varying wood content, screw speed, and throughput.

4   Discussion

Producing WPC granulate material via extrusion process as a pre-processing step is a common way to compound wood and polymer before producing profiles or injection moulding parts (Shahi et al., 2012). During compounding the material is subjected to high temperatures and to shear forces affecting the morphology of the wood component (Michaeli & Menges, 1989). As shown by Yam et al. (1990) and confirmed by the results above, the reduction of wood particle size strongly depends on the wood content. With rising wood content the viscosity of the filled polymer melt increases and higher shear stresses are imposed on the material resulting in a more severe degradation of the wood particles. The viscosity of polymeric materials is even higher at low shear rates which are directly related to the screw speed (Klyosov, 2007). Thus, a low screw speed leads to high shear forces and, in addition, to a longer residence time of the material being subjected to the process conditions. This is confirmed by the results above as there is a dependency of particle size on screw speed, especially for the 30 % wood filled material. At higher wood content the viscosity might already be at a level where the effect of screw speed is only small.

No differences in particle size attributed to the throughput could be detected in this study. It was expected that a higher throughput would lead to a stronger degradation of particles due to higher shear forces and pressure imposed by an increased filling of the free volume in the extruder. The results might be explained by the fact that the levels of throughput chosen for this study are at the lower end of the throughput range possible for the used extruder. So, the fillings of the free volume at a throughput of 4 kg/h and 8 kg/h probably differ only marginally.

5   Conclusions

As an example for the application of dynamic image analysis for the characterisation of wood particles, different WPC granulate materials have been produced via extrusion. The wood content of the WPC and processing conditions (screw speed and throughput) have been varied. Afterwards, the processed particles have been separated from the polymer via Soxhlet extraction. The dynamic image analysis of the processed particles resulted in particle size and shape distributions revealing a strong influence of the wood content during processing on the particle size. Processed at a high wood content the particles are smaller due to higher shear forces caused by an increased viscosity of the polymer melt. In

addition, it was shown that a low screw speed leads to higher particle degradation, especially at a low wood content. No influence of the throughput level on the particle size and shape could be detected.

This study shows a good example of how the research on WPC can benefit from dynamic image analysis. It can help to characterise and understand raw material properties and the influence of production processes of WPC on the wood component.

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Supply Chain of Renewable Resources

Application of sensitivity models for renewable resources and co-products

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Abstract

For biomass use one great problem is how to analyse, design and optimize the essential process chains. These process chains show a high level of complexity that leads to several problems. Use of co-products or realisation of cascades increases complexity in addition. For development of new harvesters for new or changed process chains understanding the processes is an important requirement. Combination of technology and process chains actually is not solved for biomass process chains.

For closing this gap, an approach using sensitivity models is presented in this paper. First results show, that sensitivity models are applicable for biomass process chains and product development can be based on this method.

Keywords (required)

Sensitivity-model, biomass, energy supply, self-sufficiency, co-product, harvesting, process chain, compact harvesting

1   Introduction

Cascade use of biomass and bringing more and more co-products into use, could be a worthwhile alternative for today's energy supply. Several research works make demands on this (e.g. Bringezu, 2008, UNEP, 2009). One great problem is how to analyze, design and optimize the essential process chains. The high level of complexity makes high demands on this. Further challenges are existing during practical application of ideas for new biomass usage. For example required harvesters to gain additional biomass as a co-product have to be developed, because actual harvesting technology is not prepared for these additional functions, yet.

In this paper two main aspects of our research work are presented: The integrated approach by use of sensitivity models and the application to an example of a new harvesting technology and process.

2   Problem

The target is, to provide energy for heating, power and mobility, based on an efficient way to use available biomass from co-products. Co-products are organic materials that accumulate while producing agricultural goods. These co-products are not the primary purpose and they are often treated as waste or residual products. If more biomass use from co-products is required, the corresponding process chains have to be understood better. Unfortunately these process chains show a high complexity and there are several external factors with influence on these chains (economics, energy output, sustainability, carbon footprint, sustainability etc.).

Today there is no standard method for modeling and examination of biomass process chains and no agreement about the best procedural method. One reason is the high level of complexity already mentioned, another one is, that several different points of view and expert's opinions have to be respected, each with own requirements. In addition, today's harvesting technology is not prepared for the new task to collect biomass for co-product use while harvesting food and forage. The requirements for new or updated machines have to be derived from the process chains to close technological gaps. In the best case a changing point of view –from a general perspective to get knowledge about relationships along a process chain over relations between market and supplier to specific technological details– should be possible by a proven method.

3   New, integrated approach for biomass supply chains and co-product use

Only building and selling machines is not enough. Also trying to bring new sources for biomass into use is not enough, if the customer's requirements are not respected during development (Beneke et al., 2010). The problem is, that technical aspects, market requirements, realization of process chains etc. have to be respected at the same time. All these different points of view are interconnected. A high number of subjects and a high number of interconnections are a sign of high complexity of a given system.

In a research project, supported by the *Claas Foundation*, sensitivity models have been successfully tested as a new approach for a detailed

examination of biomass process chains by the renewable resources research group at UAS Schmalkalden (see Götze, 2012, Brummel, 2012) based on the ideas published in (Beneke et al., 2010). Sensitivity models are known in several tasks, but they are not used for biomass applications, yet. For the first time this method has been adapted to biomass questions. Details of this project are presented in this paper to introduce a new approach for biomass process chains: How to build models for biomass process chains, complexity reduction, multilayer-models for several levels of detail, preparation of scenarios and simulation.

With the example of co-product use in grain production influences on both, harvesters and process chain have been examined, too. The energetic use of chaff and short straw, e.g. as pellets, is possible and the available biomass quantity can be significantly increased. Alternative harvester concepts and necessary changes along the process chains and their consequences are examined in detail. These results together are used in a research project about energy autarkic structures in agriculture. Influences on the process chains and necessary changes are observed, also requirements on possible future combine concepts are shown.

3.1 Sensitivity Models

3.1.1 Method

Sensitivity describes a factor's influence to a system. The system may show reactions as a consequence of the influencing factors. Sensitivity models allow to detect structures or patterns in a system with a high complexity level and provide an opportunity to examine complex systems' behaviour. The target is

- to know the determining factors of a given system,
- to examine, how different factors influence this system (stabilizing, destructive, high or low level of influence etc.),
- to see time dependent effects,
- … .

The problem in complex systems is that the high level of complexity does not allow an approach by reducing the system to its single parts. If this would be done, the connections between the system's parts disappear and a complete description is not possible therefore. Linear correlations are not able to describe the complete system, too. Sensitivity models integrate several levers and connections between the system's parts and simulate the system's behavior altogether. Main flows of mass, energy or information

can be represented. The result is a statement about the system's behavior and stability as well as finding adjusting levers for an active system configuration.

Sensitivity models as a scientific method have been developed by *Frederic Vester* in his research group and have been tested out in several applications (see Harrer, 2011, malik management, 2012, Vester, 1990/1995/1997). For easier use of this method a software tool had been developed. This tool is used for the examination of biomass applications by the renewable resources research group at Schmalkalden.

3.1.2 Conclusions for R&D

The research task for the renewable resources research group in Schmalkalden was to examine applicability and potentials of sensitivity models for biomass applications.

Functionality and results from working with sensitivity models allow a detailed examination of complex systems. Biomass applications can be handled and their special properties can be respected in an adequate way. Configuring the system means development and use of technical components (machines), too and gives input for necessary R&D. One additional great advantage is, that design theory in mechanical engineering uses aspects of technical systems and the description of mass, energy and information/signal flows, too (Figure 1). So technical aspects can be derived directly from the sensitivity models and technical aspects can be integrated in the models. This is a new kind of view for technical systems and could not be found in research for biomass applications and technical development before.
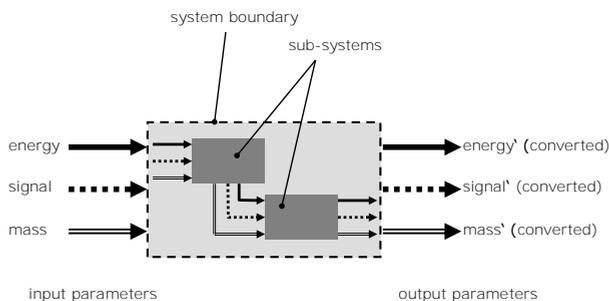
Figure 1: Technical systems, energy, mass and information flows (according to *Pahl/Beitz*)

The symbolic diagram of a technical system in Figure 1 can be used as the basis for sensitivity models for simulation of a system's behavior. Reverse it is possible to find out requirements and basic conditions for technical development tasks by system analysis. For modeling biomass applications,

several connected models in several levels of a system have to be built (Figure 2). Every level focuses on own topics. As a result structures and system stability can be examined, dynamic behaviour can be simulated and basic conditions for technical development can be derived (Figure 3).
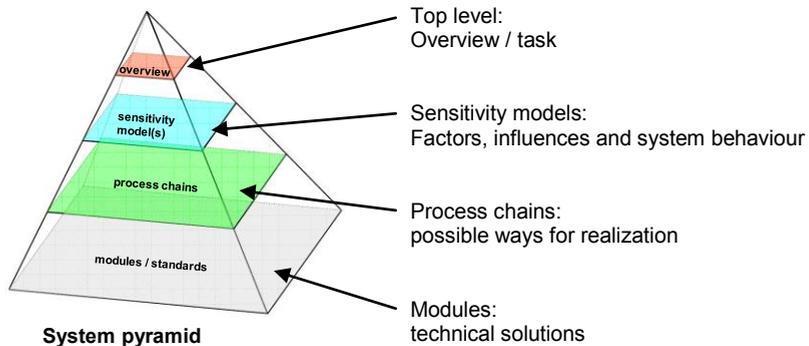
Figure 2: Several levels for sensitivity models in biomass applications and main aspects (source: Brummel & Beneke, 2013)
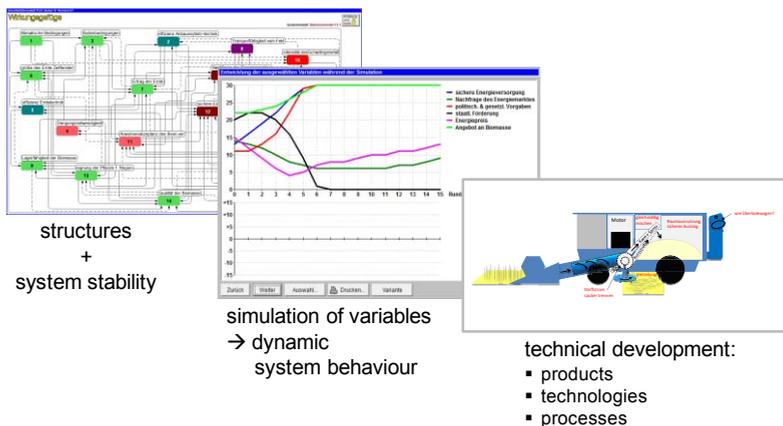
Figure 3: Sensitivity models for biomass applications, different aspects for research

4   Example: Material other than grain to be used as an energy carrier

In former times people collected chaff while they harvested grain and used this additional harvested material for feeding animals. While modern combines offered more and more performance and with reduced customer

demand for chaff to use, chaff collecting is not an actual part of grain harvest today.

Material other than grain[1] (MOG) limits the cleaning processes in a modern combine and requires a great part of the combine's power for separation and cleaning processes and spreading this unused material back to the field. Anyway, the old idea of colleting MOG is actual more than ever. Chaff for example offers a biomass resource of 1-2 tons/hectare. This resource actually is still used rarely. For some applications harvesters now had been equipped with a kind of backpack even for collection of MOG as additional biomass. In an additional grain tank these light-weighted materials are collected during threshing. This simple idea of threshing and getting additional biomass at the same time shows great influences on the complete harvesting chains. The processes in today's grain harvest (Figure 4) are enlarged by a wide additional subprocess (Figure 5).
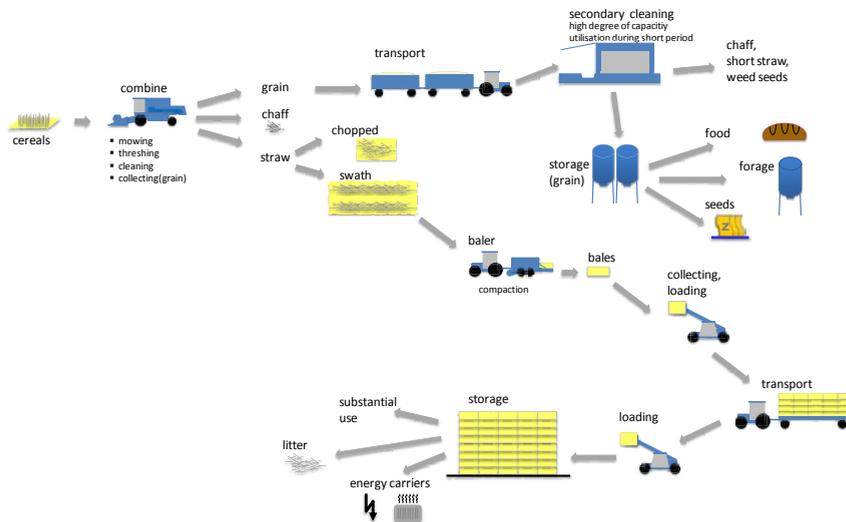
Figure 4: Harvesting chain for grain (straw use included)

This additional sub-process causes additional work, requires transport capacity and deals with problematic, because light-weighted material. Co-products even change the requirements to machines and harvesting processes. In conclusion, just adding a collecting unit to a combine solves the technical problem of biomass collection, but new sub-processes in the harvesting chain appear at the same time and increase complexity.

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[1] Material other than grain is a general term in grain production for the biomass that is not grain. The term includes e.g. straw / short straw, chaff or weed seeds.
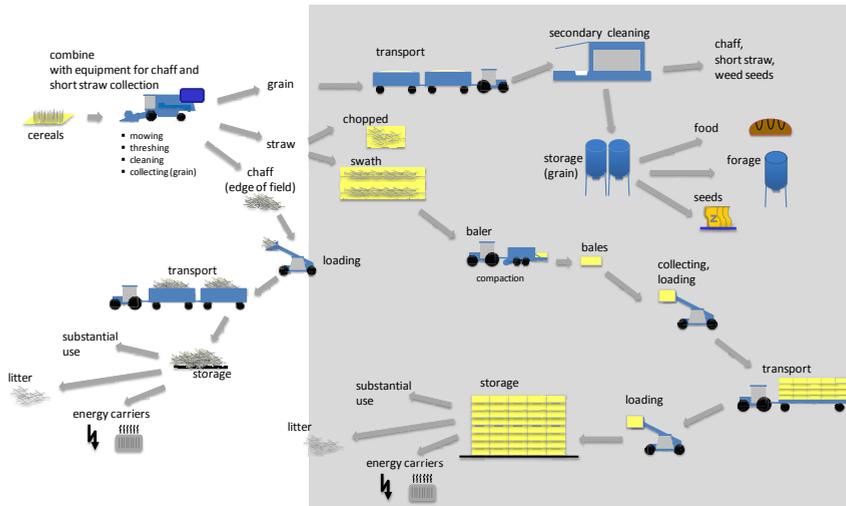
Figure 5: Harvesting chain for grain (straw use included) with additional collection of material other than grain

Notice: the grey box marks the identical parts compared to Figure 4.

After harvesting additional biomass, its storage, conversion and use has to be realized. The very fact, that several possible ways are available for converting biomass into a usable form for energetic use (see Figure 6) shows the high level of complexity in biomass use again.
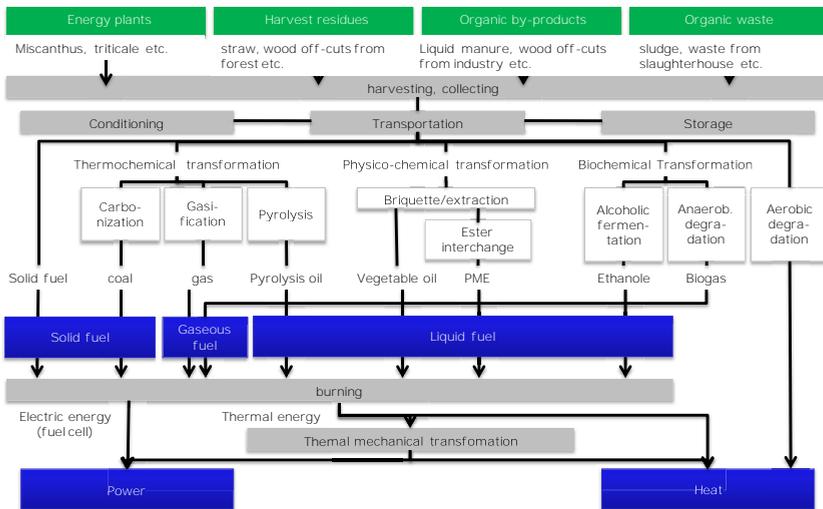
Figure 6: Biomass conversion, overview (according to FNR 2006, translated)

Decisions have to be made for *each* step in the complete process chain for biomass use with respect to possible effects on each other part of the process chain. This shows, that it is impossible to optimize a single step without respect to the changes in the remaining process chain.

Another approach for an integrated view to biomass use from co-products is the compact harvesting. The idea is, to harvest grain and material other than grain at the same time and in a single harvesting process. Straw harvest is included. This requires a new design of the process chain with a changed harvester in the key role. Harvester and harvesting process according to *Rumpler* have been published e.g. in Rumpler, 2010, Rumpler, 2010a, Rumpler, 2011, Rumpler, 2011a. The compact harvesting is shown in Figure 7.
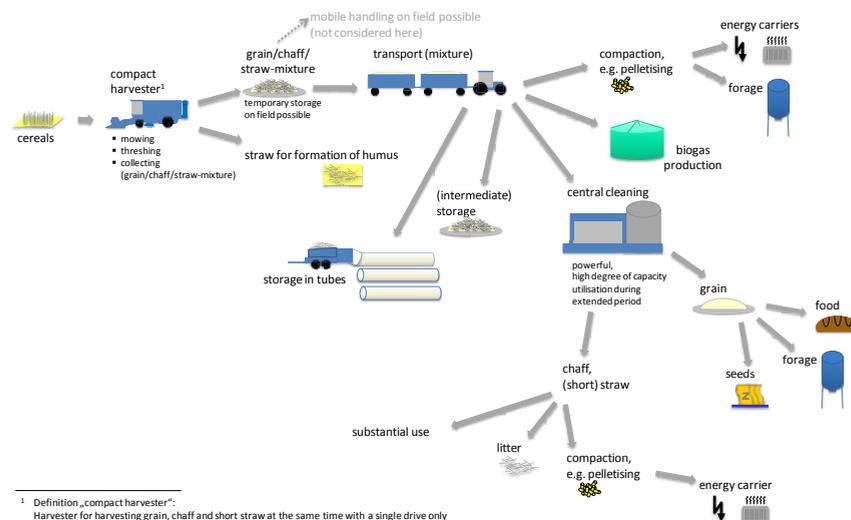
Figure 7: Compact harvesting: harvesting chain for grain, straw and chaff as integrated additional collection of material other than grain

Several different alternative process chains of the compact harvesting have been examined. Actually the layout shown in Figure 7 seems to be the most efficient one. This has been researched in experiments in praxis. A new approach in these experiments has been the use of tubes for storage. This is not a low-budget storage, but offered new potentials by a new technical approach. Further research projects follow up. One aspect is to find out more about the effect of drying in the tube which significantly could influence grain harvest.

5   Conclusions

Sensitivity models are suitable for understanding complex correlations in biomass applications. With this method, new ways for using co-products can be tested before realizing them. Technical development, e.g. harvesters, can be optimized, because there is a much better knowledge of the requirements. With the example of co-products from grain production an economic and sustainable use of additional biomass without conflicts between food and energy, can be shown. A future energy supply, based on biomass from co-products, is actually examined. The target is, to compose new, in parts or complete self-sufficient structures in agriculture. First results are presented as described in chapter 4.

6   Outlook

If additional biomass can be harvested while producing food and forage, the energy contained in this additional biomass could be used for providing energy e.g. to a farm. This is examined in an actual project (see Figure 8) at the renewable resources research group at the University of Applied Sciences in Schmalkalden with project support by the *Claas Foundation*. In several scenarios (farm type, size and structure, geographical position, available co-products etc.) the role and importance of co-products are examined. The target is to find out, if co-products from agricultural processes are able to supply a part of the farm's energy demand. If it is possible, proposals for conversion routes and energy carrier types shall be worked out. One main aspect is the future mobility of farm machines and the source for their energy supply. Necessary machines for closing gaps in future biomass application chains have to be developed.

Sensitivity models are the base for these investigations. Technical proposals for a later realisation of future process chains for energy supply based on biomass shall give technical development new impulses.
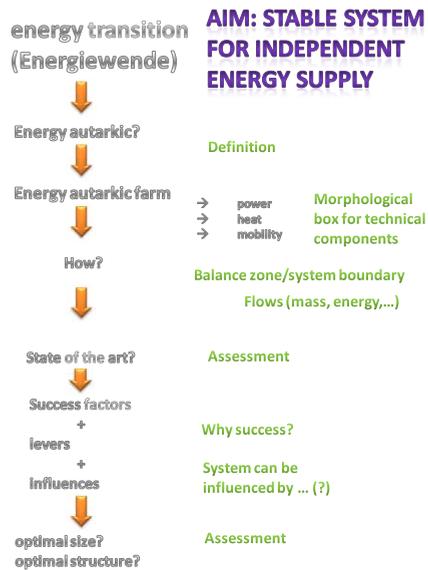
Figure 8: Actual research in use of co-products for energy-supply

Acknowledgement

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Reduction of Forest Areas Available for Wood Supply (FAWS)

Impacts on the Austrian Forest-Based Sector

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Abstract

The aim of the study is the analysis of the impacts of reduced wood supply, e.g. as a result of nature conservation, on the value-added wood chain. The simulation model of the Austrian forest-based sector (FOHOW) was used to simulate a base-scenario and scenarios with a 10% reduction of the forest area available for wood supply (FAWS). In addition, it was assumed in one of the scenarios that Austrian roundwood imports would decrease, posing an even more tightening wood supply situation on the forest-based sector. A reduction of FAWS area increases the pressure on the remaining FAWS regarding higher harvests there, but also on the FAWS in neighboring countries (higher roundwood imports). But lower domestic roundwood supply cannot be fully compensated. Forest-based industry production goes down and international competition decreases due to higher roundwood costs and product prices. When decreasing roundwood imports are assumed in addition, the goals of the National Renewable Energy Action Plan will be beyond reach in quantitative terms, but also the costs of wooden biomass for energy rise dramatically. The forest-industry has to further reduce capacities with a strong negative impacts on employment, value-added and export-values of the sector. The study clearly reveals the conflicting goals of nature conservation, climate protection and economy.

Keywords

Reduction of FAWS area, roundwood procurement, economic impacts, forest-based sector in Austria, simulation model.

1   Introduction

Interests in forest conservation on the one side as well as the substitution of fossil-based materials and energy by renewables on the other lead to increasing conflicts regarding the management of forests. Wooden biomass availability and a possible scarcity due to the reduction of forest area available for wood supply (FAWS) are of crucial importance for the Austrian forest-based sector (see e.g. Döry, 2012; Kulterer, 2012). Such a reduction could result from the political pressure of environmental non-governmental organizations (NGOs) pushing for setting aside more forest areas for conservation purposes.

2   Goal and Research Questions

The overall goal of the study was the analysis of the impacts of reduced wood supply on the value-added wood chain (use of wood for materials and for energy). The following research questions were investigated:

- How will Austria timber harvests change due to a reduction of FAWS in terms of quantities and assortment composition?
- How will timber supply for the users (material and energy) be affected?
- What is the interaction between domestic supply and import supply of timber? In addition to the reduction of FAWS, what impact has a reduction of roundwood imports due to increasing processing capacities, increased use of wood for energy and also forest conservation in neighboring countries which have been roundwood exporters to Austria?.

3   Method

The main method used in this study is a quantitative forest-sector specific simulation model, called "FOHOW" (Forst- und Holzwirtschaft). The Austrian forest-based sector is modeled as a whole (system), from forest growth to the use of paper (Figure 1). It does not deliver exact forecasts but tries to analyze longer-term effects of events ("what-if" questions; see e.g. Schwarzbauer, 1993; Schwarzbauer et al., 2013). Here, the "what-if" questions are related to consequences of the reduction of FAWS.

FOHOW is a System-Dynamics (SD) simulation model programmed in "Professional Dynamo Plus" (Pugh-Roberts Associates Inc.,

1986). The current version of FOHOW consists of approx. 1500 equations, of which about 250 are levels, 250 rates, 400 auxiliaries and the rest table functions and constants. FOHOW consists of four types of modules (Figure 1):

- <u>General economy</u>: includes only exogenous variables (gross domestic product [GDP], population).

- <u>Forest industry and forest product markets</u>: includes supply, demand, prices and trade for each semi-finished product.

- <u>Forestry</u>: includes timber supply from three ownership categories: small private forest owners (< 200 ha), larger private forest owners (>= 200 ha) and Austrian Federal Forests. Timber markets are between forestry and forest industry.

- <u>Forest resources</u>: includes forest area, growing stock and increment each broken into coniferous and non-coniferous forests, ownership categories and two age-classes.
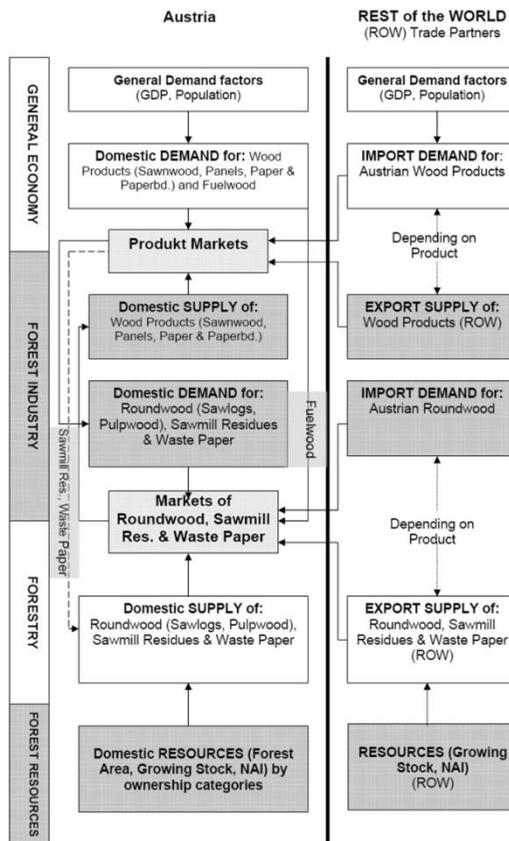
Figure 1: General Structure of FOHOW

4 Scenarios

Three scenarios were simulated for this study, which are briefly presented together with their major exogenous assumptions.

4.1 Base-Scenario

The base scenario represents "business-as-usual" with moderate GDP and oil price growth rates. However, it is further assumed that the goals of the Austrian National Action Plan for Renewable Energy 2010 (BMWFJ, 2010) are met by 2020. These are a reduction of overall energy consumption of 10% by 2020, an increase in the share of renewable energy of 34%, whereof 45% are wooden biomass. Beside these assumptions no further interventions of any kind are implemented.

4.2 Scenario FAWS Reduction I

All assumptions are the same as in the base-scenario, except:
- Until 2015 10% of total FAWS will be taken out of timber production.
- The areas taken out of production correspond to average FAWS forest areas in terms of growing stock and increment (the same with the remaining FAWS).

4.3 Scenario FAWS Reduction II – Roundwood Import Reduction

In addition to the assumptions in the base-scenario and FAWS reduction scenario I, it was assumed in one of the scenarios that Austrian round-wood imports would decrease, posing an even more tightening wood supply situation on the forest-based sector. The rationale behind: increase of wood demand of forest-based industries (capacity growth) and for energy (energy policy) as well as also reduction of FAWS (conservation) in neighboring countries.

5 Results

A 10% reduction of FAWS area increases the pressure on the remaining FAWS regarding higher harvests, also in neighboring countries (higher roundwood imports). But lower domestic roundwood supply cannot be fully compensated. Forestry, due to higher roundwood prices is not suffering and even can improve its gross production value in FAWS reduction scenario II (Figure 2).
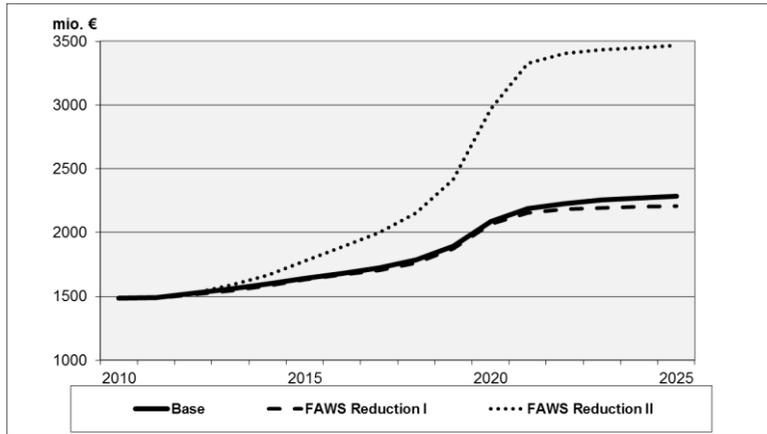
Figure 2: Gross Production Value Forestry (real prices 2000)

Production and international competition (exports) of the forest-based industry decreases due to higher roundwood costs and product prices (see Figures 3 and 4 for illustration).
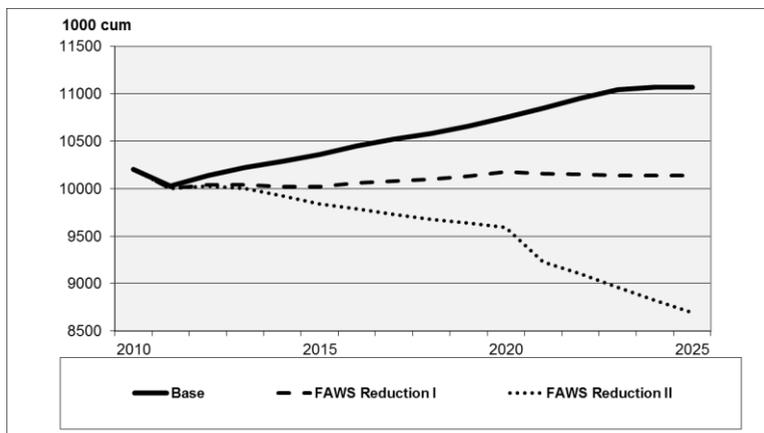
Figure 3: Production of Coniferous Sawnwood
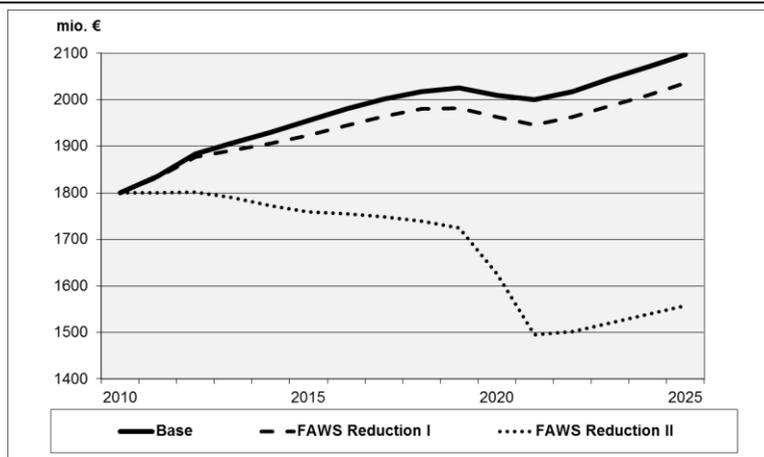
Figure 4: Paper Industry: Gross Production Value minus Raw Material Costs
(real prices 2000)

When decreasing roundwood imports are assumed (FAWS reduction II),
the sector will specifically suffer from the following impacts:

- The quantitative goals of the National Renewable Energy Action
  Plan will be beyond reach, but also the costs of wood for energy
  rise dramatically (Figure 5).
- The forest-industry has to further reduce capacities with strong
  negative impacts on employment, value-added and export-values
  (Table 1).

Table 1: Deviations between the FAWS reduction scenarios from the base-
scenario – selected macro-economic figures for 2025

		Deviations from the base-scenario 2025	
		FAWS Reduction I	FAWS Reduction II
Jobs[1]	absolut	-19.000	-95.000
	in %	-6,4	-31,9
GDP Contribution in %[2]		-3,1	-22,9
Net-export values in %[3]		-4,2	-21,3

[1] calculations according to Dieter (2009)

[2] calculations according to Statistik Austria (2012a, 2012b)

[3] direct result of FOHOW
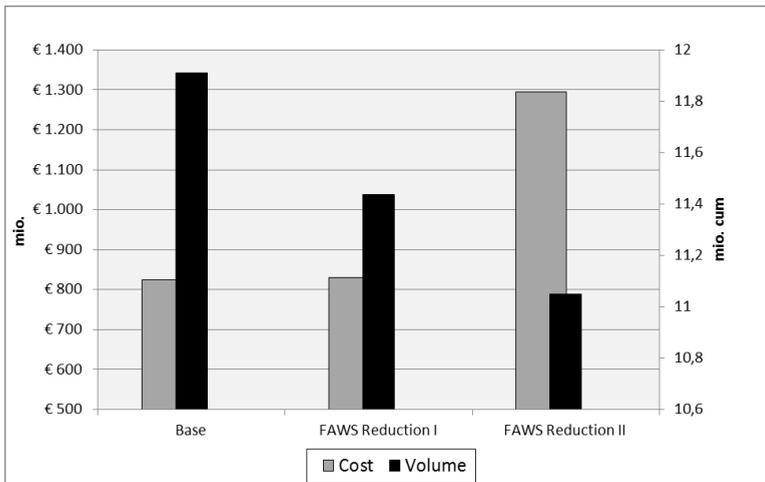
Figure 5: Quantities and costs (real prices 2000) of wooden biomass used for energy - base-scenario and FAWS reduction scenarios

The macroeconomic impact of a FAWS reduction is generally negative for the forest-based sector as a whole. When a reduction of roundwood imports is assumed in addition, there would be 95.000 less jobs in the sector in 2025 (almost one third), the contribution to GDP would decrease by almost one fourth and the value of forest products net-exports by more than one fifth. Without the assumption on roundwood imports the results point in the same direction, but are much less dramatic (Table 1).

6 Discussion – Scrutinizing the Results

6.1 Conservation vs. Wilderness

The assumption is that 10% of FAWS are totally taken out of production. This is correct for wilderness areas, but not necessarily for other measures of conservation (e.g. Natura 2000 areas; s. e.g. European Commission, 2012). Therefore a 10% reduction of FAWS must not necessarily lead to an overall 10% reduction of harvests.

6.2 Type of FAWS Taken Out Of Production

The assumption is (because no better data is available) that FAWS taken out of wood production represent average forest areas in terms of growing stock and increment. This has not necessarily to be the case. There are

indications that less productive FAWS will be taken out of production (s. e.g. ÖBf AG, 2012). Therefore timber harvests could be less affected than assumed.

6.3   The Role of Roundwood Imports

The largest deviations from the base-scenario occur due to the assumption on reduced roundwood imports (not directly through domestic FAWS taken out of production). These import reductions could be partly based on FAWS taken out of production in neighboring countries. However, in addition these reductions could be also caused by two other reasons: capacity increase of forest-based industries and increase of wood used for energy in current export countries. Hence, neither domestically nor through trade FAWS reduction can be seen as the main cause for the largest negative deviations.

6.4   The Harvest Intensity in Remaining FAWS

In Austria growing stock has increased during the last decades by about 50% (BFW, 2012) - due to ongoing harvests below the increment. An increase of harvests in the remaining FAWS could – at least partly - compensate the shortage caused by reduction of FAWS and roundwood imports. Due to the Austrian energy policy and the high demand for wood fuel harvests are also increasing in the base-scenario and lead to a moderate decrease in growing stock over time. A FAWS reduction, in particular in combination with a roundwood import reduction, would further decrease growing stock. But this would increase increment at the same time (stands will become younger in average). Therefore increased harvests in remaining FAWS due to less area available leading to a decrease in growing stock may not necessarily mean a violation of the principle of sustainability.

7   Conclusions

Even with the qualifier above (chapter 6) the study clearly reveals the conflicting goals of nature protection, climate protection and economy. A minor cutback in growing stock – like in the base-scenario – seems to be the most stable development for all stakeholders; political goals can be reached, economic risks are low and a long-term balance between economic and ecological sustainability can be expected.

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Regional Bioenergy Inventory for the Central Germany Region

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Abstract

The decentralised nature of biomass production and decentralised bioenergy production will greatly affect regional sustainability, rural economies, as well as altering the ecosystems services provided by the regional landscape (Dale et al., 2010, Robertson et al., 2008). For this reason using the regionalised approach for assessing bioenergy chains has been identified as one of the most appropriate scales for assessment (Hoffman & High-Pippert, 2010). The assessment of bioenergy and biofuel production chains is a complex task and accurate assessments must capture spatial variation in order to account for the impacts of bioenergy production (McKone et al., 2011). Life cycle analysis (LCA) is one of the most important assessment tools used for the promotion of bioenergy. However, there are a number of key challenges to produce an accurate and spatially representative life cycle assessment that can provide a sound scientific basis for evaluating regional bioenergy sustainability (McKone et al., 2011, Cherubini et al., 2009). The project presented here is part of a larger collaborative research study currently being conducted by the UFZ Bioenergy Systems Analysis (BEN) department and the Deutsches Biomasseforschungszentrum (DBFZ), both situated in Leipzig, Germany. The overall aim of the collaborative research is to establish a framework for sustainable bioenergy production in the "Central Germany" (CG) region, as a case study approach. The aim of this project is to produce a spatially dependent LCA for regional bioenergy production. The approach for developing this inventory is the focus of this paper.

Keywords

Life cycle inventory, biomass, bioenergy, regional assessment.

1   Introduction

1.1   Regionalised Bioenergy Systems

The context of bioenergy production is fundamentally rooted in location, as the potential substrate for energy production is now scattered in a diffuse manner across many landscapes, both within a region and across many regions. The energy supply chains are switching from the traditional energy intense, gas fields, oil fields, coal mines, with large scale globalised processing and distribution networks (Karger & Hennings, 2009, Gormally et al., 2012), to energetically lower fuels such as biomass, diffused across a region, resulting in relatively smaller regionalised processing and supply chains (Wolfe 2008, Egbendewe-Mondzozo et al. 2012). Accordingly the impacts of these new conversion systems are shifting from globalised levels to more regionalised and localised level (Parish et al. 2013, van der Hilst et al. 2010).

In general regionalised approaches are promoted for assessing bioenergy chains, because assessments at this scale can help to identify the range of variances which can influence the management of natural resources (van der Hilst et al., 2012, Hoffmann, 2009). A region in the context of this paper is defined according to Loiseau et al. (2012) as "a spatial scale below a nation, usually including two or more communities with naturally or arbitrary determined boundaries, and which covers from tens to thousands of kilometres".

1.2   Life Cycle Assessment Tool

Traditionally "LCA is considered a globalised assessment tool, in which emissions are aggregated across the whole supply chain regardless of where they were produced or released, making it more a tool for pollution prevention, rather than avoidance of environmental risks"(Hauschild, 2006). In general this approach was justifiable as Frischknecht (2006) pointed out, because "the product system of any product includes (to a variable extent) the diversity of the world's economy, i.e. mining industry, energy industry,… building industry, chemicals industry, farming and food industry, transport services…waste management services…".

Therefore, the main concept of LCA is to provide a screening approach using mass loadings which enables the overall material and energy usage of a system to be assessed, which helps to identify all relevant burdens across the whole life cycle of a product or a process. In this way identifying where a shift of burdens from one process step to another may

occur (Azapagic, 1999, Owens, 1997). However, regionalized energy concepts provide an opportunity to explore and include greater spatial aspects within the LCA tool; due to the more "regionalised" interlinkages in supply chains. Therefore, the key challenge is to produce a "regionalised" bioenergy inventory which can be used within appropriate LCA approaches (Heijungs, 2012). Indeed the discussions on spatial/regional differentiation within the LCA approach are diverse, with many contrasting views; however this will not be discussed here, due to space constrictions.

The limitations of LCA was noted by de Haes et al. (2004), for which they proposed three strategies to overcome both its spatial and temporal limitations; (1) extension of LCA; (2) use of a toolbox; and (3) hybrid analysis. The focus of this project is to produce a regionalised LCA for bioenergy production. Therefore, the proposed first approach to assess the bioenergy production in the CG region can be defined as a "tool box", as it involves integrating the results of different modelling approaches, LCA tools (GABI 5.0) and ESRI ArcGIS©, as well as additional information from crop modelling (DailyDaycent)(Del Grosso et al., 2005, Parton et al., 1996). The first step for developing a spatially dependent or regionalised LCA is the establishment of a Life cycle inventory (LCI), with spatially disaggregated foreground data at the regional level for biomass-to-bioenergy production systems identified within the region.

1.3   Scope –"Central Germany" Region

The Central Germany region (CG) is located in Eastern Germany and consists of three federal states or "Bundeslaender". The total land area of these three states, Saxony (18 417 km²), Saxony-Anhalt (20 447 km²) and Thuringen (16 172 km²) is approximately 55 036 km² (German Federal Statistical Office 2011)). The mean precipitation 1961-2010, ranged from 1700 mm in the Harz Mountains to around 450 mm in Halle (Saale), which is in the rain shadow of the Harz Mountains (Figure 1a). The mean temperature 1961-2010 ranged from 4-5 °C in the Harz and Ore mountains, to almost 10 °C in the low-lying region between Leipzig and Magdeburg (Figure 1b) (German Weather Service (DWD))[1]. The BÜK 1000 (2007) is the mapped soils of Germany, which classifies 72 soil types in total, of which 44 soil types can be found in the CG region. The most fertile soils can be found in the Magdeburger Boerde region having an "Ackerzahl" or agricultural production value of 90. The "Ackerzahl" values for a site are

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[1] Maps are produced on the base of all available DWD-Weather Stations (Courtesy of the Central German Climate)
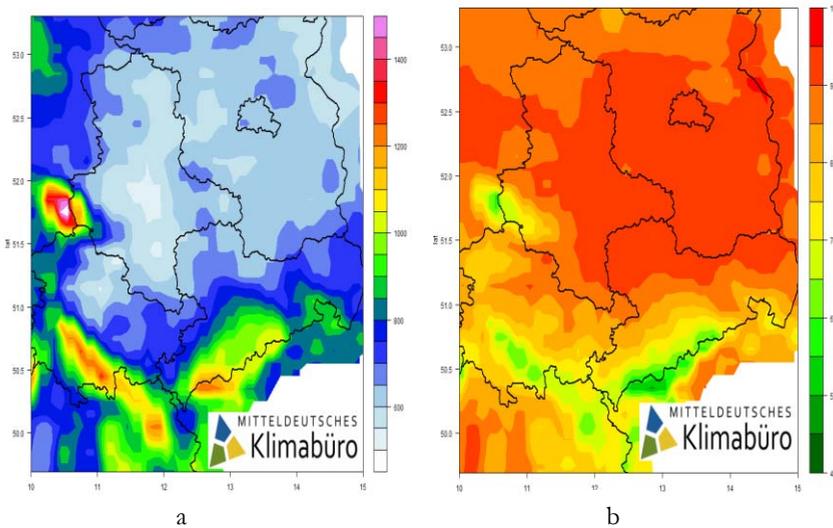
Figure 1: Distribution of mean annual a) precipitation b) temperature, across Saxony, Saxony-Anhalt and Thuringia between the years 1961 -2010

estimated using soil fertility, slope, elevation and climate of a particular site. For CG the "Ackerzahl" ranges mostly from 31-60, with some areas having a value as high as 90 (Figure 2)[2]. Therefore, it is not surprising that the region supports approximately 18% of Germany's 17 million ha of agricultural land, with 2.3 million ha of arable land and 0.5 million ha of grassland. Due to historical reasons, the average sizes in the CG region are much larger; with farm sizes in Saxony nearly triple the size of the average German farm size (56ha), with an average of 145 ha. The average size farm in Thüringen and Saxony-Anhalt are nearly 3 to 4 times bigger, with 215 ha and 279 ha respectively (Statistische Ämter des Bundes und der Länder, 2011). The farms in CG manage approx. 1.2 million cattle, 2.5 million pigs, 13.8 million chickens and 0.4 million sheep (Statistisches Bundesamt, 2011). Forestry also plays an important role in the region, with approximately 14% of Germany's 11 million ha of forest found in CG, with 0.18, 0.5, and 0.8 million ha of deciduous, coniferous and mixed forest, respectively found in the region (German Federal Statistical Office, 2011).

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[2] Data for Saxony provided by the LfULG, data for Thuringia and Saxony-Anhalt based on Regionale Wertansätze data from 2004 (www.bvvg.de). And for the Ackerzahl of Saxony: Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie.1993
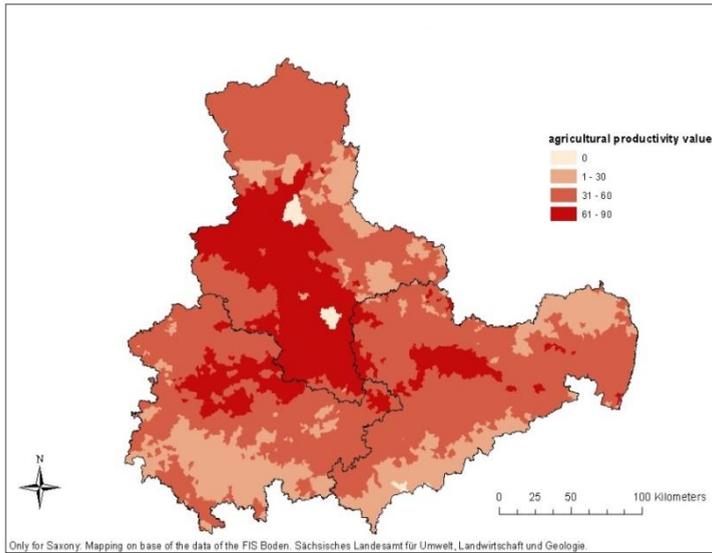
Figure 2: Agricultural productivity value for Central Germany. Note: areas which have a value of 0 were areas where no information was provided.

With this backdrop of biomass production, it is also appropriate to find a relatively large development of associated bioenergy conversion systems in the CG region. In 2010 there were approximately 600 biogas plants, with an estimated total installed electrical capacity of between 250-350 MW. The main feedstock observed for CG region is in most cases, animal slurry (cattle and pigs predominantly), often used in a combination with maize silage, grass silage and other cereals (TLL, 2010, LLfG, 2012, LfULG 2011). In Central Germany there are three large scale bioethanol producing facilities, mostly located in Sachsen-Anhalt, with a total annual production capacity of greater than 450,000 tonnes of bioethanol (DBFZ, database). Thick syrup (from sugar production) and wheat are the predominant feedstocks used (TLL, 2007, Südzucker Bioethanol). In 2010 there were approximately 14 biodiesel producing plants in the CG region, producing approximately 1 million tons of biodiesel, with oilseed rape as the main oil feedstock (FNR, 2011, Agentur für Erneuerbare Energien, 2013). In 2010 there were 37 solid woody biomass based heat and power plants, with a total installed capacity of approximately 190MW (DBFZ, 2010). It is not entirely certain how many heating plants are installed in CG, however, estimations place it at a number greater than 270 plants with a combined installed thermal capacity of greater than 430MW (DBFZ, database).

2 Approach for developing regional bioenergy inventory

2.1 Approach for feedstock inventory

The Corine Land Cover 2006 (CLC2006) was used as the basis for determining the distribution of land use related to biomass production in the CG region. This was then used in conjunction with other physio-climatic data (e.g. soil type and properties, climate data, land use), as well as natural protection areas (e.g. Natura 2000 (BfN, 2010)), to develop a holistic map of the CG region in the mapping software ESRI ArcGIS©.

This map was then segmented into land parcels or grid cells of 25 hectares. These grid cells were then used to calculate the theoretical cropping area, using a number of constraints based on "Ackerzahl", soil-clay content, elevation and slope, as well as the cultivation area statistics for each administrative district. The cropping area was in total calculated for 10 different crops: winter wheat, rye, summer barley and winter barley, sugar beet, maize, winter rape seed and an aggregated category of legumes (e.g. clover and peas). All crops relevant to bioenergy production were considered. In the cases where the area devoted to a certain crop was approximately 1% of the total cropping area, these crops were allocated to the other cropping area, due to both physiological similarities and similar growing conditions. Potato was one such crop, as the area dedicated to potato cultivation was so low, it was decided to allocate it to the area of the other crop categorised as a "root crop", sugar beet.
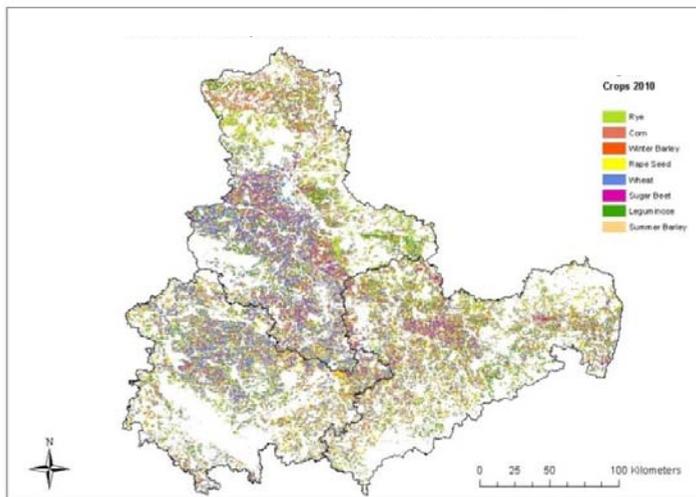
Figure 3: Map of crop allocations based on the cultivation statistics for 2010 (unpublished).

A program in C++ was written to allocate the crops according to the cultivation statistics at a "Landkreis" or district level and according the preference areas outlined above for each crop. Distribution of crop allocation for the CG region is shown in Figure 3.

2.2 Approach for bioenergy technology inventory

The inventory phase or LCI is one of the most important phases of the LCA. The main steps in trying to develop a regional inventory for bioenergy systems are to first determine the types of conversion systems operating e.g. combustion, anaerobic digestion, fermentation, transesterification. The second step is to determine the number of associated bioenergy plants operating in a base year. The third step is to determine the associated operational ranges observed for these plants e.g. installed capacities, operating hours, feedstock used, feedstock demand, technologies, as well as the spatial distributions of these plants. The DBFZ has one of the most extensive and comprehensive databases for biomass power plants in Germany (Witt J. et al., 2012) and through collaboration with the DBFZ, the different bioenergy systems along with their operating parameters and their regional distributions could be determined for CG in the base year of 2010 (Figure 4). For the majority of plants when possible (i.e. reasonable visibility in map), the spatial locations were also assessed using Google maps and the level of locational uncertainty was recorded. In some instances the plants were also cross checked with the locations used in the study of Das S. et al. (2012).This inventory forms the backbone for modelling the regional bioenergy chains (Figure 4).

For the purpose of this paper we will use two terms to indicate the overall regional distribution associated with a conversion system, spatially diffuse and non-diffuse. Spatially diffuse conversion systems refers to those bioenergy conversion systems which have a large number of mostly decentralised plants scattered across the entire region (e.g. anaerobic digesters or combustion plants). Non-diffuse conversion systems refers to those bioenergy conversion systems which have a low number of plants located in the region and in general operate at much larger scales i.e. centralised, large scale bioethanol and biodiesel plants. The reason for this differentiation is due to the different approaches required for making a regional inventory of these conversion facilities within the CG region.
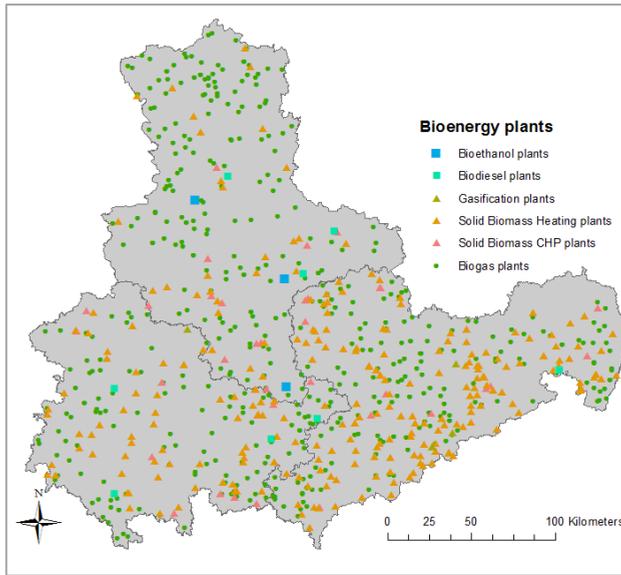
Figure 4: Bioenergy plants in the Central Germany Region 2010 (Source: DBFZ)

2.2.1 Spatially diffuse conversion systems

In order to determine the "status quo" (2010) for diffuse bioenergy conversion systems (mostly combustion and anaerobic digestion) in the CG region, it was a requirement to first try and identify the number of possible "conversion plant set ups" i.e. biomass feedstocks and technologies within a certain capacity range and which are representative of the "status quo" bioenergy systems in CG. Through collaboration with the DBFZ, data mining of the bioenergy database was carried out using various statistical approaches e.g. summary statistics, contingency tables and chi square analysis for categorical data. This analysis allowed several aspects to be identified, including; 1) possible feedstock combinations; 2) technology set ups associated with the various feedstock combinations; 3) the ranges of installed capacities (kW) for which these combinations operate; 4) the frequency of these combinations (Figure 5). Through this analysis and expert discussion with colleagues of the DBFZ, "model plant concepts", which are characteristic to the whole of the CG region, were developed.
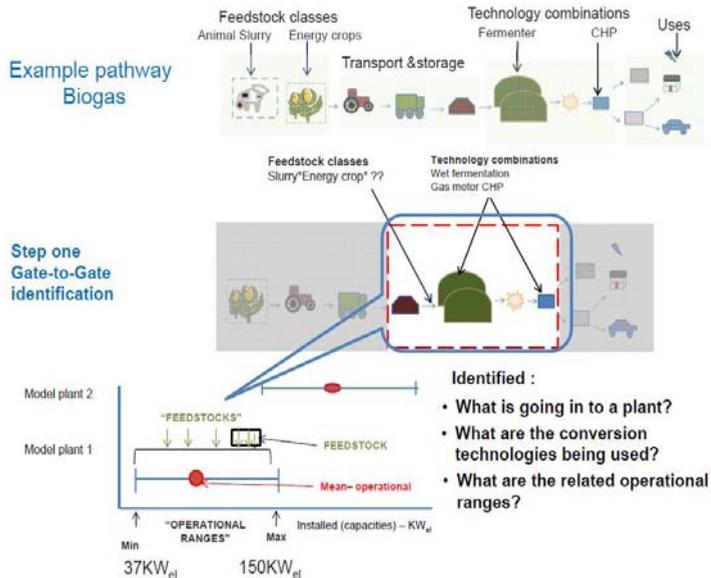
Figure 5: Visualisation of the approach identifying representative "model plants" for the CG region (gate-to-gate).

2.2.2   Non- spatially diffuse conversion systems

The non-diffuse technologies with a much larger scale of operation and occurring in much lower numbers required a different approach to determine the "status quo" (2010). These conversion plants in general are significantly larger and in most cases develop uniquely, depending on the regional setting. The range of operational capacities can also increase in an almost stepwise manner, which may, or may not be associated with a change in the associated technology e.g. Hexane extraction used in larger scale biodiesel plants, as opposed to mechanical pressing. Therefore, through the expertise modelling of the DBFZ, scientific literature and regional company information the model plant concepts for the region were developed.

2.3   Model plant concepts

For the four conversion systems identified; anaerobic digestion, combustion, trans-esterification and fermentation, nineteen "model plants", which are characteristic and representative of the CG region, have been identified in Table 1.

Table 1: List of model plants determined for the CD region through collaboration with the DBFZ

Conver. system	Type of plant	Feedstock categories	Main Technology	Installed capacity
Combustion	Stove heaters	Wood logs	Stoves	<10 kW
	Heat	Wood pellets	Stoker	32-400 kW
	Heat	Wood chips	Grate	150-1000 kW
	Solid HP[1]	Untreated wood-chips	ORC[4] – CHP[4]	0.55-2 MW
	Solid HP	Untreated wood chips	ST[4]. CHP	2.6-13 MW
	Solid HP	A1-A2 wood chips[2]	ST. CHP	1-4.15 MW
	Solid HP	A4[2] (treated wood) chips	ST. CHP	1.4 -14 MW
Anaerobic Digestion	Gaseous HP	AS, MS,C, GS[3]	CSTR[5]	< 150 kW
	Gaseous HP	AS, MS,C, GS	CSTR	150 -500 kW
	Gaseous HP	MS, AS,C, GS	CSTR	150 -500 kW
	Gaseous HP	AS, MS,C, GS	CSTR	500 -1000 kW
	Gaseous HP	MS,AS, C, GS	CSTR	500 -1000 kW
	Gaseous HP	MS,AS, C, GS	CSTR	>1000 kW
	Gaseous HP	Bio and industrial wastes	CSTR	>500 kW
	Biomethane	MS, AS,C	CSTR	350 und 700 Nm³/h
Trans-	Small – medium scale bio-diesel	Rapeseed oil	Biodiesel plant combined with decentralised oil mill	5000 -100,000 t/a
	Large scale biodiesel	Rapeseed oil	Biodiesel plant combined with central oil mill	>100,000 t/a
Fermentation	Sugar bio-ethanol	Processed juice from sugar beet factory	Bioethanol (associate with sugar plant)	>100,000 t/a
	Starch bio-ethanol	Wheat based	Starch bioethanol plant	>100,000 t/a

1. Heat = heat producing plants only; HP = heating and power plants.
2. Wood feedstocks: A1= mechanically worked wood; A2= waste wood treated, but with no halogenated organic compounds in the coating and no wood preservatives; A4 =Waste wood treated with wood preservatives (BMU 2002).
3. Feedstocks for biogas: AS = animal slurries, MS = maize silage, C = cereals, GS = grass silage.
4. ORC = Organic Rankin Cycle, CHP = combined heat and power plant, ST = steam turbine CHP.
5. CSTR = continuous stir tank reactor.

3   Work in Progress

The proposed next steps include expansion of the model plants to model pathways; typical of the region i.e. connection of the biomass production inventory to the model plants using a mixture of tools and GIS analysis. Once this is complete a final inventory for exploring a spatially and regionally dependent LCA for the year 2010 will be established. As a first step approach a classical scoping attributional LCA will be applied in order provide an overview or starting point to identify the important environmental impacts characteristic to each regional "model pathway". It is then proposed at a more advanced stage of modelling to disaggregate the regionalised inventory into foreground and background. Background in this case refers to everything outside the regional scope. In doing this, the foreground data can then be coupled with other environmental impact models which are also being developed for the region as part of a larger Helmholtz project "Biomass and Bioenergy Systems".

In addition to this, it is also aimed to integrate temporal components investigating bioenergy and land use scenarios until 2050. The model plants outlined above have also been developed in collaboration with the "Milestones 2030" project of the DBFZ which aims to identify the technical and organizational milestones which need to be achieved by 2030 in order to establish a successful longer-term strategy to 2050. Through this collaborative work the model plants of the status quo will be adapted and modified to "future model plant concepts" e.g. second generation biofuels. These will then be used along with the future Central Germany regional scenarios of Hauck & Priess (2013), to investigate future regional options for bioenergy production.

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Efficient utilization of wood sources for Wood-Polymer Composites

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Abstract

The rising demand for wood sources, driven by the increasing utilization of energetic biomass, led to increasing prices for the wood processing industry. Beside the price aspect and performance of the product, the material utilization of wood sources is gaining greater importance, induced by the long-term CO_2 storage effect of multiple cascade utilization. Hence the usability and performance of alternative wood sources for the production of WPC was investigated. For this investigation, sources like less valued beech wood assortments (*Fagus sylvatica*), and composite products, e.g. chip- and MDF boards, were used for WPC. These wood flour polypropylene compounds contain 60 % wood or composite particles and were manufactured using a co-rotating extruder. Consolidation was done via injection moulding. Mechanical and physical properties were investigated. X-Ray computed tomography (µCT) was used to evaluate the dispersion of particles and composition of the internal composite. The main conclusion was that new sources of wood assortments such as beech wood, chipboard- or MDF board particles are highly suitable for manufacturing WPCs. The mechanical properties of the composites were noteworthy increased using chipboard or MDF board particles. The µCT results confirmed a homogenous dispersion of particles and highlighted the differences in their internal composite structure.

Keywords

WPC, polypropylene, new wood sources, cascade utilization, mechanical properties, µ-CT

1   Introduction

Wood-Polymer Composites (WPCs) are determined as new hybrid class composite materials. These composites are described in numerous definitions, which include a wide range of constituents and applications. In the last decade, WPCs were in the centre of extensive research analysing processing procedures, formulation adaptation and product optimization (Clemons, 2002). The product segments range from building products, e.g. deckings and claddings, to infrastructure and transportation (Klyosov, 2007). In recent years, the market for WPC increased constantly and was characterized by the development of new products, marketing strategies and focus on alternative resources (Carus, 2011).

Nowadays the resources for WPC mostly still consist of by-products from the timber and timber-based industry, containing spruce (*Picea abies*) and other softwoods assortments. But in regard to changes in energy policy, the support of sustainable biomass energy, and forestry concepts, which provided silviculture concepts dominated by broadleaf, the demand on existing resources increased and so did the prices (Mantau, 2009). This effect induced a reflection on available resources and concepts for a sustainable and more efficient material utilization.

To investigate a potential cascade utilization of recyclates, this study focuses on the characterization of WPC, chipboard and MDF board particles, the manufacturing process and the analysis of mechanical and physical properties. Several studies demonstrated that the particles' size and morphology strongly influences the mechanical properties (Migneault et al., 2008; Migneault et al., 2009; Wolcott & Englund, 1999; Stark, 1997). By using wood or other particles with a prospective aspect ratio, the properties are expected to be improved (Radovanovic, 2007). In contrast, there was shown that fibre material, even with a high initial aspect ratio, is often unable to improve mechanical properties due to the fibre degradation during processing (Schirp, 2010; Schirp, 2009; Sobczak, 2012a). Nevertheless, the properties of WPC are mainly affected by wood content, applied process, and used additives (Kumari et al., 2007; Kim et al., 2008). To implement further material and cascade utilisation, knowledge about the process and the amount of additives is needed to equally analyse the influence of particles on structural composite properties.

2   Experimental

2.1   Materials

For the production of the MDF fibres, peeled beech logs with high amount of multi-coloured heartwood were used. The manufactured MDF boards (12 % UF resin) were supplied by the Fraunhofer Institute for Wood Research (WKI, Germany). For the production of chipboards, beech chips with bark were used in the core (CL) and spruce particles without bark in the surface layer (SL) with an amount of 60 and 40 weight per cent, respectively. The used UF resin (Kaurit 350) content amounted for 10 % in the surface layer and 8.5 % in the core layer. All wood (or recylates) assortments were prepared in two steps, using a hammer mill with a prior aperture size of 15 mm followed by an aperture size of 1 mm. Debarked panels of Norway spruce (*Picea abies*) and beech (*Fagus sylvatica*) were used as initial wood resource. Isotactic polypropylene (PP) Sabic 575P (homopolymer) was used as a matrix polymer in the form of granulates and was provided by Sabic Europe. As coupling agent, Licocene PP MA 7452 TP (Clariant SE) was added. All formulations consisted of wood (or wood composite recyclates), PP and MAPP (refer to Table 1).

Table 1: Composition and labelling of WPC formulations

Label	Particles [%]	PP [%]	MAPP [%]	Description
WPC (B)	60	37	3	Beech (*Fagus sylvatica*) 1 mm particles (without bark)
WPC (S)	60	37	3	Spruce (*Picea abies*) 1 mm particles (without bark)
R-WPC(B)				Recyclates - WPC (B)
R-WPC(S)				Recyclates WPC (S)
WPC (CB)	60	37	3	SL[1](40%): Spruce (*Picea abies)* shavings without bark; UF 10 % CL[2] (60%): Beech (*Fagus sylvatica)* shavings with bark; UF 8,5 %
WPC (MDF)	60	37	3	Beech (*Fagus sylvatica*) TMP Fibres; UF 12%

[1] Surface layer

[2] Core layer

Wood (or composite recyclates), polymer, and coupling agent were compounded to granulates at 170 °C mould temperature using a Leistritz MICRO27GL/GG40D co-rotating twin-screw extruder (Leistritz Extrusionstechnik GmbH, Germany) with gravimetric feeders (Brabender GmbH & Co. KG, Germany) and a hot-cut pelletizer. All compounded formulations were injection moulded using an Arburg ALLROUDER 320 C (Arburg GmbH + Co KG, Germany) to tensile test specimens according to EN ISO 527-1. The injection moulded pressure ranged between 1400 bar and 1900 bar at a temperature of 185°C. Fifty specimens of each formulation were processed according to the requirements of testing.

Particle length and shape of particles were examined prior to compounding by using dynamic optical particle analyser. The analyser (QICPIC, Sympatec GmbH, Germany) was connected to a vibrating chute (VIBRI, Sympatec GmbH, Germany) and a particle disperser (RODOS, Sympatec GmbH, Germany). The particles were dispersed in air and transported in a laminar air stream passing a laser light and an optical detector. The detector was able to collect a 2D-image of every particle between 10 µm to 20.000 µm.

Each particle was analysed using a skeletonization algorithm determining the shortest distance between the farthermost endings to calculate the particle length (LEFI[3]). The projected area of the particle was divided by the total length of the skeleton sections, which coincides with the particle diameter (DIFI[4]). All particles were classified into 50 length classes. Aspect ratios (AR) were calculated for each class by the division of mean LEFI and mean DIFI. Particle distribution was calculated by relative amount [%] of each class and summarized cumulatively based on particle length (Q1).

Specimens of all composites were analysed using µCT[5] imaging in order to evaluate the internal structure and composition. All composites were scanned in a µCT device (Nanotom s, GE Measurement & Control, Germany) with 70 kV and 180 µA, using a molybdenum target. Within the software Datos 2.0 (GE Measurement & Control, Germany), a 16 bit signed greyscale volume with a resolution of 5 µm voxel size was reconstructed based on 2.200 2D-projections. First, all volumes were analysed using Avizo Fire 7.2 (VSG, Visualization Science Group, France) separating the air, polymer and wood fraction, via their specific threshold value. Secondly, virtual slices were visualised to characterise the internal structure of the following 2 regions:

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[3] Length of fiber

[4] Diameter of fiber

[5] Mirco computer tomography

(1) Cross-section from the middle part of injection moulded specimen

(2) Longitudinal section from the middle part of injection moulded specimen - virtual slice along the internal core

The mechanical properties of the composite were determined by testing tensile and impact bending strength. Tension strength and modulus were determined according to EN ISO 527-1 using a Zwick/Roell universal testing machine, model Z010 Allround Line. For each formulation 10 samples were tested at a cross head speed of 2 mm/min. Unnotched impact strength test was performed according to EN ISO 179-1 by using a Ceast, Resil Impactor (pendulum energy 1 J, 10 replicates per formulation).

3   Results and Discussion

The created wood particle and composite recyclate assortments were evaluated regarding their length (LEFI[6]) and diameter (DEFI[7]). A high amount of particles ensured statistical relevance of our data. The evaluation of statistic intervals (x_{10}, x_{50}, x_{90}) confirmed several dissimilarities in relation to the particle length (LEFI) within the various particle mixtures. X_{10} showed a low amount of small particles (dust) especially for the beech and chipboard assortment. The median (x_{50}) exhibited a wider distribution with lower values for the chipboard and beech particles. The MDF board recyclate assortment showed the longest particles. Within the interval x_{90}, comprising the 10 per cent of the largest particles, the wood assortment of spruce and MDF fibres showed the highest values. Within this interval the chipboard particles revealed a considerably decreased particle length, conceivably related to the former processing steps. The values of the determined median aspect ratio (x_{50}), ranged between 2.3 and 4.4, showing variations between the different wood particles as well as for the recyclate particle assortments (see table 2). Concerning the issue of particle values, the length and aspect ratio were analysed before processing. These values have to be seen as initial values. The induced friction during the compounding and production process is supposed to lead to further reduction of particle length values. The µCT measurements can give an indication for reduction and dispersion of particles.

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[6] Length of fiber
[7] Diameter of fiber

Table 2: Effect of milling process on wood particle assortments and composite recyclates concerning particle length within the statistic intervals (x_{10}, x_{50}, x_{90}) and determined aspect ratio for the interval x_{50}.

Label	No. of analysed particles	x_{10} - value [μm]	x_{50} - value [μm]	x_{90} - value [μm]	AP [for x_{50}]
Beech 1 mm	5 223 421	29	105	539	2.4
Spruce 1 mm	2 424 451	37	152	609	3.3
Chipboard	6 027 094	28	97	421	2.3
MDF	1 981 987	46	165	546	4.4

Figure 1 shows the tensile strength values of the injection moulded WPC specimens. The strength values ranged between 38.4 MPa (R-WPC$_{(S)}$) and 48.4 MPa (WPC$_{(MDF)}$) whereas the tensile modulus was determined between 5263 MPa (R-WPC$_{(S)}$) and 6403 MPa (WPC$_{(MDF)}$).
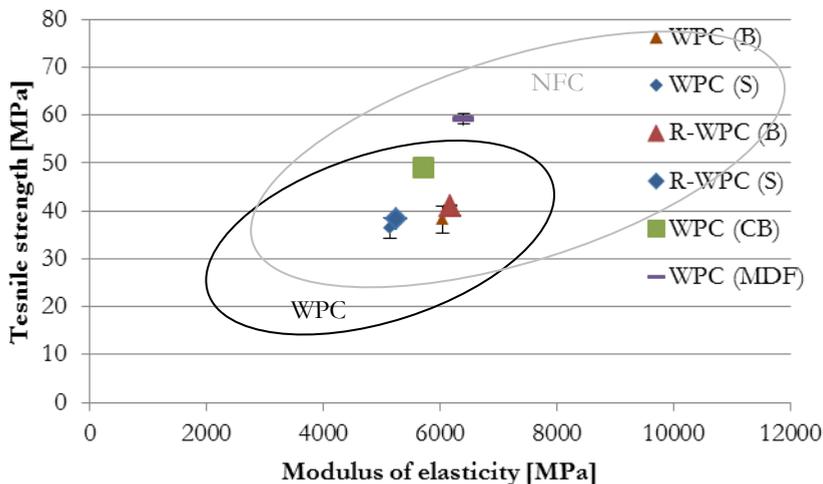
Figure 1: Ashby plot illustrating tensile strength vs. modulus of elasticity of investigated wood or composite recyclate/ PP compounds. Based on literature references, the range of WPC and NFC tensile properties was highlighted by an elliptical shape (Sobczak, 2012a).

The investigated tensile strength values are consistent to tensile properties of other injection moulded WPC formulations (Sobczak, 2012a). Furthermore, Sobczak 2012b noted that the strength properties have to be either affected by an increasing aspect ratio or traced back to an increased fibre-matrix interaction. It is expected that the dispersion of particles combined

with a strong adhesion to the matrix is even more effective, than the reinforcement of relatively short fibres, which we could expect here for the recycled MDF board fibres. Nevertheless, the increased aspect ratio of MDF board fibres could partly lead to an increase in strength properties as well. As stated by Radovanovic 2007, the wood content causes the major influence on strength and stiffness. In this case, the existing additives and thermosetting residues within the recyclate composites seemed to positively influence the strength properties and the modulus of elasticity. According to the strength values of the WPC$_{(CB)}$ composites, the improvement of adhesion due to the thermosetting residues seems to be very likely. Thus, the WPC$_{(CB)}$ particles consisted of beech and spruce particles with 60 and 40 weight per cent, respectively. The influence on stiffness can be attributed to the type and morphology of particles. Hence, with the increase of beech or compressed beech fibre content the elasticity was also increased. Overall, still open issues are the effects of processing behaviour and adequate conditions, the plant growth and harvesting conditions on composite properties (Sobczak, 2012a).

Concerning the impact strength, the WPC$_{(MDF)}$ formulation showed the highest value with 20.1 kJ/ m². The composite formulation R-WPC$_{(B)}$ revealed the lowest impact strength values with 10.5 kJ/ m² (see figure 2).
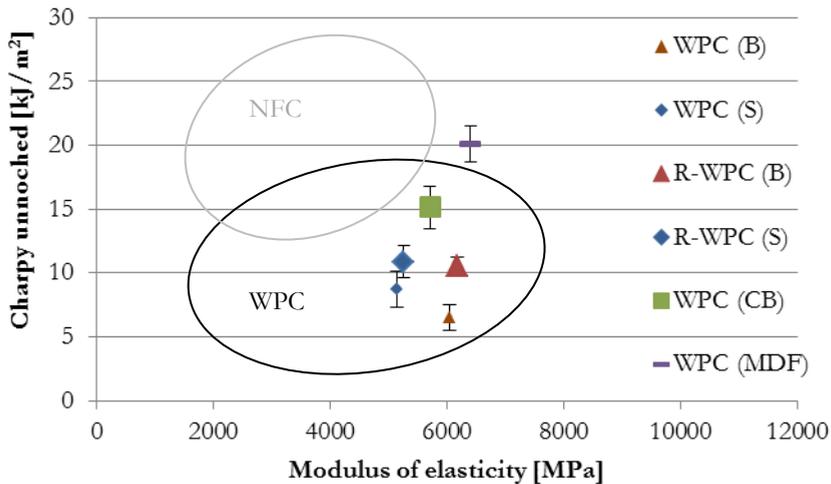
Figure 2: Ashby plot illustrating unnotched Charpy impact strength vs. modulus of elasticity of investigated wood or composite recyclate/ PP compounds. Based on literature references, the range of WPC and NFC impact bending properties was highlighted by an elliptical shape (Sobczak, 2012a).

Generally, impact strength indicates the ability of the composite to achieve a rapid transfer of stress into the bulk material. The avoiding of stress peaks can be attributed to strong interfaces. Hence, compared to the recy-

cled WPCs, the "waste" recyclates from chipboards and MDF boards revealed higher impact values. Compared to recent studies, the mechanical properties of the WPC$_{(MDF)}$ composites showed promisingly results concerning the impact values of produced WPC formulations (Sobczak, 2012a). The differences in mechanical properties seem to be affected by the wood particle assortment and furthermore the heterogenic and complex wood structure. The wood structure is featured by significant differences in mechanical properties, regarding the wood species and micro- and macroscopic structure (Niemz, 2005; Eder et al., 2008).
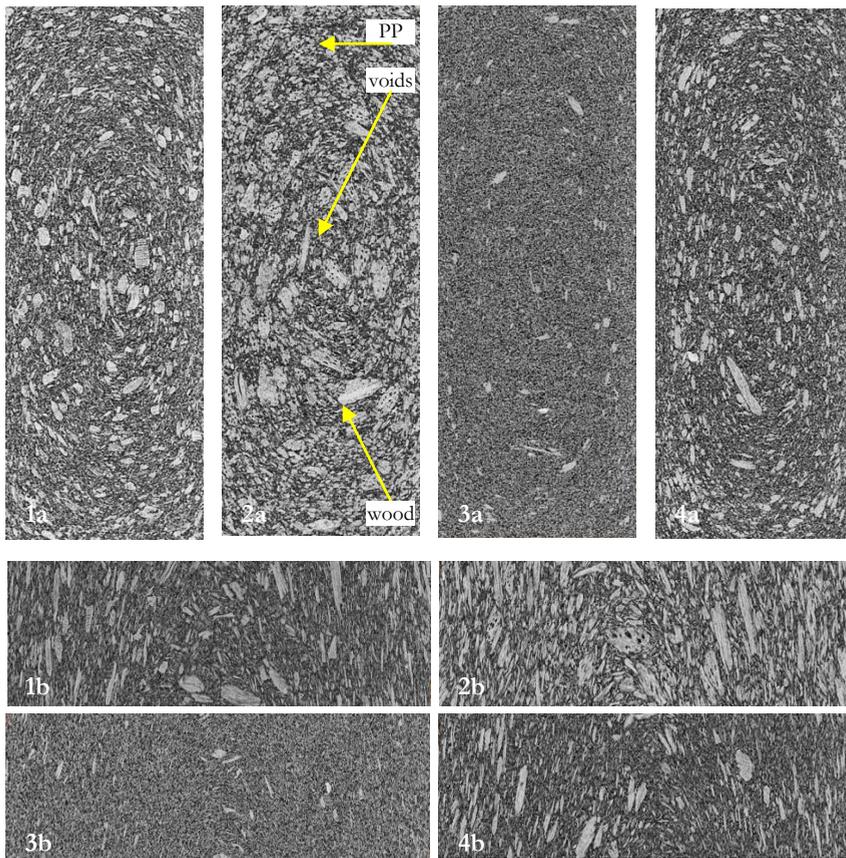
Figure 3: Visualisation of composition and internal structure of the WPC material by using X-ray microtomography (µCT). [a] Cross-section of a [1] R-WPC (S), [2] WPC (B), [3] WPC (MDF) and [4] WPC (CB) injection moulded specimen. [b] Longitudinal-section of the same composite specimen.

The X-ray micro tomographic images visualised the internal composition of the composites, illustrating the particle length and shape and how these particles are imbedded in the polymer matrix (see figure 3). Regarding the

illustration of the material composition, the air fraction and bubbles were visualised in black colour, while wood particles and PP matrix were marked in light grey and dark grey colour, respectively. High absorbing particles were highlighted in a bright white colour. Due to the mixed grey values of small particles and PP, just larger particles were easily visible. It is assumed that in some regions the depict layers of PP were thinner than the resolution (5 µm). Therefore, the PP matrix was also measured together with the wood particles. Hence, a detection of an interfacial failure within the polymer matrix could not be realised. The orientation and alignment of wood particles within the specimens can be investigated especially through the longitudinal-section of the composites. As stated by Krause (2012) the images displayed a more parallel alignment of wood particles close to the surfaces and perpendicular to the compression direction. The particles in the centre exhibited a random alignment. For the composite specimen based on the chipboard recyclate (see figure 3 4a&b) an appearance of highly absorbent particles was observable. This could be traced back to the used beech assortment with bark, containing mineral residues as fine silica particles.

Moreover, the relationship between the used particle assortment and resulting densification and particle morphology was investigated. The two WPC recyclates were principally influenced by the same stress level, concerning milling of particles, compounding, and injection moulding process. The CT images displayed the characteristic anatomical structures of hardwoods, with the presence of vessels, and the tracheids as the principal element of softwoods (Standfest et al., 2013). Softening of lignin directly influence the effect of temperature and moisture on the mechanical behaviour of wood (Kärenlampi et al., 2003). A higher compression of spruce particles within the WPC (S) resulting from the increased lignin content could not be clearly revealed. Small air voids are displayed in the inner core layer of nearly all composites. A direct association to the particle mixtures seems not yet evident. The decent void population is certainly caused by the hydrophilic nature of wood particles and set process parameters.

4 Conclusions

The study has shown the successful use of WPC recyclates and recycled composite materials for the processing of WPC. An efficient compounding with PP was achieved, along with a homogeneous dispersion of wood particles/ fibres in the polymer matrix. The initial particle assortments showed differences regarding their particle lengths, related to the utilized tree species and composite material. The mechanical properties were noteworthy increased by the utilization of either chipboard or MDF recyclates. The observation via x-ray micro tomography was suitable to investigate the internal composite structure for defects and confirm the homogeneous dispersion of particles within the investigated WPC formulations.

Acknowledgement

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From Waste to Value – Composite Materials from Industrial Process Wastes

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Keywords

Waste material, paper, wood plastic composites, WPC, lignocellulosics, resources, processing, extrusion, injection molding

1 Introduction

The use of reinforcements and fillers in thermoplastic materials has been a long and well-documented practice in industry. In general, filled thermoplastic materials are stiffer, stronger, and more stable than unfilled materials. In contrast, other properties such as impact bending strength may decline. Fillers are typically inorganic such as talcum, or glass fibers. The use of wood fibers as a replacement for traditional, inorganic fillers has been practiced for some time. A number of materials use a considerable amount of natural fibers as the main component, as filler or reinforcing component. These materials range from particle boards, fiberboards, oriented strand boards, to a number of engineered wood products, and also to polymers reinforced with wood or other natural fibers (e.g. hemp, flax, coir, kenaf). These materials are known but not limited to WPC (wood-plastic/polymer-composites). The largest commercial applications for WPC are decking, but also furniture, packaging, housing goods, and selected interior components for automotives are produced. Today, WPC represent a relatively small but rapidly growing material class. One significant argument to use wood instead of inorganic fillers are the lower costs. However, this situation seems to be changing. Since wood is favored and greatly pushed as a key resource for energy production ("bioenergy"), prices for low-quality wood stocks have significantly gone up. According to Mantau (2010) 46% of the European wood consumption go into energy use. This share will continue to rise up to 53% by the year 2030, as predicted. Saw log prices in Germany have risen by 30% between the years 2005 and 2008, and wood residues are up even by 70% during the same

period (Sauerwein, personal information). Alternative natural fibers may be seen as substitutes to wood fibres in WPC. However, fibers such as hemp, flax or sisal are much higher in price, and since their fiber length is in the centimeter range, these fibers also need to be cut to become processable in an extruder or injection molding machine.

The search for alternative fibers that are resource and eco-efficient has led us to the question if cellulose-containing wastes can be utilized for composite material development. At the Institute of Natural Materials Technology, IFA Tulln, research has been initiated some time ago looking at different cellulosic-type waste sources, with the goal to develop and ultimately manufacture 3D-shaped materials (Mundigler 2004, Bittermann & Sykacek 2007). This research effort has been steadily growing over the past years, indicating that industry is increasingly concerned about resource efficient production. The key question is how these cellulose-containing wastes perform as polymer-filling materials. If suitable materials properties are determined, a number of applications can be developed.

2   Materials and Methods

Different types of paper-based wastes have been collected: *TetraPak®* (beverage) packages, poster paper, cardboard-type paper, other polymer-coated waste paper. Due to multiple polymer-coating most of these paper types are not collectable in standard paper recycling pins. The material of a e.g. juice package consists of a cardboard layer that has been foliated with 2-3 polyethylene layers, as well as an aluminium layers, to achieve sufficient mechanical stability and liquid-tightness. In the recycled fraction the poly-ethylene content of coated paper wastes might be as high as 20%. The paper-based materials were cut in sieve-mills at mesh-sizes between 3 and 10mm. During processing special care had to be taken due to metal or mineral inclusions (Figure 1).

Figure 1: Different types of pre-processed waste-paper materials

Wood plastic composites (WPC) are usually processed in two steps. First, a granulation step is done, using a co-rotating, conical double screw extruder with a granulator mounted at the exit nozzle. Second, the compounded granules are then fed into the profile-extruder. For the paper-waste materials direct extrusion was tried, since sufficient homogenisation seemed to be achievable. The paper particles were mixed with polypropylene and polyethylene granules as well as additives, before the mixture was fed into a battenfeld-cincinnati extruder. The geometry of this conical twin screw extruder was especially suitable for low density materials. With a special extruder screw configuration the material was homogenized, densified, and heated to obtain an endless viscous polymer strand, which was then shaped through the mounted form die into different profile shapes (Figure 2).
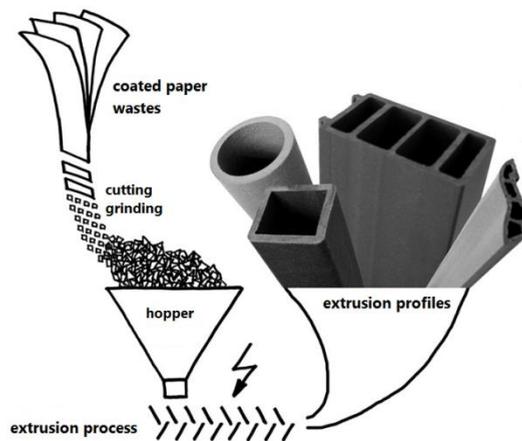
Figure 2: Simplified process scheme - from coated paper wastes to extruded profile materials

Preliminary research on de-inking paper sludge (DPS) as a special filling material was also included in the study. This material is a major waste product resulting from the paper recycling process. De-inking paper sludge is about 60% inorganic, additional pre-processing is necessary prior to profile-extrusion. We partially replaced the wood component in standard WPC recipes, with polypropylene used as the matrix polymer. A standard two-step process was applied, which means materials went into the extruder with a mounted granulator, before the granules were fed into the hopper for the actual profile extrusion. The extruded profiles were characterized for mechanical-physical properties using standard material testing procedures.

3   Results and Discussion

3.1   Thermoplastic materials from coated waste paper

A number of recipes were tested, having different proportions of waste paper, thermoplastic polymers, and additives. Wood fibres as reinforcing components were also used. The waste paper content went up to maximally 70%. After optimizing processing conditions, extrusion profiles were produced and then tested. The surfaces of the produced profiles appeared homogeneous and smooth, profile edges were to size and accurate. Examples of the different profiles are shown in Figure 3.
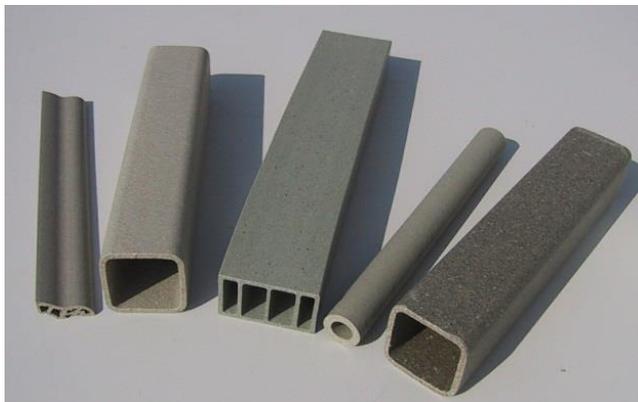
Figure 3: Different profiles of extruded paper-based polymer composites

Test strips were cut from sides of the profiles, to determine mechanical properties as well as water uptake percentages. Table 1 shows a comparison of three typical examples. *TetraPak®* represents a blend of 40% *Tetra-*

Pak® paper particles (3mm), 20% writing paper particles (3mm), 25% polypropylene, and the additives talcum filler and coupling agent. The "*Poster paper*" type consisted of 60% poster waste paper, 28% polypropylene, and also talcum and a coupling agent. WPC was a standard wood-plastic-composite with 60% wood filled in polypropylene. Results show that the *Tetra-pak®* as well as the *poster paper* versions are having high impact bending strengths compared to the standard WPC. The other properties bending strength (MOR) and bending stiffness (MOE) are at comparable levels; and the same is true for water uptake. The conclusion is that waste-paper based polymer composites deliver materials with a very acceptable property profile.

Table 1: Selected properties of WPC (Wood-PP (60/40)), Poster Paper – PP, and TetraPak®-PP (MOR modulus of rupture, MOE modulus of elasticity, IBS Impact Bending strength, and water uptake after 24h immersion

	WPC	Poster Paper	TetraPak®
MOR [MPa]	51	30-40	35
MOE [MPa]	4430	2500-3000	2240
IBS [kJ/m²]	8,2	8-9	13
Water uptake 24h [%]	1,5	1,5-2	1,6

Waste-paper filled polymer composites have further advantages over wood-plastic composites (WPC). Since lignin and resins are almost absent in paper, the processed composites are less prone to UV degradation. This results to higher weathering resistance, as proved in various outdoor tests. Further, the lack of lignin allows higher processing temperatures at the extruder, making the production more versatile and better adjustable to desired properties. In can be concluded, that polypropylene filled with special waste-paper types results in a new type of material, which is named called *Paper-Polymer-Composite*, or PPC.

Continued research and development at the Institute of Natural Materials Technololgy, IFA Tulln, Universität für Bodenkultur Wien, has led to products, such as with UPM-Kymmene. Decking products filled with recycled laminated papers have been developed and they are now successfully established on the market, as *UPM ProFi Deck*. This new decking type has proven as a durable and new outdoor solution used as garden decks, patios, terraces, marina or boardwalks.

3.2 Thermoplastic materials made from de-inking paper sludge (DPS)

From the different test mixtures using DPS two results are presented in Table 2. A WPC recipe was chosen, having 70% wood and 30% PP (plus additives). In the first trial, half of the wood was replaced by DPS. The second trial refers to a full replacement of wood by DPS. Bending strength and stiffness show considerably higher levels, compared to standard WPC (see Table 1 for WPC values).

Table 2: Modulus of rupture (MOR), modulus of elasticity (MOE) and impact bending strength (IBS) of extruded Wood – DeInking Paper Sludge (DPS) – polypropylene composites.

	Wood/DPS 35%/35%	Wood / DPS 0%/70%
MOR [MPa]	52	56
MOE [MPa]	7511	6648
IBS [kJ/m²]	4,7	3,6

Different processing conditions with wet and dry DPS were tested, which are not reported here. The conclusion is that added-value materials can be manufactured from DPS. There is a considerable amount of paper sludge, which the paper industry generates during papermaking. About 3 million tons p.a. paper sludge is discharged in Japan, 8 million ton in the United States, and 6 million tons per year in Western Europe. De-Inking paper sludge contains good quality reusable fibres, and the high inorganic portion gives rise to additional characteristics such as fire resistance, or higher surface hardness. These residues are usually disposed as landfills or are used as a low-quality additive in the cement industry, all at significant costs for the paper industry (Yamashita et al. 2010). With new material applications the overall resource efficiency for cellulosic waste material can be greatly improved. Advanced material development with DPS will be a focus of future research.

4 Conclusions

While virgin materials, i.e. wood, experience increasing prices and therefore reduced availability, a vast amount of cellulose-based waste materials have currently low-value usage. Multi-coated paper products, as used for e.g. milk and beverage packages, or other laminated waste paper fractions, need to be separately collected due to higher polymer contents. However, the higher polyolefine-content is making them suitable for thermoplastic processing. It was possible to extrude paper particles with polypropyl-

ene/polyethylene to profiles showing superior material characteristics. The other material tested was de-inking paper sludge, a highly inorganic matter that is currently discharged at high costs. It was possible to demonstrate that added-value materials can be made, which gives rise to great improvements of resource efficiency. Future developments will most likely demonstrate that manufactured materials can be commercialized.

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Renewable resources in Germany and their possible utilization in composites

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Keywords

Renewable resources, fillers, plastic composites, substitution of wood

Abstract

For several years thermoplastic wood-plastic composites are studied with growing interest in science and industry due to increasing prices of crude oil-based plastics and ecological sustainability.

In varying percentages wood particles are combined with plastic and additives and processed in various methods such as injection molding or extrusion. However, other fillers and reinforcing materials from renewable resources have been tested, too. Against this background the questions arise which renewable resources are widespreadly cultivated in Germany in terms of quantity and which of them are able to substitute wood particles in wood-plastic composites due to their specific characteristics.

Based on statistical data ten cultures with the highest production volume in Germany were chosen. In a second step the applicability of these cultures as filler in composites were investigated by searching in literature databases for recent publications for the suitability. Aim of this work is to give first indications which of these resources have the potential to replace significantly quantities of wood as filler in thermoplastic composites.

1   Introduction

1.1   Renewable Resources

In the past few years, the demand for wood as energy and material source has risen greatly. The reasons for this are the increasing prices of fossil fuels, the ecological sustainability of renewable raw materials, and the potential of reducing greenhouse-gas emissions. Wood from commercially exploited woodland is considered to be the most important supply of renewable raw materials. But also other plant-based material arising from the agricultural sector can be used for the production of energy.

This increased total demand has led to shortages and to competition on the renewable raw materials market, leading to price increases and bottle-necks in supply. This, in turn, could have negative effects on the future commercial use of these products.

The declared long-term political aim in Germany is to reduce the use of fossil fuels to a minimum (Bundesregierung, 2010). However, the replacement of fossil fuels and their products by renewables has not been able to be implemented in all sectors of the country's economy. Indeed, due to the large degree of uncertainty involved, particularly with respect to availability and quality, renewable resources are not being used to the extent which the present state of technology would allow.

1.2   Materials

The materials industry uses large amounts of renewable raw materials in the form of wood. Wood has been considered since time immemorial as a material which is excellently suited for building and other uses, whereby the aim has always been to utilise all its byproducts optimally. In tune with this concept, wood-plastic composites (WPCs) are being used in the relatively new sector of the materials industry and are being more intensively scientifically investigated. In WPCs, woodflour (eg. as saw-mill byproduct), plastics and various additives are combined in differing proportions. These combinations are then processed using various techniques such as injection moulding or extrusion (Vogt, 2006). The aim of this admixing is to use as little plastic as possible and to combine the characteristics of plastics made from fossil fuels with wood. Lignocellulosic agricultural raw materials can also be used as a substitute for wood in such materials (Faruk et al., 2012).

1.3   Land use in Germany

The technical substitution potential of globally cultivated agricultural raw materials has been investigated in several studies (eg. Abdul et al., 2012; Faruk et al., 2012; John & Thomas, 2008). Germany is an agricultural land as about half of its total landmass is used for agricultural production (187 291 km²; Figure 1). Additionally, Germany has ca. 107 534 km² of woodland available for commercial use (Statistisches Bundesamt, 2009).
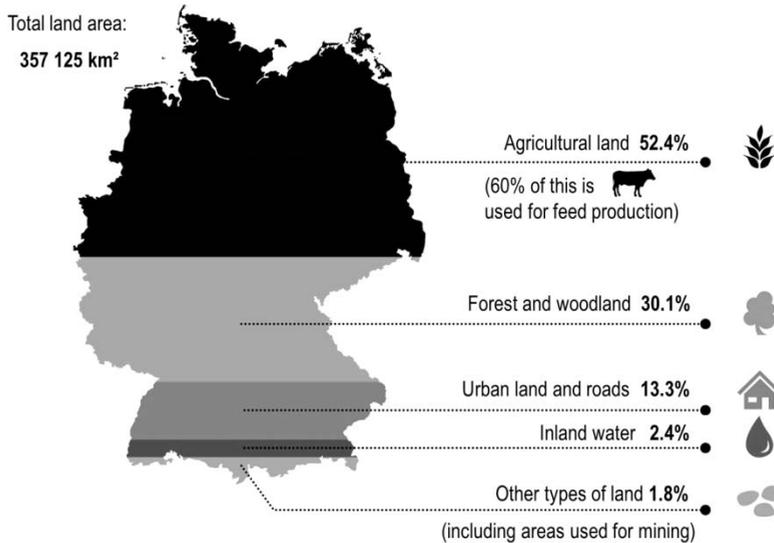
Figure 1: Land use in Germany (adapted from Statistisches Bundesamt, 2009)

The question arises as to which types and quantities of agricultural raw materials that can be used as substitutes for wood are potentially available in Germany and which are suitable for replacing wood as fillers in WPCs.

2   Material and Methods

First of all, the ten crops with the highest production volumes in Germany were identified using statistical data. Secondly, the suitability of these crops as fillers in WPCs was assessed by searching for publications which showed this suitability in the literature data banks using English, German and Latin terms.

The worldwide production of agricultural and forestry goods is documented by the FAO (Food and Agriculture Organisation of the United Nations). Using the information from 2001 to 2011, the FAO data on Germany was sorted according to year and production volume. An average

was calculated for each crop in Germany and then the ten most productive were chosen for further investigation. A comparison was made of the yields, in tonnes, of these crops over the aforementioned ten-year period.

Simple diagrams of the production chains for each of these ten crops were drawn so that the various byproducts could be elicited. By assessing these byproducts, it could be determined whether or not the use of a particular raw material as a wood replacement would be practicable or not. Above all, this assessment took into consideration the criteria of the theoretical technical suitability (feasibility) as well as considering the possibility of a worthwhile economic implementation.

3 Results

3.1 Crops and Literature Research

Table 1 shows the ten most productive crops in Germany using the average yields from 2001 to 2011 according to FAOSTAT (2013). Sugar beet and wheat are at the top of the list with yields of more than 20 million metric tons (wet weight); barley and potatoes are in the middle range with 10 million metric tons. The other six crops have a yield of less than 5 million metric tons. If the cereals are grouped together (wheat, barley, rye and triticale), then this group provides the largest quantity of material. It can also be seen in the table that more than half (6/10) of these crops have been already tested as to their usage as filling or reinforcing materials in plastic composites.

Table 1: Overview of the ten most productive crops in Germany and their use as fillers or fibres in composites. Source: ("FAOSTAT")

Rank	Crop	Average production volume (2001 – 2011) [metric tons]	Tested in composites
1	Sugar beet	24,662,691	No
2	Wheat	23,034,445	Yes
3	Barley	11,388,327	Yes
4	Potatoes	11,332,253	No
5	Oilseed rape	4,877,868	Yes
6	Maize/Corn	4,079,995	Yes
7	Rye	3,321,739	Yes
8	Triticale	2,569,549	Yes
9	Grapes	1,252,109	No
10	Apples	931,191	No

3.2 Evaluation of Results According to Crop

3.2.1 Sugar beet

Sugar beet is the most highly produced crop in Germany. After cultivation, the beets are harvested between the end of September and the middle of December. The leaves are usually left on the fields as green fertiliser or, in rare cases, are used for silage. The root-leaf ratio is ca. 1:0.6 by weight. In the classical processing method, the beets are chopped and the sugar is extracted via cooking, pressing and drying. The residual dried pulp is then used as animal feed.

Until now, sugar beet leaves have not been specifically investigated with respect to their use in WPCs. This can be explained by the high water content of the leaves at harvesting. Technically speaking, however, the dried sugar beet leaf mass is comparable with the biomass from other crops, such as seaweed or banana leaves, which have already been tested for their suitability as filling and reinforcing materials (Annie Paul et al., 2008; Hassan et al., 2011, 2008). Therefore the leaves could theoretically be suitable as filling material for WPCs, but this use would have to compete with their use as fertiliser or silage. This is why sugar beet, despite its large yield, has only a moderate substitution potential with respect to saw-mill byproducts in Germany.
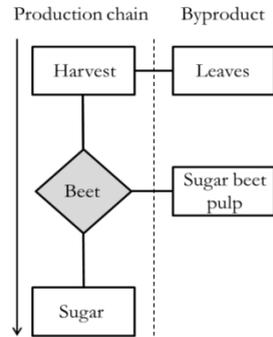
Figure 2: Production chain of the sugar beet (grey box) and its byproducts

3.2.2 Wheat and other cereals (barley, rye, triticale)

The wheat harvest occurs in the summer months. During the harvesting process, the straw and husks are separated from the grain. The corn-straw ratio is 1:1. The straw is often left on the field to be incorporated in the humus cycle. An alternative is harvesting the straw so that it can be used, for example, as bedding in animal production. Smaller amounts are used as building material or for producing energy.

Various studies have already analysed the characteristics of straw in composite materials, showing that it is basically suitable as a filling material (Amintowlieh et al., 2012; Avella et al., 2000; Farsi, 2012; Hornsby et al., 1997a, 1997b; Le
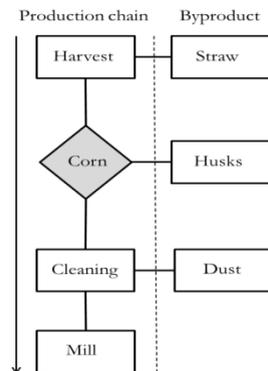
Figure 3: Production chain of wheat (grey box) and its byproducts

Digabel et al., 2004; Malkapuram et al., 2008; Panthapulakkal & Sain, 2006; Panthapulakkal et al., 2006; Reddy et al., 2010; Schirp et al., 2006).

Two other possible byproducts which could be used are the husks and the dust arising from the cleaning of the grain before it is milled. However, a large proportion of mineral constituents can be expected in the dust fraction as this consists mainly of dried soil particles from the field and could cause problems in the processing. Technically, cereal straw is interesting and is produced in large amounts in Germany. One disadvantage of this material, however, is its low transportability due to its low density.

3.2.3   Oilseed rape

Oilseed rape is harvested in Germany from roughly the middle of July onwards. The seeds are the main product, with straw and husks as byproducts. The seed-straw ratio of oilseed rape is on average 1:2.9. This is equivalent to ca. 10 t straw/ha. Due to the standard method of harvesting this crop, rather long stubble is left on the field, meaning that it would not be possible to utilise the whole of this potential biomass (Apfelbeck, 1989).

Rapeseed straw is sometimes sold as animal bedding. The rapeseed meal left after the oil has been extracted is mainly used as animal feed. Neither the husks nor dust have been investigated with respect to their usefulness as potential fillers. The behaviour of rapeseed straw as a filling material in composites has already been investigated and consideration has been given to its use as an inexpensive wood substitute (Akier, 2011; Paukszta & Zielińska-Maćkowiak, 2012).

Oilseed rape straw has a substitution potential as there are virtually no competitors for its utilisation. In addition, the high cutting height during harvesting means that it has only a very low mineral content. However, it has the similar transportability disadvantages as cereal straw (Apfelbeck, 1989).
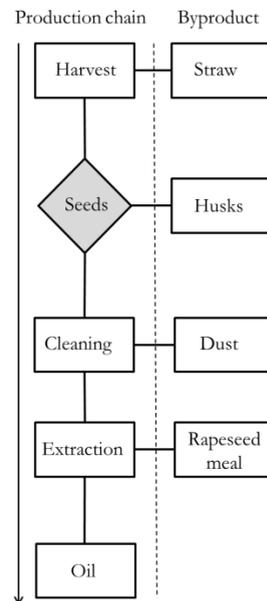
Figure 4: Production chain of rapeseed (grey box) and its associated products and byproducts

3.2.4 Potatoes

In the standard method of producing potatoes, the ripening of the tubers is controlled using crop desiccation, which means the killing of the potato plant using physical, chemical or mechanical means (Diepenbrock, 2011). After desiccation, the leafy part of the plant remains on the field and cannot be harvested.

The literature search did not bring to light any publications reporting the use of potatoes or their constituents as filling materials in composites.

In theory, however, the potato plant is available as it cannot be used as feed due to the presence of toxic alkaloids. Why it has, despite this, not been investigated for the use in WPCs may be due to the high water content of the plant at the time of harvesting.
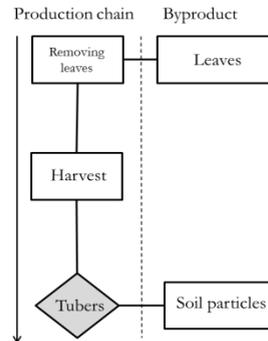
Figure 5: Production chain of potatoes (grey box) with the byproduct leaves. Soil particles stick to tubers and were removed in the further process

3.2.5 Maize

With maize, a differentiation is made between its use as whole crop silage (WCS) or for the production of grain. When maize is used as WCS for animal feed or is used in the biogas sector, only the stubble remains as unused biomass. At present, there are no concepts available for the harvesting of this. In the production of corn or corn-cob mixtures for animal feed, a corn-straw ratio of 1:1.3 can be expected (Döhler, 2009).

Ground maize straw as well as ground maize stalks have already been tested in combination with wheat straw as a filling material in polypropylene (Panthapulakkal & Sain, 2006). Theoretically, therefore, maize byproducts are suitable for the use in WPCs but due to the strong competition for their use, this is not really practicable.
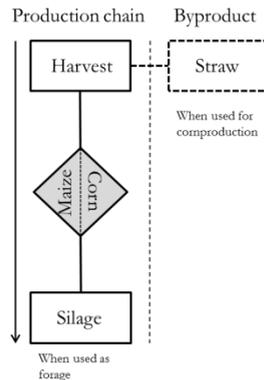
Figure 6: Two production chains of maize (grey box): production of maize for silage or production for corn

3.2.6   Grapes

Grape vines are harvested for the production of wine. The grapes are then pressed and the resulting juice is fermented to produce wine. The byproduct of this is the pomace, which consists of the skins, pulp, seeds and the fruit stems. No reports about the use of pomace in composites could be found during the literature search. However, (Djidjelli et al., 2007) have reported on the use of olive pomace in composites.

      Grape pomace is, however, used in many other processes, such as the production of animal feed, for the distillation of alcohol, or in biogas plant fermentation. This means that there is a great deal of competition for this material, so it is not really practicable for the use in WPCs.
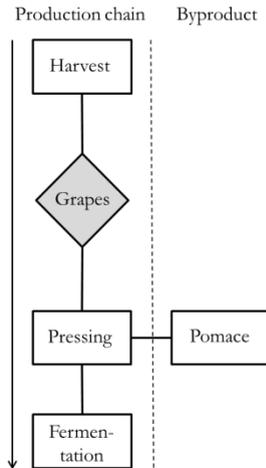
Figure 7: Grape processing chain with the byproduct pomace

3.2.7   Apples

There are virtually no byproducts associated with the harvesting of apples as a fruit. The whole apple is picked and sold as such to the consumer. In contrast, apple pomace arises from the production of apple juice or cider.

      The suitability of apple pomace as a filler has already been investigated and its characteristics have been described in a study (Chiellini et al., 2001, 2003).

      A general suitability could be proven, however, there is strong competition for its use (e.g. for the production of animal feed) making it less practicable.
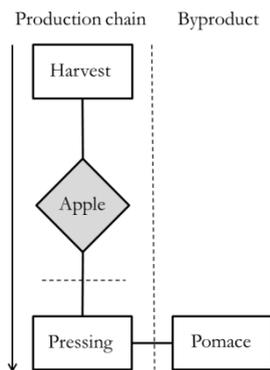
Figure 8: Apple process chain with the possible byproduct pomace

4   Discussion

Six of the top ten crops cultivated in Germany have already been investigated as to their suitability as filling materials in composite materials. This shows that not only the plants traditionally used as lignocellulosic fillers, such as flax or hemp (Biagiotti et al., 2004; EI-Sabbagh et al., 2009; Mohanty et al., 2005; Rowell et a., 1996) but also other crops could be used as fillers in composites. This is advantageous in not only that convenient filling materials with respect to price and the saving of fossil raw materials are accessible, but also many of their byproducts can be utilised thus enabling a complete utilisation of the crop plant. However, the restrictions placed upon this form of utilisation due to competition by other uses will have to be considered in detail in further studies.

Although in general such raw materials may be used as fillers, it will be necessary to look at the regional distribution of these resources within Germany. In addition, the quality of the raw materials and other issues (e.g. logistics, available harvesting techniques, and the competition for the use of these resources) will have to be investigated in detail. With the aid of this information, it will be possible to gain a better understanding of the possible methods of use of agricultural byproducts in Germany so that their material utilisation as fillers can be optimised.

Another important factor that has to be taken into consideration is the price of these raw materials, which depends greatly on their availability and yield as well as the transportation and processing costs. The true quantity of the raw materials should be itemised in additional investigations. Some preliminary work has already been done (e.g. for straw; Grimm, 2013), but this must be furthered to improve the material usage potential within the German agricultural sector.

5   Conclusions

According to their production volume, apples, barley, grapes, maize, oilseed rape, potatoes, rye, sugar beet, triticale and wheat are the ten most important crops in Germany. Six of these crops have already been investigated with respect to their suitability for use in wood-plastic composites and could be more or less suitable substitutes for wood. However, there have been virtually no investigations in which the potential of their use has been undertaken with respect to quality, quantity, different technical and commercial aspects of the value-added chain under the consideration of competing uses at the regional level. Furthermore, there is a lack of infor-

mation about the consequences arising from an increased material use of these crops. These factors should be investigated in further studies.

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Increasing the Eco Friendliness by reducing the Local Impact: the case of VOCless Waste Water project

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Abstract

VOC emission are released from mechanical pulping process and can be abated by different cleaning technologies: catalytic oxidation, UV filtration and biofiltering. In the Life project (LIFE 09 ENV/FI/568) these technologies were tested at the aerobic and anaerobic waste water treatment plants, with the aim of increasing the local eco friendliness of pulp manufacturing (reduction of odors, smog, ozone, NO_x).

In order to analyze the innovative solutions for the VOCs abatement, a collaborative network was implemented with a leading company.

Keywords

ECO Friend pulp, VOC Mechanical Pulp, VOC biogenic Abatement

1 Introduction

The Eco Friendliness concept is for one side very appealing, for the other is difficult to be accepted like any other environmental issue. Subjects like Green electricity or recyclables, nowadays are well affirmed in many European countries, but their acceptance by the population was not very simple at the beginning.

One aspect that can be addressed for increasing the Eco friendliness of a product is its local impact, that is the impact in the geographic area where products are manufactured or used.

Environmental Assessment of a product can be based on its global emissions, not considering specifically the area where emissions happen. In this manner, it is possible to keep the Environmental Analysis simple, avoiding the inclusion of local data and local indicators.

Also, in many LCA studies, environmental loads are expressed in term of CO_2 and other emissions, not specifying how those emissions are spatially distributed, inasmuch it is not known in advance where products are used or disposed.

In reality, it makes sense to evaluate also such local aspects in defining the eco friendliness of a production. In biofuel industry, for instance, it makes sense the level of pollution in the soil, even if this resource (biofuel) is renewable. Even if the level of noisy in manufacturing solar photovoltaics can contribute in defining the local environmental performances of a production. This aspect increases the complexity of the evaluation process, but it certainly can contribute in determining correctly the effectiveness eco-friendliness of the decision making process.

Including local impacts can be cumbersome and it requires studies site specific with national data. But an effort that can be done to increase the Eco-friendliness is trying to reduce the local emissions in the life cycle of a product. In the paper, this idea to reduce local impact is considered and applied to mechanical pulping. In particular, an environmental abatement is considered: VOC emissions from Mechanical Pulping.

In mechanical pulping (figure 1), the wood fibres are separated from each other by mechanical energy applied to the wood matrix, causing the bond between the fibres to break gradually realising fragments, single and bundles of fibres. Raw materials are logs that are first debarked. Debarking is followed by either of two different mechanical defibration processes. Due to the high temperature of defiberizing, part of the wood extractives evaporate during the process in a form of VOCs.
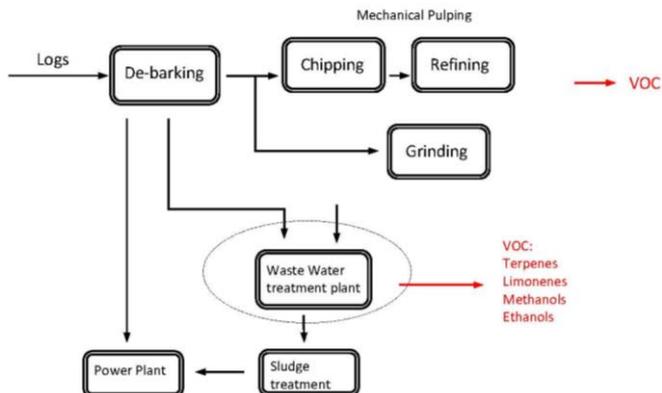
Figure 1: Main steps of the mechanical pulping

Those emissions are biogenic, naturally delivered from the wood, so they not require any abatement by the law (figure 2). Nevertheless, VOC emissions may have a relevant local impact, in terms of Smog generation in combination with NO_x, Ground Level Ozone and Odour formation.
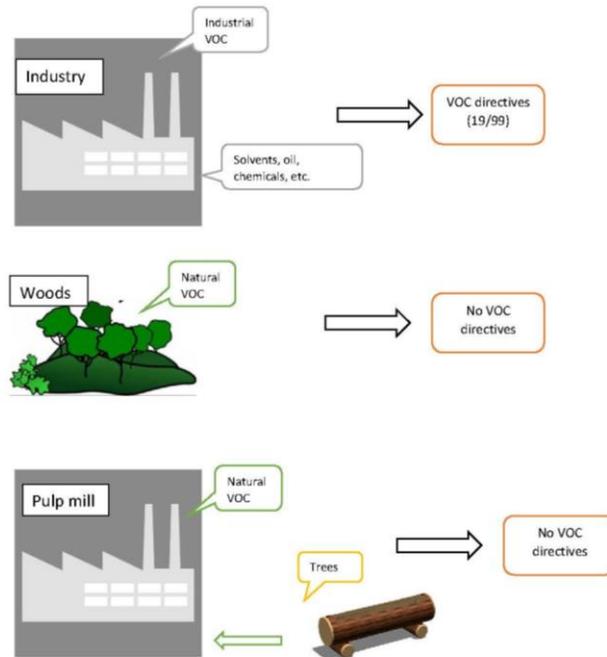
Figure 2: Anthropogenic and biogenic VOC

In the research program LIFE+ VOCLESS PULPING WASTE WATER VOC (www.voclesspulping.com) biogenic emissions from waste waters are considered. This, to create healthy environment for the pulp mills workers and people nearby pulping mills.

The VOCless Waste Water project is aimed in increasing the Eco friendliness of Mechanical Pulping production, by increasing the "local" eco friendliness of pulp manufacturing. In the VOC less project Emissions are measured from waste water treatment plant and several pilot plants are considered for the abatement: Catalytic Incinerator, Biofiltering, UV filtration. By the end of the project (September 2013) technical, environmental and economic evaluations of abatement methods will be provided.

In order to analyze innovative solutions for the VOC abatement, a collaborative network between several small partners with different expertises was implemented. In the collaborative network, there was a leading company (Virtual Development Office, VDO) and one partner for every technology involved, biofilter, incinerator and UV abatement.

In Section 2, related research illustrates the relevant issues concerning the local impact from VOCs emission in mechanical pulping. In Section 3, collaborative network, the members of the network are presented with their technologies for the emissions reducing. In Section 4, the activities and the results are described. The paper ends with a conclusion in Section 5.

2   Related research

In (Löfgren et al. 2008) the hurdle rate of environmental investment is evaluated, considering uncertainties and evaluation the pulp and paper industry in particular. Results show uncertainties affect the hurdle rate, from 2.7 to 3.1, and this can cause delay in the adoption of irreversible abatement technologies.

In (Kimmo et al., 2009) the importance of Pulp and Paper industry in Finland for the environment is underlined. Moreover, the "LOCAL IMPACT INDICATOR" are introduced to evaluate the effect of the IPPC introduction. Those Local Impact Indicators take into account the Water Framework Directive and the Clear Air for Europe. VOC emissions are not expressly considered.

Concerning the local impact in (Brownlee et al., 1995) and interesting case of local impact from VOCs emissions from Waste Waters in pulp is shown. Waste waters were discharged in the Athabasca River and VOC odors, because of ice, were noticed up to 1000 km of distance.
Another local issue of VOC from waste water is considered in (Texeira et al., 2013) where the work safety aspects from indoor airborne Waste Waters VOCs emissions are analyzed. Waste water treatment facilities were total covered and only in some sampling sites contaminants were above the occupational exposure limits.

Considering more specifically the issue of odor abatement with biofilters in (Lebrero et al., 2013) the results of VOC abatement from Waste Water Treatment Plant are shown. Even Waste Water are different from Mechanical Pulp for VOC typical of wood, like limonene, the abatement is above 99%.

3   Collaborative network

The VOCLESS project creates a collaborative network between small partners, with a leading company. The output is an innovative network model that introduces products/services innovation through collaboration

between companies, with a particular focus on small and medium enterprises, the VDO model (Saetta et al., 2013).

The model (figure 3) provides a central entity, namely the Virtual Development Office (VDO), which has tasks of creation, coordination and management of the network of enterprises, supplying some interface with the market and guaranteeing the consolidation of relations of mutual confidence between the actors of the community in a perspective of strategic alliance of long period (Cardoni et al., 2010).

In the following part of the paragraph, members of the Collaborative network are described. Those are:

- the VDO member, Meehanite;
- the other members Desinfinator, Formia, Meehanite;
- the external enterprises involved in a particular BO (see figure 3), University of Perugia, AX consulting, Stora Enso.
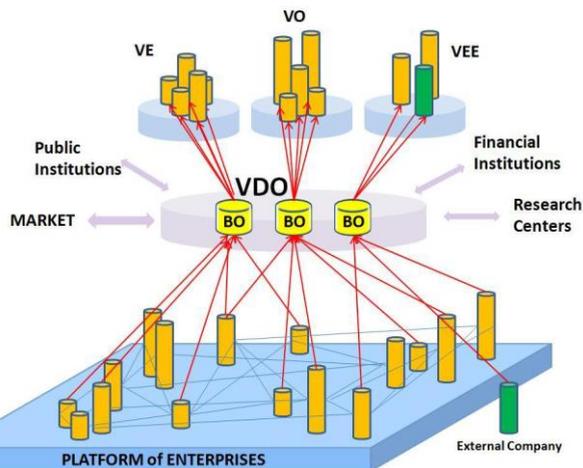
Figure 3: The VDO model (source MIGEN – Innovative models and tools for the networks management)

The VOCLESS project management structure is shown in figure 4:
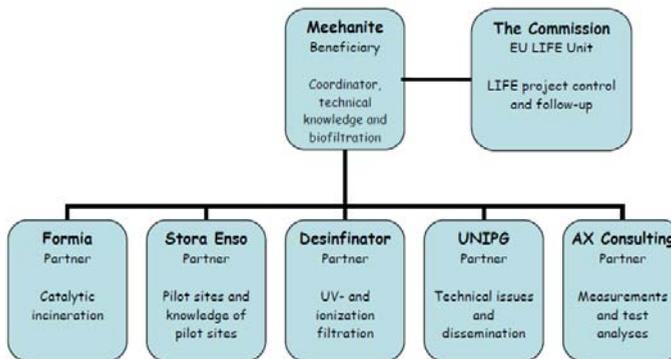
Figure 4: VOCLESS project management structure

3.1 VDO partner

Meehanite is the project coordinator and acts as the leading company. Meehanite has personal recourses both technical management and administration. Central management activities such as deploying the project management, follow-up of project progress and pilot plant tests, needed arrangements of the pilot sites in Finland and Germany, deliverables, milestones, activity reports to the Commission, financial follow-up, costs reporting, results reporting etc. Meehanite acts as VDO.

3.2 UV – filtration partner

UV Filtration is based on Desinfinator technology. This is a combination of reactions and the process combines various different phases to reach the maximum cleaning efficiency. By adding special diffusion filters coated by using the latest nanotechnology and adding other air cleaning processes this product is of high technology level. The main technologies for VOC filtering include:

- Pre-filtering
- UV-C –light
- photocatalysis filters
- OH –radicals
- Ozone
- VOC filters; active carbon filters re-generated by ozone

Further technical details are available in the technical reports produced by the partners and in Saetta et al. (2012)

The chemical reactions that occur in the filter are:

$O_2 + e^- \rightarrow O_{2*}^-$
$2O_{2*}^- + H_2O \rightarrow O_2 + HO_{2*}^- + HO^*$
$2O_{2*}^- + O_3 + H_2O \rightarrow 3O_2 + HO^- + HO^*$
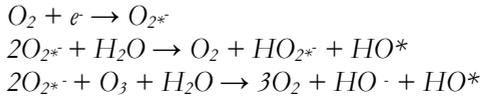
According to these reactions, the process creates highly reactive hydroxyl radicals and these are partly helping the cleaning process.

3.3 Catalytic incinerator partner

Thermal and catalytic are the most popular incineration methods for VOC emissions abatement. During incineration process, VOC-compounds are oxidized to carbon dioxide and water by heat. The main difference between thermal and catalytic incineration is amount of needed heat. Thermal process normally requires over 800°C temperature for good VOC destruction while catalytic process requires only 300°C temperature.

Catalytic oxidation offers several advantages in comparison to thermal oxidation, especially with low VOC contents. The most important are cost savings by reduced energy consumption, cleanness of the process, and its small size.

The biggest problem for VOC abatement is the low VOC content, which is typically in the range of 0.1 to 10 g/Nm³. In order to oxidize such a small concentration of VOC, an enormous amount of air must be heated to a temperature where the reactions can happen and a lot of supporting energy is needed. Catalysts lower the activation energy for oxidizing VOCs and thereby the required reaction temperatures. By using a catalyst and efficient heat exchanger, only one third of the energy is needed compared to thermal oxidation.

3.4 Biofilter partner

The cleaning systems, called as biofilters consist of solid support media where micro-organisms biodegrades pollutants. The typical support media employed are chopped wood and wood bark, composts or other origins, fibrous peat and heather that may be combined with one another or other structure-giving materials. All these materials are normally arranged as randomly packed beds through which the waste gas flows. As the waste gas passes through the bed of media, the pollutants are sorbed onto the surface of the filter media where they are degraded by micro-organisms. For optimum growth and metabolic activity, the micro-organisms rely on defined environmental conditions (moisture, pH, oxygen content, temperature, nutrients, etc.) which must be controlled within narrow limits. Biofil-

ters lend themselves to all waste gas cleaning applications involving air pollutants that are readily biodegradable.

4   Activities and Results

The tests were done in two different plants: Stora Enso Anjala pulp mill for the measurement at the aerobic waste water treatment plant and Kotkamills pulp mill for the measurement at the anaerobic waste water treatment plant.

4.1   Pilot tests in aerobic waste water treatment plant

The process flow-chart is illustrated in figure 5.
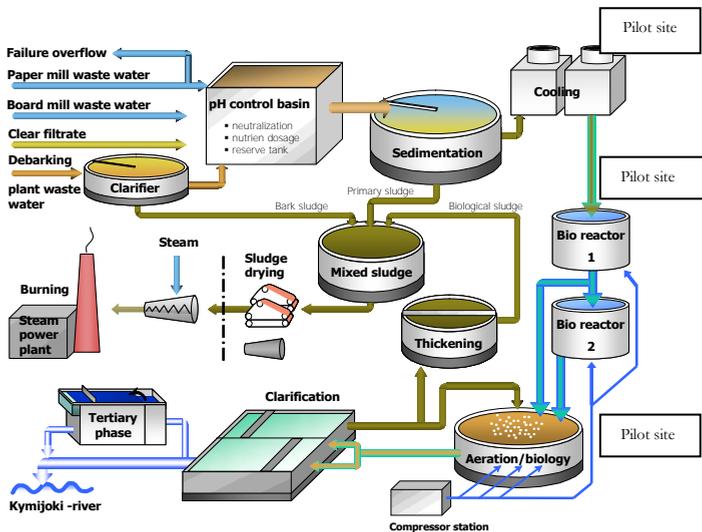
Figure 5: Aerobic waste water treatment system

The aim of this process is to remove soluble and insoluble organics from waste water stream and to convert the material into flocculant microbial suspension and this allows the use of gravitational solids liquid separation techniques.

The process used in this case is so called nutrient restricted MBBR/activated sludge process (moving bed biofilm reactor). The easily degradable organic materials will be degraded in MBB-reactors.

In aerated reactors the microbes are cleaning the waste water using the soluble materials as nutrition and consuming oxygen. Additional nutrients (like phosphor and urea) are needed. The yield will be carbon dioxide,

water, heat and new microbes. Microbes, activated sludge will be returned after the final sedimentation to the aeration basin, and the excess sludge to the sludge handling.

Process conditions are restricted, pH about 7, temperature under 40°C. After the final sedimentation clarification, the cleaned water is led to the river Kymijoki. The excess sludge from the biological waste water handling and other sludges are mixed, dewatered, dried and incinerated in the boiler house.

In this treatment plant, tests were done at the cooling towers and at the MBBR. The idea was to test the operation of the abatement systems and to measure the cleaning efficiency from each of the small-scale pilot plants at least for the two-week period of time. VOC emissions measurements were carried out before the start of each test period and after two weeks, at the end of the test period.

4.1.1   Cooling tower

In the cooling towers the waste waters are cooled to 37°C. Results of the tests at the cooling towers are shown in table 1. Desinfinator is responsible for the UV filtering abatement system, while Formia Emission Control is responsible for the catalytic oxidation system.

Table 1: VOC cleaning rates at the cooling tower

	VOC CONCENTRATION (mg/Nm³)		CLEANING RATE	AVERAGE VALUE
	before	after	%	
Biofilter 1	3,7	4,8		75%
	2,5	0,6	75%	
Biofilter 2	3,3	0,7	79%	80%
	3,4	0,7	81%	
Desinfinator	4,1	0,9	79%	73%
	2,9	0,9	68%	
Formia	3,9	0,9	78%	78%
	3,2	0,7	78%	

4.1.2   Activated sludge process (MBBR)

After the presedimentation basin, waste water is conducted via cooling towers to the pumping station and further to the MBB reactor number 1 and then to the second basin. The two reactors are sequential. The aim of the activated sludge process is to remove soluble and insoluble organics from the waste water stream and to convert the material into flocculant microbial suspension that is readily settled and will permit the use of gravitational solids liquid separation technique.

Results of the tests are shown in table 2. Desinfinator is responsible for the UV filtering abatement system, while Formia Emissions Control is responsible for the catalytic oxidation system.

Table 2: VOC cleaning rates at the MBBR

	VOC CONCENTRATION (mg/Nm³)		CLEANING RATE	AVERAGE VALUE
	before	after	%	
Biofilter 1	11,1	3,5	68%	64%
	18,1	4,7	74%	
	29,9	13,6	55%	
	25,0	13,9	44%	
	12,9	2,9	78%	
Biofilter 2	12,1	4,4	64%	55%
	10,0	2,8	72%	
	22,0	13,0	41%	
	11,7	6,6	44%	
Desinfinator	9,7	3,1	68%	68%
	18,0	5,7	68%	
	22,0	10,9	50%	
	17,4	2,7	84%	
Formia	14,7	2,4	84%	72%
	13,5	2,4	82%	
	21,6	6,3	71%	
	19,8	9,4	53%	

Results shows good perfomance abatement of catalytic incinerator but also from biofilters. Biofilters have the advantage that in standard operating conditions have less CO2 emissions.

4.2   Pilot tests in anaerobic waste water treatment plant

The process flow-chart is illustrated in figure 6.
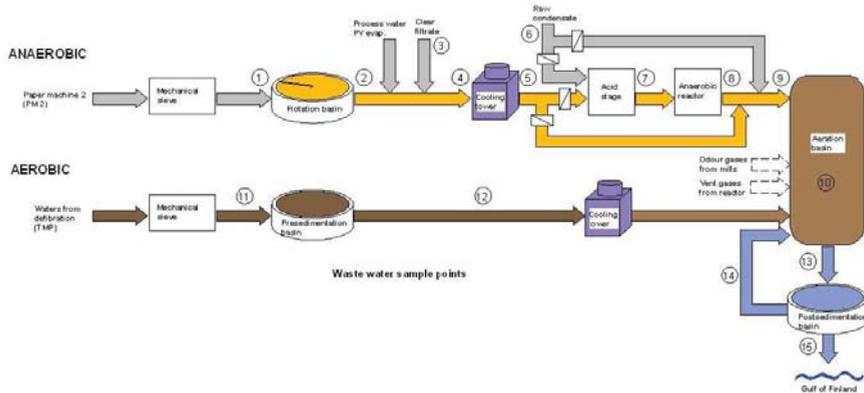
Figure 6: Anaerobic waste water treatment system

Waters are pumped to anaerobic (10-15%) or/and aerobic (85-90%) waste water treatment. The objective of this process is to remove soluble and insoluble organics from waste water stream and to convert the material into flocculant microbial suspension that is readily settleable and will permit the use of gravitational solids liquid separation techniques.

The process used in this case is so called anaerobic/aerobic treatment with activated sludge process. The easily degradable organic materials will be degraded in aerobic basin in the end.

The highest concentrated waste process waters are led to anaerobic treatment. First, the waters are cooled in cooling tower and then to anaerobic reactor where anaerobic organisms are mixed into cooled water. Water stays some two days in the reactor. Organic compounds are degraded to water and methane with some CO_2.

In aerated reactors waste water treatment process are similar to the one depicted in the aerobic test case in paragraph 4.1.
After the final sedimentation clarification, the cleaned water is led to the sea, Gulf of Finland.

The system was tested at the anaerobic reactor and aerobic aeration basin treatment phases.

4.2.1   Anaerobic reactor

After the presedimentation basin, waste water is conducted via cooling towers to the anaerobic reactor where anaerobic organisms are mixed to water. The anaerobic reaction is very sensitive.

In anaerobic reactors the microbes are cleaning the waste water using soluble materials as nutrition. The yield is methane, water, heat, some carbon dioxide and new microbes. Microbes and activated sludge will be

returned after the reaction to the beginning of the reactor and excess sludge is going to the sludge handling.

Results of the tests are shown in table 3. Desinfinator is responsible for the UV filtering abatement system, while Formia Emissions Control is responsible for the catalytic oxidation system.

Table 3: VOC cleaning rates at the anaerobic reactor

	VOC CONCENTRATION (mg/Nm³)		CLEANING RATE	AVERAGE VALUE
	before	after	%	
Biofilter 2	113,7	40,6	64%	64%
	119,3	43,1	64%	
Desinfinator	30,5	22,0	28%	29%
	42,0	29,1	31%	
	39,1	29,9	24%	
	172,8	104,1	40%	
	132,7	88,5	33%	
	100,0	81,6	18%	
Formia	128,7	6,5	95%	92%
	123,3	6,3	95%	
	112,0	6,6	94%	
	38,3	4,0	90%	
	33,4	4,4	87%	

4.2.2 Aeration basin

The aeration basin is a pool constructed into soil.
Results of the tests are shown in table 4. Desinfinator is responsible for the UV filtering abatement system, while Formia Emissions Control is responsible for the catalytic oxidation system.

Table 4: VOC cleaning rates at the aeration basin

	VOC CONCENTRATION (mg/Nm³)		CLEANING RATE	AVERAGE VALUE
	before	after	%	
Biofilter 2	787,0	564,0	28%	49%
	477,0	347,0	27%	
	1034,0	672,0	35%	
	305,0	257,0	16%	
	38,3	20,5	46%	
	96,7	54,1	44%	
	50,4	27,3	46%	
	18,8	3,0	84%	
	11,8	1,9	84%	

	522,6	92,9	82%	
	517,0	58,2	89%	
	744,0	73,4	90%	
Desinfinator	543,0	414,6	24%	50%
	415,0	309,2	25%	
	540,0	433,4	20%	
	419,0	40,2	90%	
	444,0	34,0	92%	
Formia	521,0	19,3	96%	93%
	1142,0	35,2	97%	
	207,0	21,4	90%	
	257,0	26,4	90%	

Concenring the anaerobic plant is noteworthy that in this case the more efficient solutions seems to be incinerator. The 2 examples, aerobic and anaerobic ones, shows that the collaborative network can offer multiple choices, thanks to its members. It seems more efficient biofilters in the case of aerobic treatment plant, while catalytic incinerator is the more efficient in the case of anaerobic plant.

5 Conclusions

The issue of VOC biogenic abatement is considered. The industry of Mechanical Pulp is treated and three abatement technologies were tested at a aerobic and anaerobic waste water treatment plants.

Results shows that the collaborative network build up for the project is able to offer several feasible solutions to its clients and it is able to find the best one in terms of environmental performances.

The aim of the network was to reduce the VOC emissions beyond the law. In this manner is possible to highly increase the local environmental quality in terms of smog formation and odor abatement.

The issue how to take into account the Eco Friend VALUE of the VOC abatement in the final product is still open, but it will require the consideration of the local environmental benefits for both the population and the workers.

Acknowledgments

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Usage of Cell Wall Components, esp. Hemicelluloses

Development and Characterization of high performance of Natural Rubber nanocomposites using biologically prepared Isora nanofibers

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Abstract

Natural fiber reinforced polymer composites have raised great interests among material scientists and engineers in recent years due to the need for developing an environment friendly material, and partly replacing currently used glass fiber for composite reinforcement. Natural fibers can be used as precursors for the preparation of micro/nano particles having wide range of properties and can be used as effective reinforcement in polymer matrices. In this work, isora nano fibers (INFs) are prepared from a natural fiber 'isora'- a bast fibre from Helicteres isora plant, by a novel enzymatic treatment followed by bleaching, acid hydrolysis and homogenization. The obtained nano fibers are isolated and characterized by AFM, TEM, FESEM, FTIR, WAXRD, DLS and TGA. Nanocomposites are prepared via a two-step process involving (a) masterbatch preparation of INFs at varying compositions in NR latex (b) different master batches are compounded with solid NR followed by subsequent curing. The resultant nano composites are characterized by mechanical testing which indicate a significant improvement in their properties relatively at low fiber loadings. The enhancement in properties like Tensile strength, Tear strength etc is maximum for 1.0 wt% of INFs indicating a uniform dispersion and strong filler matrix interaction. The performance of a composite depends upon the interfacial strength and uniform dispersion. The tensile modulus, abrasion resistance, compression sets are also increased to a significant level from INF 0 to 2 wt%. This increase can be attributed to the restricted mobility of the polymer chains due to the higher contacts with the INF's.

Keywords

Delignification, isora, nanocellulose, rubber nanocomposites.

1   Introduction

Lignin, the abundant aromatic biopolymer which act as a structural adhesive to hold cellulose micro fiber together for composite like strength in the cell wall of all woody plant . After cellulose, it is the most abundant organic material on earth, making up 20-30% of the dry weight of wood (Penkina,2012, Johjima,1999) Although the mechanism of lignin degradation is not yet fully understood, white-rot fungi are thought to be the only known organisms that can completely break down lignin to carbon dioxide and water . Laccase, lignin peroxidase (LiP) and manganese peroxidase (MnP) are among the major enzymes of white-rot fungi involved in lignin degradation. The basidiomycete Phanerochaete Chrysosporium has become the most commonly used organism due to its good delignification properties,fast growth and easy handling in culture. Nanotechnology and Nanoscience has emerged as important areas of research, the preparation of nanocellulose fibers based on plant fibre has great importance in current environment. (Fackler,2006; Levin,2010; Rodrı,2002; Levin,2010;)

Being a biobased polymer, the use of bio-nanoreinforcements in NR is beneficial in the development of biobased and green nanocomposites. Further more, biobased nanoreinforcements are usually available as aqueous suspensions and hence latex blending provides a viable route to disperse nanoreinforcements in the matrix. (Johar,2012; Pandey,2013; Pasquini,2010; Abraham,2012).In this study reports on the extraction of nano cellulose fibers from isora fiber and their use as a reinforcing phase in NR matrix. In this study, NR-based, cellulose reinforced micro and nano composites were prepared using a master batch in latex followed by compounding using a two-roll mixing mill. Further, the amount of nanocellulose fiber were optimised and prepared hybrid nanocomposite with this amount of nanofiber. The objective of this study was to understand the effect of cellulose microfiber and nanofiber and the processing method used on the morphology and properties of the resultant materials.

2 Experimental

2.1 Materials

Natural Rubber (NR) was supplied in latex form from Njavalli Latex, Ernakulam,kerala and and NR in solid form from Rubber Research Institute (RRI) Kottayam, Kerala, India, and were used as the matrix material. The dry rubber content of NR latex used was 60%. Isora fibre was separated from the bark of Helicteres isora plant from Thommankuthu, Idukki, Kerala by retting process and was used as the raw material for the extraction of Isora Nanofiber(INF).

2.2 Preparation of INF

The experimental technique for the preparation of INF is given below.
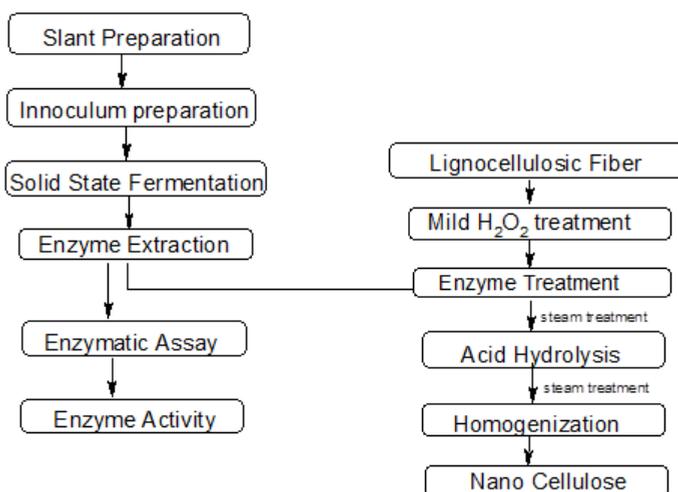
Figure 1: Experimental technique for the preparation of INF

2.2.1 Production of Ligninase enzymes by Solid State Fermentation by using isora fiber as subatrate

Phanerochaete Chrysosporium was selected as suitable organism for Solid State Fermentation (SSF) due to its high lignin degrading efficiency. Fungi was maintained on PDA slants and transferred to liquid medium until sufficient growth was achieved.Kirk's Medium & Inocculum was used as moisturing media.Fungi was innoculated into different sets containing 10g

of Isora Fiber with 60% moisture level. Fungi with 60 % moisture level exhibited maximum growth and delignification efficiency ; hence was selected as optimum moisture level for SSF. Harvested on 15th Day of fermentation .The enzyme is dissolve in the sodium phosphate buffer and stored in small aliquots at -20oC.

2.2.2 Enzymatic Delignification

Enzymes produced by SSF was extracted and applied to isora fiber along with Tween 80, 0.1 mM hydrogen peroxide, Sodium tartatrate buffer (PH 4) at 60% moisture level. Decrease in Lignin Content was observed. Delignification efficiency was found to be maximum at 34%.

2.2.3 Acid hydrolysis

The enzyme treated fiber is treated with 5% oxalic acid and autoclaved for 1hour at 121oC and washed through filler paper.

2.2.4 Homogenization

The acid hydrolyzed fiber is homogenized for 8 hours at 12,000 rpm.Dried the sample and morphological studies are done.

2.3.1 Preparation of NR- INF composite

Microcomposites using INF with natural rubber(NR) were prepared in a two-step process involving
(a) masterbatch preparation in NR latex and
(b) compounding of the masterbatch with solid NR and vulcanizing agents using a two-roll mill followed by curing.

2.3.2 Master batch preparation

In the master batch processing step, NR latex and Isora Micro Fibre(INF) in aqueous medium were mixed together using a magnetic stirrer for 8 hours to obtain a uniform dispersion of micro cellulose in NR latex. The concentration of INF was adjusted to have a final INF concentration of 0.5,1,2,4 phr in 33.3 gram of latex to get 20gram dry rubber in different master batch. This dispersion was then coagulated using 1% formic acid and dried in an oven. This master batch was then masticated and used for the next processing step. NR latex without INF was also prepared by the same method and was used as the control master batch for comparison.

2.3.3 Compounding

In this step, the compounding of the master batch with solid natural rubber and vulcanizing agents was carried out using a two roll mixing mill. The formulations used are given in Table 1. INF compositions (0, 0.5,1,2,4

phr) in master batch were mixed with 80 gram of solid NR to get 100 phr. The cure time for the vulcanization was determined using a Monsanto rheometer and optimum curing times (t90) were calculated and pressed into vulcanized sheets using a compression molding in hydraulic press. Curing was carried out at 150 °C.

Table 1: NR-INF composite formulation

Sample Name	Solid NR (phr)	Master Batch (phr)	INF (phr)	ZnO phr	Stearic Acid (phr)	Non ox SP (phr)	CBS (phr)	Sul-phur (phr)
INF 0	80	20	0	5	2	1	0.6	2.5
INF 0.5	80	20	0.5	5	2	1	0.6	2.5
INF 1	80	20	1	5	2	1	0.6	2.5
INF 2	80	20	2	5	2	1	0.6	2.5
INF 4	80	20	5	5	2	1	0.6	2.5

2.4　Experimental methods

2.4.1　Compositional analysis of raw fiber, enzyme treated and acid hydrolyzed fiber

Cellulose ,Lignin, Hemi Cellulose amount was determined　according to ASTMD 1104, ASTMD 1106, ASTMD 1103

2.4.2　Scanning electron microscopy

SEM analysis of fiber was done using Scanning Electron Microscope (JEOL JSM-5800, Japan)

2.4.3　Tensile and tear properties

The tensile and tear behavior of NR and the nanocomposite films were analyzed using a H50KT (Tinius Olsen) Universal Testing Machine with a load cell of 1000 N. The experiments were performed at room temperature (25^0C), with a crosshead speed of 500 mm/ min. The sample dimensions were $10 \times 5 \times 1mm^3$ and the results were the average of five measurements.

2.4.4　Abrasion test

DIN abrasion test is based on the German test method DIN53516. The sample is pushed against the drum with a specific force. The sandpaper is a specific type OF 500μm and the speed of the drum and number of revolutions is controlled to obtained 40 meter rotation. The sample is weighed before, and after the test and the volume loss is calculated and expressed

in cubic millimeters. The lower the number obtained, the better the abrasion resistance. A picture of the test machine is shown below:

$$\text{Volume Loss} = \frac{\text{Mass change}}{\text{specific gravity}} \qquad (1)$$

2.4.5   Hardness Test

The hardness of the composites was measured by the shore type A Durometer according to DIN 53505 with 806.5 cN and pressure 12.5N with truncated cone at 350.
All tests were conducted at room temperature (25°C).

2.4.6   Compression Test

Specimen is compressed 25% for 24 hours at room temperature. Compression set is taken as the percentage of the original deflection after the material is allowed to recover at standard conditions for 30 minutes.

$$CB = \frac{(t_o - t_i)}{(t_o - t_n)} \times 100 \qquad (2)$$

where is t_0 the original specimen thickness, t_i is the specimen thickness after testing, and t_n is the spacer thickness.

3   Results and Discussion

3.1   Compositional analysis of raw fiber, enzyme treated and acid hydrolyzed fiber

Table 2 shows the chemical compositional of raw a fiber ,enzyme treated fiber and acid hydrolyzed fiber. After enzymatic treatment and acid hydrolysis the percentage composition of crystalline cellulose increases and composition of lignin is reduced to considerable extent.

Table 2: Compositional analysis of raw a fiber and enzyme treated fiber

| Parameter tested | Percentage % | | | Procedure followed |
	Raw fiber	Enzyme treated	Acid Hydrolysis & Homogenization	
Cellulose	73	80	82.5	ASTMD 1104
Lignin	21	9.5	1.8	ASTMD 1106
Hemi cellulose	3.2	2.5	2	ASTMD 1103

3.2 Morphological Studies-SEM
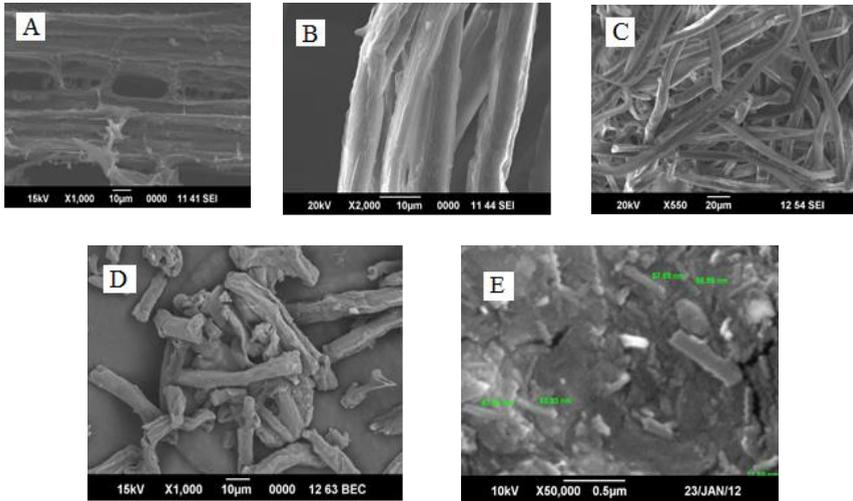
Figure 2: SEM images of (A) untreated,(B) enzyme treated isora fiber,(C) Bleached sample,(D)Acid Hydrolyzed sample,(E)Homogenized sample SEM image shows that fiber diameter can be reduced to the nano level

3.3 Cellulose Crystallinity Index Analysis (WAXRD)
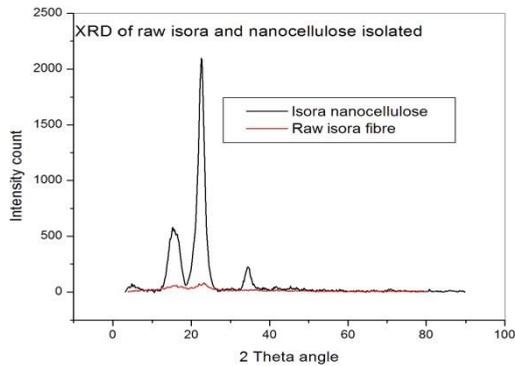
Figure 3: XRD of raw fiber and INF

XRD studies were done to investigate the crystalline behavior and size of the fibers. The percentage of Crystallinity of the fibers was also found to be increased.

3.4   Tensile and Tear properties of the nanocomposites

Table 3: Tensile and Tear properties of the nanocomposites

Sample Name	Maximum Tensile stress (MPa)	Modulus @ 100 % (MPa)	Modulus@ 200% (MPa)	Modulus@ 300% (MPa)	Tear Strength (N/mm)
INF 0	17.02	0.356	0.562	0.716	44.7
INF 0.5	21.8	0.508	0.901	1.223	64.5
INF 1	25.7	0.803	1.159	1.556	75.2
INF 2	22.9	0.64	0.94	1.229	54.6
INF 4	21.8	0.508	0.901	1.223	52.4
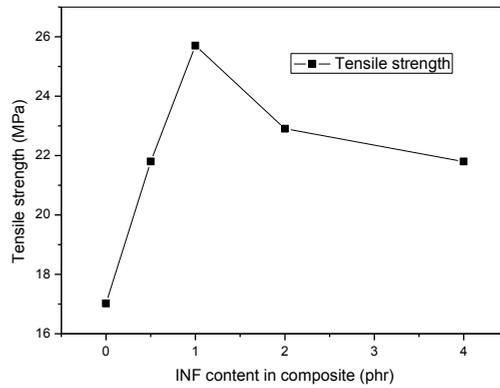
Figure 4: Tensile Strength of nanocomposites
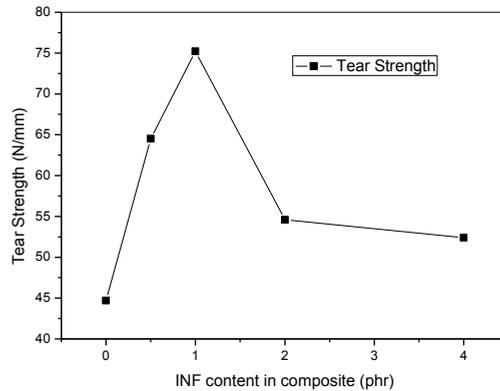
Figure 5: Tear Strength of nanocomposites

The tensile strength of NR-INF composite films were also analysed at room temperature. The tensile strength of resulting nanocomposites was increased from 17.02 MPa to 25.7 MPa with increase in nanocellulose content 0–1 phr (see Table 3). An increase in tensile strength is observed with INF filled samples at all loadings than pristine sample. The Nano-composite with 1 phr INF showed maximum tear strength of 75.2N/mm.

3.5   Abrasion test
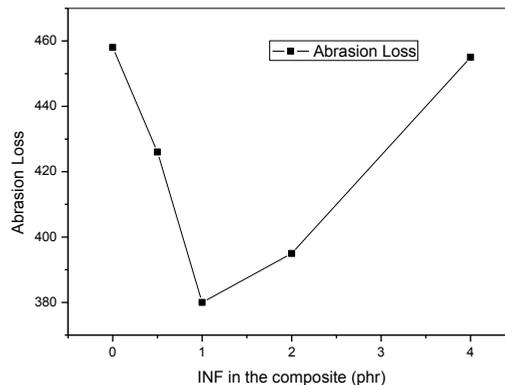
Figure 6: Abrasion loss with various INF loading

Figure 6 shows the DIN abrasion loss of the cellulose filled NR compo-sites. Abrasion loss is less in the case of cellulose filled NR composites than the case of neat NR. This improved abrasion resistance in the cellu-lose -filled composites are due to the improved rubber–filler interaction. Composite with 1 and 2 phr cellulose shows highest abrasion resistance, this is due to the uniform distribution of filler in NR. However, NR with 5phr of cellulose shows lower resistance due to the agglomeration of the filler.

3.6   Hardness

The microcomposites with 1phr INF shows maximum Hardness. This improved hardness in the cellulose-filled composites are due to the im-proved rubber-filler interaction.
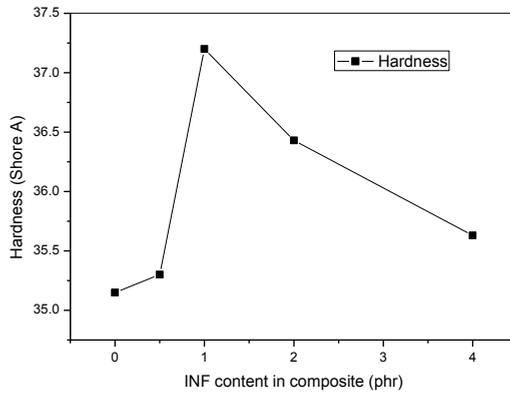
Figure 7: Hardness (Shore A) with various INF loading

3.7 Compression Results
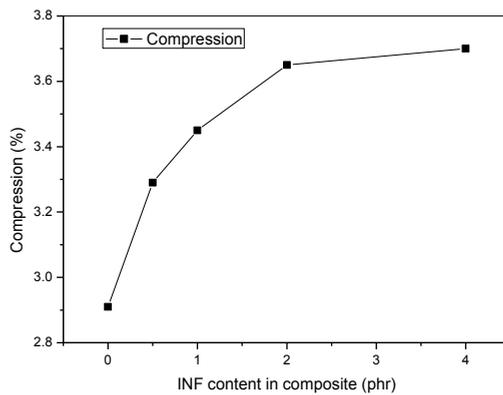
Figure 8: Compression set(%) with various INF loading

Compression set (%) results shows as the filler content increase the value of compression set also increased. This is due to the as the amount of filler increase it resist the compressive nature of the composite.

4   Conclusions

INF having a diameter of 50-80 nm were successfully prepared from isora fibers by enzymatic followed by homogenization. Lignin content is reduced from 21% to 1.8%. Cellulose Crystallinity Index was found to be increased after treated with enzyme and acid hydrolysis. SEM studies reveal structural and morphological changes occurred on to the fibre surface. FTIR studies indicate the decrease of lignin, hydrogen bonding in -OH groups, and increase in crystallinity etc. The tensile strength and modulus values increased with the INF addition, accompanied by a moderate decrease in elongation at break. The Nanocomposite with 1 phr INF shows an increase in tensile properties to an extent of 51% and tear strength of 68% .The Micro composite with 2 phr INF shows highest abrasion resistance, and 1 phr INF shows maximum hardness value.

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Hot water Extraction of Hemicelluloses from Spruce Wood

Extractions using an accelerated solvent extractor

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Abstract

A pre-extraction of wood and other lignocellulosic materials can provide additional value giving the opportunity to use extracted materials and to process the remaining material. To improve the properties of extracted materials and products made of the remaining material the extraction method has to be optimized. In this work extractions have been made with an accelerated solvent extractor using only hot water as solvent. Extraction time and temperature were varied to study their influence on the molecular weight of extracted molecules. It can be seen that an increase in time and temperature leads to higher molecular weight up to a certain point and then molecular weight decreases. On the other hand, the amount of extractable content is rising constantly with rising extraction time and temperature.

Keywords

Extraction, hemicellulose, ASE, hot water, spruce

1   Introduction

A pre-extraction of wood and other lignocellulosics can be performed under various conditions (temperature, pressure and time). If the goal is to extract hemicelluloses, these conditions have to be adapted accordingly (Song et al., 2012). There is a growing interest in the extraction of hemicelluloses as these can be the feedstock for the production of sugar-based chemicals and also as high molar mass hemicelluloses in the food, health, papermaking and other industries (Ebringerova et al., 2005). Extracted wood can be used, e.g. to produce particle boards with improved properties (e.g. water resistance) or wood polymer composites (WPC) (Pelaez-Samaniego et al., 2013; Yemele et al., 2008). OSB made of extracted strands had improved decay resistance to white rot fungi (Howell et al., 2008); OSB and particle boards made from extracted material exhibited lower thickness swell (Paredes et al., 2008; Blumentritt, 2010).

Also the production of lighter boards is possible as hemicelluloses contribute more in weight than in strength (Blumentritt, 2010).

The extraction method for sugars displays a compromise between high yield and high molecular weight. For the extraction of polymeric or oligomeric hemicelluloses a modest extraction method has to be chosen. This can be done for example using neutral hot water, while alkaline water enhances the yield. It is important to prevent the degradation of extracted hemicelluloses through acids which are built during the extraction process (Song et al., 2008). It is also important to prevent lignin and cellulose from degradation as these substances are important for the further usage of the remaining material.

Main goal of this work is to find extraction methods and conditions which lead to polymeric hemicelluloses and allow the production of particle boards with improved properties from the residual materials.

As a first step extractions were done in an accelerated solvent extractor (ASE) under 35 bar pressure with varying temperature, time and particle size. With an ASE it is possible to extract very fast and with varying temperature. The ASE results are presented in this paper. A further step will be the up-scaling to an 80 l-reactor.

2 Materials & Methods

2.1 Wood Particle Preparation

Wood particles were produced from spruce woodchips without bark using a Pallmann knife-ring flaker (Messerringzerspaner Typ PZ 8P; Ludwig Pallmann KG, Zweibrücken/Pfalz, Germany) and sieved with a tumbler screening machine (Allgaier, Typ TSM 1200/2; Uhingen, Germany) with a mesh size of 0.4 mm.

2.2 Extractions using ASE

Extractions of wood particles and wood flour were done with an Accelerated Solvent Extractor (Dionex ASE 200; Sunnyvale (Kalifornien), USA). Extraction cells were filled with 3 to 5 g of wood material and extracted using water as solvent with the following parameters:

> Static: 5 to 40 min
> Flush: 80 %
> Purge: 70 sec
> Cycles: 1
> Pressure: 35 bar
> Temperature 150-180 °C

The parameters for each sample can be seen in Table 1.

Table 1: Extraction conditions

Sample name	Static phase [min]	Temperature [°C]
F2	5	160
F11, F12	20	150
F3, F4	20	160
F5, F6	20	170
F9, F10	20	180
F13, F14	40	150
F15, F16	40	160
F17, F18	40	170
F19, F20	40	180

An aliquot of the extraction fluid was analyzed for its solid content, the rest was stored in a fridge at 5 °C for further analyses.

Extracted wood particles were dried at standard climate (23 °C, 65 % rel. humidity) and stored in plastic bottles for further analyses.

2.3 Hydrolysis

Hydrolysis of an aliquot of the extraction solution was done with 0.5M H_2SO_4 in an autoclave at 120 °C for 40 min at 1.2 bar.

2.4 Analyses

High-performance liquid chromatography (HPLC)
Extraction fluids were analyzed for their monosaccharides content (before and after hydrolysis with H_2SO_4) using the borate anion exchange chromatography, according to Doliška et al. (2009). The column used was an Omnifit column (5*11.5 mm) filled with MCI Gel CA08F (Mitsubishi Chemical Corporation, Tokyo, Japan), a strong anion exchange resin, at 60 °C. The mobile phase contained A: 0,3M potassium tetraborate and B: 0,9M potassium tetraborate. Separation was done as follows:

0 min: 90 % A, 10 % B
35 min: 10 % A, 90 % B
43 min: 10 % A, 90 % B
49.99 min: 90 % A, 10 % B

Postcolumn derivatization was done with cubicinchoninat (0.35 ml min^{-1}) at 105 °C in a 30 m teflon coil with 0.3 mm inner diameter and detection with a UV-Detector at 560 nm.

The data was analyzed with the Dionex Chromeleon Software (Version 6.80).

Size exclusion chromatography (SEC)
The molar mass distribution was determined by size exclusion chromatography (SEC) as described by Saake et al. (2001), using DMSO:water (90:10) with 0.05 mol LiBr as mobile phase with a flow of 0.4 ml min^{-1} at 60 °C. The column used was a polymer standard service (PSS) GRAMM column. A UV-detector (LC 1200 UV/VIS-detector, Polymer Laboratories, Marseille, France) and an RI-detector (Shodex RI-71, Sopares, Gentilly, France) were used for detection.

3   Results

Table 2 shows the influence of extraction time on the molecular weight of extracted hemicelluloses. Extractions were done at 160 °C with 5 min, 20 min and 40 min static.

Table 2: ASE at 160 °C; Influence of extraction time

Sample	Static [min]	M_w* [g mol^{-1}] (UV (280nm))
F2	5	1300
F4	20	2200
F15	40	1900

*Weight Average Molecular Weight

Table 3 shows the difference in molecular size when using wood flour or wood particles. Extractions were done at 160 °C with a static phase of 20 min.

Table 3: ASE at 160 °C, static 20 min; Influence of particle size

Sample		M_w* [g mol^{-1}] (UV (280nm))
F7	flour	2800
F8	flour	2800
F3	particle	2200
F4	particle	2200

*Weight Average Molecular Weight

Tables 4 and 5 show the influence of extraction temperature on the molecular size of extracted hemicelluloses. Extractions were done at 150 °C, 160 °C, 170 °C and 180 °C with a static phase of 20 min and 40 min.

Table 4: ASE with static 20 min; Influence of temperature

Sample	Temperature [°C]	M_w* [g mol^{-1}] (UV (280nm))
F11	150	1300
F12	150	1300
F3	160	2200
F4	160	2200
F5	170	1900
F6	170	2000
F9	180	1600
F10	180	1500

*Weight Average Molecular Weight

Table 5: ASE with static 40 min; Influence of temperature

Sample	Temperature [°C]	M_w* [g mol^{-1}] (UV (280nm))
F13	150	1300
F14	150	1800
F15	160	1900
F16	160	1200
F17	170	1600
F18	170	1500
F19	180	1200
F20	180	1200

*Weight Average Molecular Weight

Figure 1 shows the influence of the temperature on the solids content of the extract solutions. Extractions were done at 150 °C, 160 °C, 170 °C and 180 °C with a static phase of 20 min and 40 min.
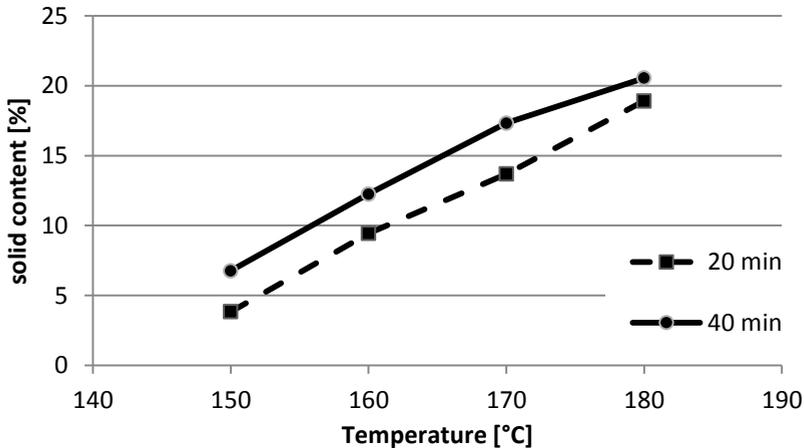
Figure 1: ASE; influence of temperature on solid content of extract solution

4   Discussion

Prolonging the extraction time from 5 min to 20 min leads to a higher molecular size, but prolonging it further to 40 min leads to a lower molecular weight (Table 2). Extraction of bigger molecules after prolonged time might be attributed to deeper penetration of the water into the particles and stronger swelling of the wood cell wall. Further prolonging of extraction time, however, might lead to hydrolysis of the polysaccharides, probably due to acids released from glucan chain groups such as acetic acid during extraction (Song et al., 2008).

When using wood flour instead of wood particles hemicelluloses are directly easier accessible for the hot water, so larger molecules can be extracted (Table 3). As one of the purposes of this project is to produce particle boards from extracted particles, further investigations will be done with wood particles instead of wood flour.

Tables 4 and 5 show the influence of extraction temperature on molecular weight of extracted molecules. With a static phase of 20 min molecular weight increases until a temperature of 160 °C and falling afterwards. A too high temperature leads to a degradation of already extracted molecules and thus diminishing their size. The same is true for a static phase of 40 min but as already mentioned, a 40 min extraction time already produces smaller molecules than a 20 min static phase.

With increasing temperature and time, the solid content that can be extracted increases (Figure 1). But as the other results show, increasing time and temperature leads to a decrease in molecular weight. Thus, the process to be conducted depends on the fact if a high yield or a high molecular weight is desired.

As the evaluation of the data from the borate anion exchange chromatography is not completed at this moment, not much information can be given on the monosaccharides content of the extract solutions. So far, it can be said, that the analyzed solutions contain mainly mannose and galactose as monosaccharides, as it can be expected for spruce wood.

5 Conclusions

Extraction of hemicelluloses from spruce wood chips using only hot water in an ASE led to results on the influence of time and temperature. Prolonging the temperature from 5 min to 20 min led to higher molecular weights, but further prolonged extraction time to 40 min diminished the molecular weight.

A modest temperature should be applied for extracting large molecules which does not exceed 160 °C. These conditions which led to highest molecular weight will be used in a next step in a larger reactor. The results from extraction in the ASE and in the larger reactor will then be compared.

Also analysis of the extracted wood chips will be done in the future.

Acknowledgements

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Track B:
Planning of Production and Value-added Networks for Renewable Resources

IS and IM in Value-Generating Networks for Renewable Resources

Improved effectiveness & optimization of renewable resources Supply Chains based on modern and advanced Simulation Modeling Software

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Abstract

In this document it is described how the unique advantages of the modern Simulation Software Simio® are reducing the risk of uncertainty in renewable resources Supply Chains. Based on a new intelligent object and providing a new object-based paradigm it is possible to take into account the nonstandard and unplanned events in renewable resource Supply Chains. Finally, the understanding of total cost of variance on the business in Supply Chain Management will be possible much easier and faster. Delivery reliability and planning dependability of companies using renewable resources are significantly increased.

Keywords

Simulation, optimization, Simio®, supply chains, 3D modeling

1   Introduction

Easy, fast and reliable results for complex models do no longer require complex and long time programming, but can be realized by user friendly, modern and powerful simulation Software taking into account various uncertainties, incomplete data or very different analysis time frames.

1.1 Renewable Resources – a complex Supply Chain Process

Figure 1 is showing the complex process of using renewable resources based on the relevant plants considered as raw materials until the final product used in different industrial sections and for many purposes. The process chain and the supply chain of those renewable raw materials are influenced by variations of the availability as well of the quality of those raw materials.

Supply Chain Management is a widely used and accepted method to link the relevant objects and information to organize the material and information flow to meet customer needs as well as producer and supplier requirements in terms of stock reduction, delivery time or transport efficiency, etc.

Nevertheless the Supply Chain Management does not take into account the uncertainties as mentioned above. Supply Chain Event Management is a modern approach to cover it better (Friedemann & Schumann, 2010). It is used to collect, control and evaluate information along the chain and should support to react to predefined events.

Those events might be standard events with high and nonstandard events with low probability. The second two cases distinguished are planned and unplanned events.

Reactions on planned events are performed based on predefined measures. But the reactions on unplanned events have to be individually managed each time it happens. Thus, Software to support managing those events in advance should be feasible to handle such cases of different events at least.
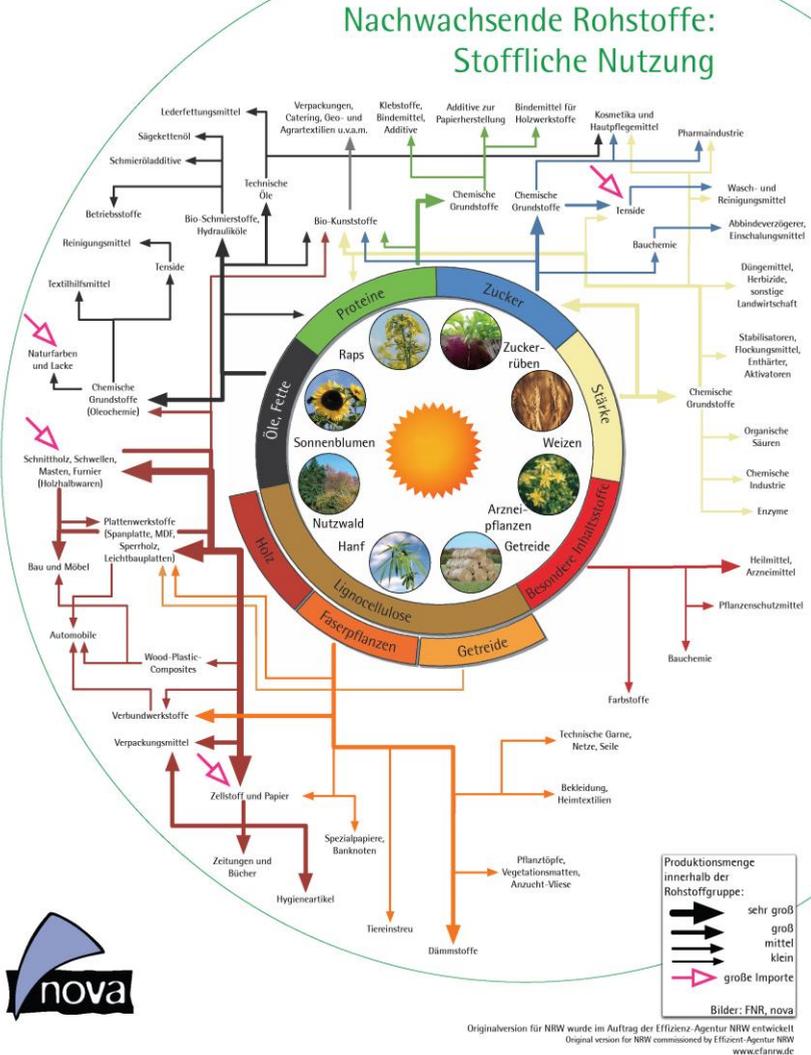
Figure 1: Renewable resources process Germany

Based on Simulation events troubles in the Supply Chain Simulation Model should be artificially created and planning systems reaction and behavior should be checked. Hereby decision making processes and planning processes should be improved.

2 Simio® Simulation is a modern and powerful solution tool for Supply Chain Management

The planning, realization and optimization of complex Supply Chains for renewable materials uses corresponding tools necessary to provide overviews and compressed information for decision makers and stakeholders for their decisions. Once these decisions are made, huge investments and complex processes are the next steps to organize and build up corresponding structures of infrastructure, logistics and production.

Using renewable materials leads to more complex tasks, because its availability all too often depends on weather changes, limited availability of transport capacities, different kinds of raw material sources and locations and other varying influences.

For Simulation this means it has to be dynamic and specifically for discrete-change stochastic dynamic on a high-level. Simulation Software Simio®, developed by the same people developing SIMAN and Arena in the past, centers around intelligent objects and provide a new object-based paradigm that radically changes the way objects are built and used.

Simio® objects are created using simple graphical process flows that require no programming. This allows solving practical problems effectively and will help to support modeling Supply Chains including unplanned and nonstandard events.

2.1 Types of Input to cover real data basis

To ensure most realistic and feasible behavior of the simulation model different types of data input are necessary. One can classify them along two dimensions in a 2 x 3 classification: deterministic vs. stochastic, and scalar vs. multivariate vs. stochastic processes.

E.g. the arrival times of raw material might be planned deterministic with fixed arrival time but in real sometimes suppliers are late or by accident transport is past due. Thus stochastic input is necessary.

If there is a relation between multiple stochastic input values one talks about multivariate distributions or random vectors. This might be the case if late incoming raw materials are linked with special inspections or extraordinary treatment to make sure the required quality level.

Considering the input with infinite number of dimensions a stochastic process is driving the simulation model.

Additionally time varying arrival rates, random number generators and random variates and processes are needed to simulate the complex Supply Chain of renewable resources.

2.2 Renewable Resources Quality to incorporate

Besides the fluctuating harvest and complex influences on the renewable resources Supply Chain they underlie important quality requirements to ensure constant processing, storage and production conditions. Thus appropriate levels of Simulation Software functions and processes are necessary to describe those.

Object oriented Software and programming is common since years. Object behavior, properties and interaction with others are described and states of them are stored and updated while simulation. States are dynamical values that may change as the model executes.

Secondly events are things that an object may fire at selected times or in special cases. This might be the case if an object like an incoming raw material lot does not fulfill quality requirements and unplanned procedures have to be performed.

Finally object logic defines how the object responds to specific events that may occur. Either traffic jam or accident happen e.g. it should have influence on the objects behavior inside the simulation model for sure.

2.3 Experiments, Scenarios and Optimization with OptQuest integrated in Simio®

As described in section 1.1 standard and nonstandard events as well as planned and unplanned events can happen. To be able to simulate those cases the possibility to perform experiments and scenarios should be covered by the Simulation Software.

Experiments are used to define a set of scenarios to be executed using the model. They are executed in batch mode. This is typically done (once a model has been validated) to make production runs that compare one or more variations of the system.

Each scenario has a set of control variables (e.g. size of each input buffer) and output responses (e.g. the throughput, waiting times, etc.). The control variables are the values assigned to properties of the associated model.

Before adding an experiment one typically adds properties to the main model to serve as the controls that one wants to change for each

scenario. Since most models contain random components (e.g. service times, failures, etc.) replications of the scenario are required to allow the computation of confidence intervals on the results.

Finally based on experiments and scenarios an optimization process can be used to find the best solution under given boundary conditions.

The Experiment properties for this example are shown below in Figure 2. The Upper Percentile and Lower Percentile properties are used in the results plots, so called SMORE plots explained in section 2.4. The Primary Response property tells Simio® which response to use for determining the optimal solution. In this example, the optimal solution should be based on the Profit Response and the objective that is defined on that Response.

For optimization the Simio® add-on OptQuest is used. OptQuest for Simio® is available as an add-on to the standard Simio products. OptQuest tightly integrates with Simio® experiments and uses state-of-the-art algorithms, including Tabu Search, Neural Networks, Scatter Search, and Linear/Integer Programming to generate and evaluate scenarios in search of optimal configurations.

The OptQuest for Simio®-Parameters section of the Experiment properties is where the user defines the information for the OptQuest add-on. In this example, Simio® will run a minimum of 6 replications and a maximum of 10 replications for each scenario.

OptQuest decides how many replications are required for each scenario. The OptQuest add-on runs multiple scenarios, until it has found the optimal solution, based on the defined Controls, Constraints and Objective on the Primary Response.

The Experiment property, Max Scenarios, indicates that a maximum of 10 scenarios will be run. In this example, the full 10 scenarios are run.

Properties: Experiment1 (Experiment)	
Analysis	
⊞ Warm-up Period	0
Default Replications	10
Confidence Level	95%
Upper Percentile	75%
Lower Percentile	25%
Primary Response	
Advanced Options	
Concurrent Replicati...	0
Replication Runner	InProcess
Distribute Runs	False
OptQuest for Simio - Parameters	
Min Replications	**5**
Max Replications	**20**
Max Scenarios	**100**
Confidence Level	**95%**
Relative Error	**0.1**
Objective Type	**Single Objective**
General	
Name	Experiment1

Figure 2: Experiment Properties – OptQuest integrated in Simio® example (Simio® Reference Guide)

Simio® Pivot Tables and Reports provide an estimate of the population mean and confidence interval based on multiple replications. While this is exactly what is needed in some situations, in others it provides an inadequate amount of information required to make a decision taking into account risk.

2.4   Reducing the risk in complex situation decisions

"A simulation is not trying to create history; instead it is trying to say something about what will happen in the future and whether one can live with it."(Nelson, 2008)

A Simio® Measure of Risk & Error (SMORE) plot displays both the estimated expected value of a scenario and multiple levels of variability behind the expected value. A SMORE plot consists of a Mean, Confidence Interval for the Mean, Upper Percentile Value, Confidence Interval for the Upper Percentile Value, Lower Percentile Value, Confidence Interval for the Lower Percentile Value, Median, Maximum Value, and Minimum Value (sample illustrated below in):
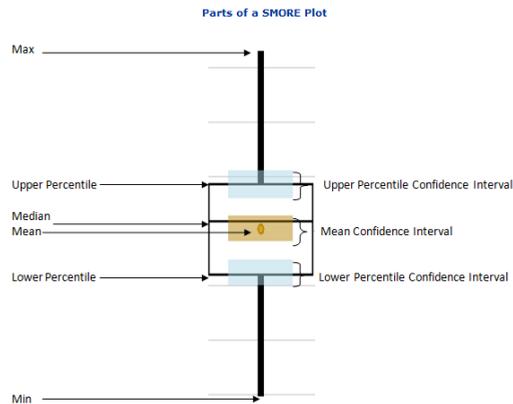
Figure 3: Simio® SMORE Plot as a Measure of Risk & Error

Thus, to model and predict system behavior and optimize those parameters leading to stable and robust systems the usage of advanced and modern simulation Software is a must.

The models give the answer for systems where it is too expensive or risky to do live tests. They provide an inexpensive, risk-free way to test changes ranging from a "simple" revision to an existing production line or to an emulation of a new control system or redesign of an entire Supply Chain.

Large or complex systems, for which change is being considered, should be able to be modeled fast, because a "best guess" is usually a poor substitute for an objective analysis. Simulation can accurately predict their behavior under changed conditions and reduce the risk of making a wrong decision.

It should take into account systems where predicting of process variability is important. A spreadsheet analysis cannot capture the dynamic aspects of a system, aspects which can have a major impact on system performance. Simulation helps to understand how various components interact with each other and how they affect overall system performance.

2.5 Simulation Software can handle systems with incomplete data

New and advanced simulation and modeling software allows systems, where one has incomplete data. Simulation cannot invent data, when it does not exist, but simulation determines the sensitivity to unknowns well. A high-level model can help to explore alternatives. A more detailed model can help identify the most important missing data.

The software allows to build models fast and based on intelligent objects. Without programming, complex systems can be realized and are the basis for communicating results with stunning 3D visualization made easy for the first time. Critical risks will be obvious and visible for decision makers and stakeholders from the beginning.

2.6   Simio® Risk Based Planning and Scheduling (RPS)

Usually Advanced Planning and Scheduling (APS) Systems are used to plan the resources and order sequences to fulfill customer demands in time and budget. Quality issues most time are handled in additional systems, e.g. Computer Aided Quality (CAQ) Systems.

Neither APS Systems nore CAQ take in account the uncertainties and the probability of unplanned events or processes that are not described as standard in the underlying databases. For the most part the ERP system and day-to-day production remain disconnected. (http://www.simio.com/about-simio/why-simio/simio-RPS-risk-based-planning-and-scheduling.html)

A critical problem with the traditional approach is that it requires that all the data be fully known and deterministic. For example all processing times must be fixed and there can be no unexpected events or delays.

Hence the resulting schedule with APS is by nature optimistic, and is typically very different from what occurs in the real facility. It is common that what starts off as a feasible schedule turns infeasible over time as variation and unplanned events degrade performance.

It is normal to have large discrepancies between predicted schedules and actual performance. To protect against delays the scheduler must buffer with some combination of extra time, inventory, or capacity; all adding cost to the system.

Risk-based Planning and Scheduling (RPS) extends traditional APS to fully account for the variation that is present in nearly any production system, and provides the necessary information to the scheduler to allow the upfront mitigation of risk and uncertainty.

Figure 4 shows the interfaces between ERP System, Simio and the systems providing process data like MES oder SCADA. These data might also be collected from RFID sensors that are typically used for tracking renewable resource materials like trees or other.
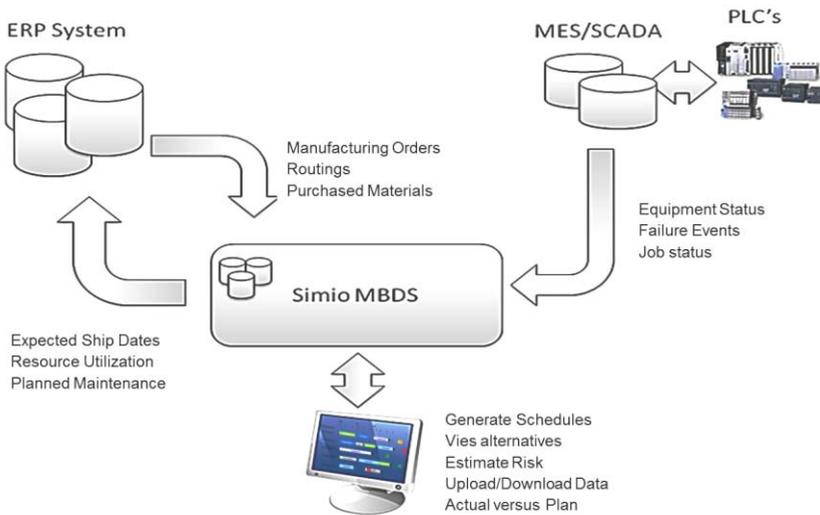
Figure 4: Simio® RPS® Interface Data

Simio® provides a family of products that makes it possible to leverage the existing investment in planning systems, such as SAP's APO, to finally close the gap between master planning and detailed production scheduling, thereby driving more revenues and greater customer satisfaction at reduced cost with existing assets.

Thus Risk Based Planning and Scheduling is the solution to consider those cases in advance.

3 Conclusions

Simio® and Simio® RPS are modern Software tools of 4th Software generation (Gartner, 2009) that are suitable to fulfill typical requirements of Supply Chain and Supply Chain Event Management as they are: risk reduction, reorder points, production allocation, inventory positioning, transportation, growth management and contingency planning.

Without programming necessarily based on a new intelligent objects and providing a new object-based paradigm that radically changes the way objects are built and used it is possible to take into account the nonstandard and unplanned event in renewable resource Supply Chains. This will reduce the risk for producers as well as for transport & logistic companies that are integral part of the system.

The simulation models take into account the real data from actual processes (e.g. RFID tracking information), link it with planning system

information and create scenarios how the situation might look like in the future. Supply Chain Event Management in advance becomes possible.

Finally, the understanding of total cost of variance on the business in Supply Chain Management, including labor variance, material obsolescence, material shortages, capital shortages, and most importantly, the demand forecast variance will be possible much easier and faster by using modern simulation Software.

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Steering Information Technology in Collaborative Networks

Development of a Balanced Scorecard

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Abstract

For engagement in a worldwide business environment, organizational forms such as collaborative networks are becoming increasingly significant. To ensure the efficient and effective use of IT resources in these networks, appropriate IT steering is essential. The IT Balanced Scorecard is a well-established tool for managing an organization's IT resources. However, little attention has been paid to IT steering by an IT Balanced Scorecard in the network context. Based on the Design Science Research Process, an IT Network Balanced Scorecard referring to the current literature will be developed and evaluated in the context of a single case study of the forestry industry.

Keywords

Inter-organizational IT steering, collaborative networks, balanced scorecard, forestry industry, design science research, literature review, case study

1   Introduction

Increased globalization in recent decades has led to greater competition and higher customer expectations. Simultaneously, enterprises must reduce production costs, manage increasing product complexity, and handle environmental regulations. To overcome these challenges, organizations are engaging more and more in complex network structures. These so-called

collaborative networks (CNs) are defined by a stable long-term relationship of more than two entities in order to achieve a common or set of compatible goals (Sydow & Möllering, 2013). According to Croteau & Bergeron (2009), large organizations with multiple business units must accomplish equivalent challenges; they will be the basis of analysis in this paper.

Furthermore, rising awareness of sustainable development is the driving force for the utilization of renewable resources in networks. By means of inter-organizational collaborative structures, organizations can increase the exploitation of renewable resources and their byproducts. In this context, an effective and efficient flow of information plays a significant role and brings together information demand, supply, and need.

To manage the flow of information as well as the efficient and effective use of IT resources, IT-controlling practices are inevitable (Hamel et al., 2012). IT-controlling can be separated into three essential parts: planning, monitoring, and steering (Hamel et al., 2012). For the IT steering process, the most frequently used tool is the IT Balanced Scorecard (IT BSC), with its flexible and comprehensive design (Gyory et al., 2012). Particularly in the field of renewable resources, organizations are often characterized by IT aversion and a lack of IT expertise. However, CNs within this industry can apply the IT BSC for communicating the mission and strategy of IT along the entire network (Kaplan & Norton, 2007). The initial design of an IT BSC is based on a set of four perspectives (customer orientation, corporate contribution, operational excellence, and future orientation) with respective objectives and measures that need to be modified according to the requirements of an organization (Kaplan & Norton, 2007; van Grembergen et al., 2004).

In regard to the increased dynamics, non-transparency, and complexity of inter-organizational networks, ordinary IT-controlling tools such as the IT BSC are not suitable (Siepermann & Vockeroth, 2008). Thus far, no research has dealt with the development of a BSC to steer IT along the entire network (Duan & Park, 2010). With an appropriate BSC, the CN could enhance their efficient use of IT resources, resulting in improved utilization and lower investment costs.

2 Research design

As mentioned previously, this research field is not well covered and re-quires further development in both the practical and scientific worlds. The design science research (DSR) approach seems adequate for delivering a contribution to both domains (Hamel et al., 2012). Furthermore, the DSR is rated as the most appropriate problem-solving paradigm for building and evaluating an IS artifact (Hamel et al., 2012; Hevner et al., 2004). With-in this paper, the artifact will be a BSC for steering the IT in a collabora-tive network, known as an IT Network Balanced Scorecard (ITNBSC). As an overarching research framework, the DSR process by Vaishnavi & Kuechler Jr. (2007) will be adapted and is illustrated in Figure 1.
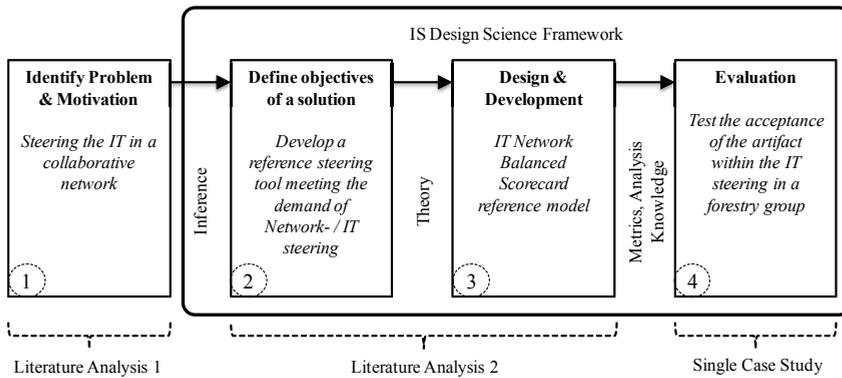
Figure 1: Design Science Research Process by Vaishnavi & Kuechler Jr. (2007)

The DSR process steps 2–4 are performed based on the IS design science framework adapted from Wieringa (2010). Within this framework, the main research question is separated into solving "practical problems" (PPs) and answering "knowledge problems" (KPs). PPs address the improve-ment of the world to meet stakeholder needs and are solved with new innovative artifacts, such as processes, techniques, or software systems. In contrast, KPs can be answered through scientific research of existing knowledge (Wieringa, 2010). In this paper, the knowledge will be gathered from existing literature as well as industry experts in leading IT positions.

  Within the DSR Process, the first step is to identify the problem based on existing literature: How to steer IT in a CN? Step 2 focuses on defining the objectives for solving the identified problem. Therefore, the objectives of an IT BSC and a Network BSC are identified by two struc-tured literature analyses, which are further explained in section 3. These findings provide answers to the following KPs:

· *What are relevant requirements for an IT BSC? (KP1)*
· *What are relevant requirements for a Network BSC? (KP2)*

Based on these two literature analyses, the objectives for an ITNBSC can be identified and the development phase (step 3) can be performed to answer the following PP:

· *How to steer the IT of a collaborative network by using a Balanced Scorecard? (PP1)*

The next step of the DSR process is the evaluation of the developed IT-NBSC. This step is realized by an explanatory single case-study approach and is further explained in section 4. After conducting the knowledge base of practical experts, the third and last KP can be answered:

· *How does the ITNBSC based on KP1 and KP2 suit the practitioners' requirements? (KP3)*

Summarizing these results provides an answer to the final PP, which presents further implications for practitioners:

· *What are appropriate requirements of a BSC to steer the IT in a CN? (PP2)*

3 Development of an IT Network Balanced Scorecard

Within this section, steps 2 and 3 of the DSR process (see Figure 1) will be covered. Step 2 defines the appropriate objectives for the solution to question PP1. Therefore, two structured literature analyses will be conducted based on the literature research process by Vom Brocke et al. (2009) (see Figure 2).
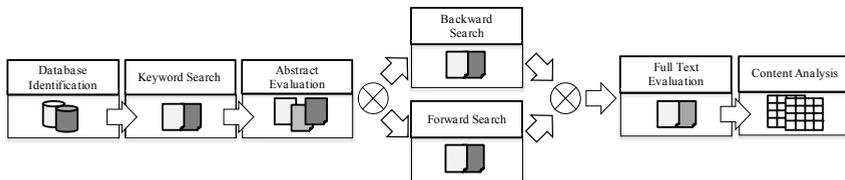
Figure 2: Literature Research Process by Vom Brocke et al. (2009)

In a first step, the databases Science Direct, Business Source Premier, and EconLit were selected for the business side; AIS Electronic Library (AISeL) and Institute of Electrical and Electronics Engineers (IEEE) Xplore were selected for the technology side. This selection was based on the recommendation of Levy & Ellis (2006), Carter & Rogers (2008), and Vom Brocke et al. (2009). In regard to several pretests, appropriate keywords for the search are identified to ensure the comprehensiveness of the literature analysis. Three keywords for the IT BSC ("IT Balanced Scorecard"; "Balanced Scorecard" AND "IT Controlling"; "IT performance

measurement" AND "Balanced Scorecard") and four keywords for the Network BSC ("Network Balanced Scorecard"; "Balanced Scorecard" AND "Collaborative Networks"; "Balanced Scorecard" AND "Enterprise Networks"; "Balanced Scorecard" AND "Corporate Network") were finally chosen. Based on these keywords, the selected databases were searched for journal articles and conference proceedings in the timeframe between 2003 and 2013. Within this first search, 190 contributions were found, which were evaluated based on their abstracts for relevance to this paper. After the evaluation, a forward and backward reference search was performed on the 35 selected papers, identifying 6 additional contributions. Several cross-references to already-identified articles and proceedings confirm the completeness of this literature analysis and the accomplishment of theoretical saturation (Webster & Watson, 2002). All contributions were further evaluated and analyzed based on the quantitative content analysis by Mayring (2010). Within this content analysis, the literature was analyzed for BSC perspectives, objectives, and measures in the fields of IT and Network BSC. The identified BSC perspectives were consolidated and clustered into two concept-centric matrices (Webster & Watson, 2002). Additionally, all IT and Network BSC objectives and measures affiliated to the clustered perspectives were summarized.

Within the IT BSC literature analysis, the perspectives can be categorized into five main clusters with the following mentions: IT financial (11), stakeholder orientation (30), business contribution (32), future orientation (37), and process (11). The Network BSC literature analysis results in the following perspective clusters with the following mentions: financial (14), stakeholder orientation (15), network contribution (4), future orientation (14), process (14), collaboration (8), and perspectives without category (7). According to Siepermann & Vockeroth (2008) a complete structural modification of the BSC was chosen. To define the perspectives, the quantitative mentioning in the literature and the requirements of an ITNBSC were consulted, leading ultimately to the following four perspectives: IT financial, stakeholder orientation, future orientation, and network contribution. Based on these perspectives, corresponding objectives and measures meeting the requirements of an ITNBSC were identified according to the selected literature. The developed ITNBSC with an example selection of objectives and measures is illustrated in Figure 3. The arrows between the perspectives indicate the overlapping objectives of the four perspectives.
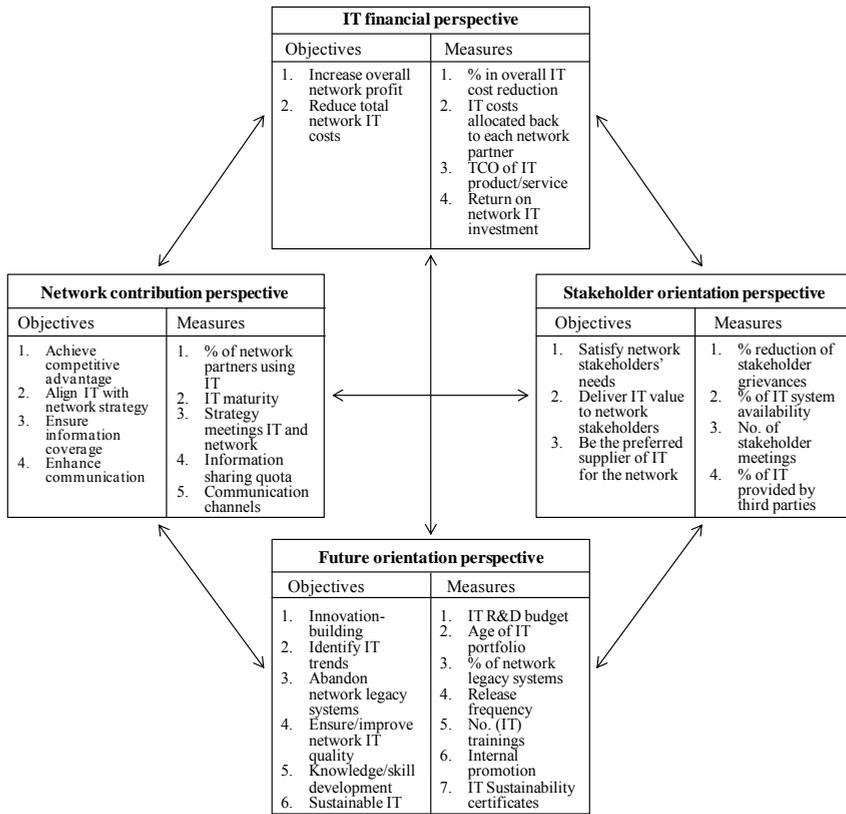
Figure 3: IT Network Balanced Scorecard (example)

IT financial perspective

This perspective does not differ greatly from the basic financial perspective of a BSC. The main objectives are to increase overall network profit and reduce network IT costs by economies of scale and -scope. Nevertheless, the literature identified measures such as collaboration-related process costs and IT expenses per network member, which appropriately consider the requirements of an ITNBSC (Siepermann & Vockeroth, 2008).

Stakeholder orientation perspective

Within a CN, several stakeholders must be satisfied (network partner, C-Level, user, etc.). The stakeholder orientation perspective is essential for steering the vast amount of contradictory requirements on IT in a network. The main objectives are the satisfaction of all stakeholders and being the preferred supplier of IT within the network. The number of stakeholder meetings and a stakeholder satisfaction ratio are suitable measures for this perspective (Wati & Koo, 2011).

Future orientation perspective

IT, as a fast-moving field, must always be steered in a future-oriented manner, particularly in a CN, where network partners with their IT join and leave more frequently than in a normal corporation. Therefore, IT trends and innovations need to be examined consistently to enhance the network IT. Legacy systems and new systems of network partners have to be abandoned or integrated as quickly as possible. It is further necessary to develop IT employees and acquire new talents to achieve a skilled present and future IT personnel. These objectives can be steered by measures such as percentage of R&D budget of each partner according to revenue, inter-organizational IT trainings, and cross-network assignments (Wati & Koo, 2011; van Grembergen & de Haes, 2005; Siepermann & Vockeroth, 2008).

Network contribution perspective

In a CN, the various IT strategies of each partner must be aligned with the overall IT and business strategies. Multiple partners need to be connected for appropriate communication, collaboration, and knowledge sharing to achieve a competitive advantage through IT. Network strategy meetings, IT service or product usage ratios per partner, and information sharing quotes are appropriate measures for this perspective (van Grembergen & de Haes, 2005; Westphal et al., 2007).

4 Evaluation of an IT Network Balanced Scorecard

This chapter focuses on evaluating the developed ITNBSC to provide an answer to KP3 based on a single case study approach. This approach appears adequate for this research purpose, as there is insufficient literature in the field of ITNBSC (see section 1) and it is a topic that must be analyzed within its real-life context (Benbasat et al., 1987; Yin, 2009). A major element of case study research is asking "*how?*" and "*why?*" questions (Yin, 2009). Therefore, it is necessary to evaluate *how* the CNs steer their IT and *why* certain perspectives and objectives are more significant. Based on Paré (2004), a scientific four-stage approach for conducting the case study was applied. The unit of analysis is one of the major worldwide forestry products groups and their network-wide IT steering. This choice was made, because of the mentioned challenges renewable resource organizations can accomplish by means of the BSC approach. The case study is built primarily on semi-structured interviews with two experts of the forestry group (division CIO (Expert1) and group CIO (Expert2)). This semi-structured approach was chosen in order to focus on topics that are more relevant without restricting the interviewee (Bortz & Döring, 2006). Nevertheless,

the major focus of these interviews was to evaluate the identified perspectives and objectives of the developed ITNBSC (see Figure 3). The semistructured interview guideline was established based on the SPSS method from Helfferich (2010). The interview structure follows six phases: introduction, general information about the CN and IT organization, information about the IT steering, validation of the perspectives and objectives, additional perspectives, and closure. For data triangulation, a questionnaire providing a quantitative evaluation of the ITNBSC was handed out, and internal (e.g., CNs' scorecards) as well as external documents (e.g., CNs' websites) were consulted. The additional material was analyzed until theoretical saturation was achieved (Dubé & Paré 2003). Based on Mayring (2010), a quantitative content analysis was performed to summarize and structure the information for building the following case study:

Regarding anonymization the CN analyzed in this paper will be called "Forestry Group." It is one of the world's largest forestry groups, involved in over 35 countries. The CN is structured in four main divisions, with each division acting as a separate network entity. Within the Forestry Group, 400 IT employees deliver services and products to manage the network IT needs. A centralized IT department accomplishes a majority of network-wide IT needs. However, each division also has a decentralized IT department to manage their more specific individual needs. The service delivery model is called "empty office approach." Based on this approach, each division has the freedom to purchase services from the centralized group IT.

IT steering within the network

The IT steering is performed by centralized IT key performance indicators (KPIs) that are consolidated in a scorecard. These KPIs are clustered in three areas: financial, operational, and project. The steering of the standardized network-wide services is handled by steering committees formed by participants from the divisions and the related group functions (e.g., finance & controlling). Regarding the steering of the IT infrastructure, the group functions are less interested in playing an active role; these committees comprise the division CIOs only. Within these committees, decisions are made about investments, future development, and service improvement.

IT financial perspective

"The business controlling always accompanies our projects and recalculates what we actually achieve with our IT investments" (Expert1). Within the entire network, costs are always considered to be the most important topic for IT. Expert1 described three different kinds of projects within the CN, but the ultimate objectives of the projects are consistently more related to cost reduction than profit maximization. Nevertheless, the IT financial perspective of the ITNBSC was rated with 7 out of 10 points regard-

ing its suitability. The objective of increasing the overall network profit is currently less focused; however, it can become more focused if the awareness of IT changes from being a cost driver to an enabler of competitive advantage.

Stakeholder orientation perspective

The Forestry Group distinguishes between group-wide IT stakeholders (e.g., human resources) and IT stakeholders on the division level (e.g., purchasing). To manage the different stakeholder needs, methods such as satisfaction surveys and special steering committees with associated KPIs are established. However, stakeholder orientation at Forestry Group was not explicitly mentioned as a single perspective, and is perceived more as a by-product of other necessary perspectives. This also reflects the relatively poor score of 5 out of 10 regarding the suitability of the stakeholder orientation perspective. Nonetheless, in both interviews, stakeholder orientation was mentioned as a necessary topic in the field of IT steering in a CN. This indicates the necessity of this perspective.

Future orientation perspective

Within the second perspective, all defined measures were mentioned and validated by the two experts, confirming the general applicability and importance of this perspective. The score of 8 out of 10 regarding the suitability of the future orientation perspective for the Forestry Group further confirms this assessment.

Network contribution perspective

The four objectives of this perspective could be validated for the most part. However, Expert2 argued that centralized network IT is more of a cost benefit compared to the competitors. The actual competitive advantage evolves primarily in the division's IT projects. The overall assessment regarding the suitability of the network contribution perspective is 6 out of 10. This result could stem from the difficulty of measuring the network contribution of IT with concrete KPIs. Nevertheless, some measures could be identified (e.g., percentage of network partners using each IT solution) and the multiple mentions of related topics in the two interviews prove the necessity of this perspective.

Additional perspectives

Multiple sources of the Forestry Group further indicate the necessity of a human resource perspective. Even if the IT employees are covered by the objective of "knowledge/skill development" in the future orientation perspective, it may require further consideration. Both experts also indicate a lack of attention to IT innovation within their own scorecard, but also mentioned the difficulty of measuring this topic by adequate KPIs. Despite this, IT innovations are covered as an objective in the future orientation perspective of the developed ITNBSC.

5   Conclusion

The aim of this paper is to provide a contribution to practitioners and researchers in the field of steering IT resources in CNs. Therefore, three KPs and two PPs were answered (see section 2). For researchers, a comprehensive literature review of the current state in the field of IT BSC and Network BSC was established, which further answers KP1 and KP2. In order to answer PP1, example IT and Network BSCs were summarized and consolidated to form an ITNBSC (see Figure 3). This ITNBSC can be the basis for further research in the field. For practitioners, a frame of reference was established, which can be used as a starting point for CNs to steer their network-wide IT resources. Appropriate perspectives, objectives, and measures can be adapted to the individual needs of each CN. To answer KP3, the ITNBSC was evaluated by a single case study in the forestry industry. Furthermore, this evaluation provides additional implications for the implementation of the reference framework and addresses PP2.

The statement by Expert1, "In my opinion, the ITNBSC covers all relevant perspectives," indicates the viability of the developed artifact in the case of the Forestry Group. In particular, the IT financial and the future orientation perspectives were rated as most appropriate. However, a greater focus on the IT employees within the network should be applied in the future orientation perspective. In addition, support was found for the network contribution perspective, though the objectives appear hard to quantify by concrete measures. The IT stakeholder management within the case study was seen less as a separate perspective but rather as a by-product of the IT financial, future orientation, and network contribution perspectives. This further indicates the difficulty of separating the four defined perspectives as illustrated by the arrows in Figure 3.

The chosen research design for this paper is not free of limitations. For the developed ITNBSC, further literature regarding the IT resource steering in CNs, besides the BSC approach, could be used to identify other appropriate areas. Because of the variability of each CN, it is necessary to verify the developed ITNBSC based on multiple networks to achieve a coherent answer regarding the suitability of this artifact. According to the evaluation with multiple networks, the ITNBSC should be further modified based on the findings for an incremental refining as proposed by Vaishnavi & Kuechler Jr (2007).

In conclusion, this paper can be seen as a starting point for researchers and practitioners in the currently under-addressed field of steering IT in collaborative networks with a BSC.

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Improvement of Traceability in Continuous Processes

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Abstract

The disturbances in production processes leading to the production of defective products are not always detected in time, so that recalls have to be issued. The ability to identify the goods concerned, their stay in the supply chain, and to take them off the market without loss of time is in demand. Such a capability is provided by a traceability system that has to be implemented along the supply chain. If only one actor within the supply chain uses continuous processes, a lack of traceability is likely, making it impossible, for example, to perform a rapid and effective recall. Traceability in continuous processes is little explored and considered as a challenge, since the processes have characteristics such as mixture, reflux, and segregation of flows without identifiable units, extreme environments etc. The aim of this work is to identify the appropriate traceability methods using the example of the pulp and paper industry. It is explained how traceability can already be improved, in order to be able to achieve the complete traceability across the supply chain and other benefits from the increased visibility of processes and material flows.

Keywords

Traceability, continuous processes, pulp and paper manufacturing.

1 Introduction

The number of circulating defective products that may even be dangerous for health is high, as there were 2278 reports of consumer goods (excluding food) posing a health and safety risk in 2012 in the EU (RAPEX, 2013). Product recalls can lead to dramatic economic consequences: the

loss of sales and image as well as higher costs. In order to keep the damage as low as possible for all parties, the use of traceability as a risk management instrument is required. While upstream traceability enables the cause of the problem to be found, downstream traceability allows determining the affected batches and their stay. The existing traceability solutions help to identify problems in time, which means that the goods can be returned before being sold to the consumer, so that the public is not affected by the recall (silent recall). The management of recalls is just one application area of traceability systems. Traceability data can be used in quality- and process-improvement, proof-of-quality and proof-of-origin, logistics, security, after-sales and accounting applications.

A lot of traceability applications are in use in discontinuous processes while only occasional descriptions of applications in continuous processes are available (Kvarnström 2008). The lack of traceability in the supply chain with continuous processes can slow down the response time to adverse events such as recalls and thus cause additional costs. The greatest challenge from the perspective of traceability in continuous processes is the flow, meaning that no batches are available to track. The generation of virtual traceable units based on historical statistical values lead to incorrect and even erroneous results, because the dynamic aspects such as segregation, hold-back as well as the properties of input materials are neglected. The natural heterogeneity of the input materials is the essential feature of the supply chains for renewable resources that contain several continuous processes: sawing in sawmills, producing bio-ethanol in bio-refineries, pulp and paper production etc. Particularly important is the improvement of traceability in the pulp and paper industry. There is a legal requirement to ensure the traceability of products (EU regulation 1935/2004/EG). Pulp and paper must meet a variety of paper processing industries needs and quality standards before they can be brought to industrial customers. Laboratory test of samples are carried out for this purpose, often taken from continuous flows. These results must be considered in relation to the sold paper rolls. For this, the creation of virtual or natural traceable units (batches) is required. Based on this, the analysis of suitable traceability methods is performed using the example of the pulp and paper industries. In the present article, the following research question will be addressed:

Which traceability methods can be used in processes of the pulp and paper industry?

The question is answered with the help of the extensive literature analysis, followed by an argumentative-deductive analysis.

This article is structured into five chapters. After the introduction, the definitions of the traceability concept and the continuous processes are provided in Chapter Two. In Chapter Three, the traceability methods in continuous processes are depicted. The description of the methodology

opens this section. Chapter Four includes a discussion on the use of methods already described in the pulp and paper industry. In the end, a short conclusion and outlook are given.

2 Definitions

In this chapter, the important definitions of the topics traceability and continuous processes are provided.

Traceability is the ability "to trace the history, application or location of an entity by means of recorded identification" (ISO 9000, 2005). According to Moe (1998), traceability has to be managed by setting up a traceability system, which captures, archives, and communicates the history of product routes and selected data. The traceability method thus allows keeping track of a lot's location in the whole or part of the supply chain and the correct linking between process and lot data (Kvarnström, 2010).

The products in **continuous processes** are refined progressively and with minimal interruptions through a series of operations (Dennis & Meredith, 2000; Fransoo & Rutten, 1993). According to APICS (APICS, 2010), continuous production has the following properties: production of a very narrow range of standard products (gasoline, steel, fertilizer, glass, or paper); adding value to materials by mixing, separating, forming, or chemical reactions; a very low rate of product change; a high volume of production at the lowest manufacturing cost; significant investment in highly specialized equipment.

3 Results of the Literature Review

3.1 Related Methodology

In this work, two targets were covered: exploring existing research on the traceability concept in continuous processes and describing traceability methods in this area using the example of the pulp and paper industry.

In order to answer the research question, a literature review was carried out according to Levy and Ellis (2006). The following databases were researched for scientific literature from the areas business informatics, forestry, timber as well as pulp and paper industry: HoWiLit, ACM Portal, CiteSeer, EbscoHost, Elsevier, IEEE Xplore, InderScience, JSTOR, ProQuest, ScienceDirect, SpringerLink, and Wiley Online Library. The literature was selected according to the keywords "traceability" and "continuous process" as well as "traceability" and "process industry". After the search for keywords, the backward and forward searches were initiated in order to

achieve higher quality literature search results. The results of the literature review include 43 scholarly articles in peer-reviewed journals, 8 papers from conferences, 3 dissertations and 10 book chapters. The subsequent application of techniques such as analysis and interpretation allows identifying the requirements for traceability methods and their performance.

3.2   Traceability Methods in Continuous Processes

The brief summary of process properties and their impact on traceability is shown in Table 1.

Table 1: Properties of continuous processes with complicating effects on traceability (Kvarnström, 2010; Skoglund & Dejmek, 2007; Fransoo & Rutten, 1993; Dennis & Meredith, 2000; Lundqvist & Kubulnieks, 1995)

Characteristic	Problem	Requirement for method
Continuous flow	No natural batches	Creation of virtual batches
Low value added to products	Large sensitivity for cost addition	Cost-effective solution
Sub-processes with continuous and batch-wise material flows	Various traceability methods for different process steps	Interface to the continuous and discontinuous processes, use of existing or emerging natural batches
Mixture and reflux of flows	Large deviations in residence time	Creation of batches based on current data
Segregation	Deviations in flow patterns based on the physical characteristics of the product	Creation of batches based on current data
Extreme environment	High temperatures and pressures, strong chemicals such as acids or bases	Robustness against environmental influences

The lack of batches can be considered a critical challenge for traceability, because the definition of a batch is the keystone in traceability systems (Skoglund & Dejmek, 2007). Kim et al. (1995) define a traceable resource unit (TRU) in such a way that no other unit can have exactly the same or comparable characteristics from the point of view of traceability. However, it is not always possible to define the TRU in continuous processes directly. Instead, the focus should be on residence time (Pinheiro Torres & Oliveirah, 1998). Andersson & Pucar (1995) define "the residence time of

the feed material as the expected time needed from entering at the input of the flow system to exiting at the output." Since real flows often show some deviations from the ideal flow patterns of perfect mixed or plug flows, residence time cannot be theoretically predicted from the solutions of such equations as the Navier-Stokes equation or statistical mechanical considerations (Wen & Fan, 1975). Instead, it is necessary to estimate the residence time distribution (RTD) function (a probability distribution function of residence time). The use of current input data for the RTD function can help to estimate the location of a feed material and to predict its future location as well as the time of output. Based on this, the relationships between input and output units are determined.

According to Kvarnström (2008), five methods can be distinguished: chemical and radioactive tracers (offline methods), process data, material signatures as well as traceable markers (online methods) (see Figure 1).
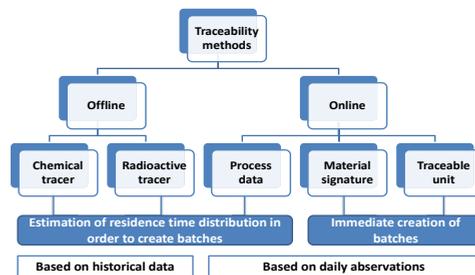
Figure 1: Classification of the traceability methods based on Kvarnström (2008)

Offline Methods. The tracers can be used in streams to examine the behavior of these streams. This is an experiment carried out over a period of time. In such experiments, the changes in the input process to be performed and the subsequent effect on the output are measured at different times. The changes are made by inserting chemical or radioactive tracers. On the basis of collected data, the modeling of the RTD function is performed. The tracer to be used must comply with the following rules (Wen & Fan, 1975): its physical properties must be similar to those of the flow, its introduction must not affect the flow pattern, its concentration must be easily monitored. The most significant disadvantages of this method are the modeling of RTD based on historical data. The deviations that occur acutely will not be considered here. In this method, it is almost impossible to accurately calculate the outgoing at different times from the input portion. It is also necessary to take samples (chemical tracer) which are then to be examined in the laboratory a time-consuming task. For radioactive tracers, permits are required. Furthermore, the effects on health need to be observed. Because of their many disadvantages, the offline methods cannot be considered as stand-alone methods. Instead, it is possible to use them as precursors for the implementation of online methods.

Online methods need daily observations. On that basis, it is possible to determine the TRUs indirectly based on RTD estimates (process data) or to create them directly (material signature and traceable marker). The knowledge about the process in the form of process data can be used to calculate the RTD, which allows the product location to be tracked through a mathematical flow model (Kvarnström, 2010). To enable this, it is necessary to find such a process variable that shows a change over time and is continuously (or at least periodically) measured during the process. However, this method requires the execution of the experiments with tracers to determine the RTD function.

The next online method is material signature (fingerprint). Here, instead of process data, the variability in structures or the amount and combination of chemical elements in a product could be monitored. For example, the resource wood is very heterogeneous, resulting in each wood product having its own intrinsic signature. This particular property has been explored in several studies, with the purpose of developing different traceability approaches based on material intrinsic signature (Charpentier & Choffel, 2003; Fuentealba, et al., 2004 etc.). Before the method can be used, it is necessary to select the characteristic(s) which is (are) able to identify the unique product (Foster & Lees, 2000). The property needs to be unchangeable within the process and comparable with the properties of other existing products in the process.

Table 2: Advantages and disadvantages of online traceability methods

Traceability Method	Advantages	Disadvantages
Process data	• Use of data from process control • Low costs	• Complicated selection of appropriate process variables • Data for mathematical models, which are to be developed and be proven with offline methods • Low precision
Material Signature	• High analysis precision • Direct creation of TRU	• High costs • Time-consuming method (needs sampling) • Only pilot projects available
Traceable marker	• High analysis precision • Direct creation of TRU	• Large amount of data handling • Development, testing of markers that must meet several rules • Sometimes costly implementation

The last method to be considered here comes from the discontinuous area. For the creation of batches, some types of marker are inserted at regular

intervals (traceable marker). The markers act as the starting and interim points for different batches (Kvarnström, 2008) and should be unique, so that the mixture of flows can be modeled. This method is already used in the health care and pharmaceutical industries (Li, et al., 2006). The same idea was used in the development of RFID tracers (corn dummies) and sugar-based and cellulose-based tracers with printed 2D barcodes to improve the traceability approach for grain (bulk goods) (Steinmeier, et al., 2009; Liang, 2013).

The summary of the advantages and disadvantages of online methods are shown in Table 2. After the description of the individual methods and the presentation of the respective advantages and disadvantages, it is possible to identify which method meets which requirements (see Table 3).

Table 3: Handling of the specific process characteristics by individual traceability methods (Kvarnström, 2010; Lundqvist & Kubulnieks, 1995; Hildt, et al., 2000; Ottino & Khakar, 2000)

Characteristic of process	Traceability Methods			
	Offline methods	Process data	Material signature	Traceable marker
Continuous flow	X	X	X	X
Low value added to products	X(only chemical)	X		X
Sub-processes with different flows			X	X
Mixture and reflux of flows		X		X
Segregation	X	X		X
Extreme environment	X	X		

4   Traceability Methods in the Pulp and Paper Manufacturing Processes

4.1   Description of the Pulp and Paper Manufacturing Processes

About 370 million tons of paper are sold every year (Environmental Paper Network, 2012). The processing of wood into chemical and mechanical pulp fibers, including bleaching, takes place in the fiber line. The primary fibers (chemical and mechanical pulp) are processed together with secondary fibers (waste paper) on the paper machine, with certain additives added, depending on the type of paper. The paper machines perform the pro-

cess stages of sheet forming, pressing, and drying to produce the finished paper. String operations and paper equipment complete the production.

The separation of cellulose fibers from each other can be done mechanically or chemically. The choice of method depends on the type of fiber source and the desired paper properties (Mercangöz & Doyle III, 2006). Since the Kraft process (sulfate) is the dominant method, used to produce 60% of total production (Mercangöz & Doyle III, 2006), this method is considered in the current work. The process steps with the assignment of input materials (raw wood from forestry and slabs, edgings as well as wood chips from sawmills) and a note on the continuity of processes are shown in the example of an integrated pulp and paper mill (s. Figure 2).

Figure 2: Flow diagram of the integrated pulp and paper manufacturing process (Mercangöz & Doyle III, 2006)

4.2 Selection of Traceability Methods Based on Process Properties

At the wood preparation, sub-processes are available with continuous and discontinuous flows. According to Table 3, only two methods can be used here: material signature and traceable marker. Since the wood preparation is a process with a low added value, the material signature cannot be considered here. Thus, only one method remains – the traceable marker.

The starting point for the pulp production is the supply of wood produced during logging or forest thinning. The raw forest wood has a small diameter (8-30 cm) as well as quality characteristics and is offered as a charge by weight or cubic meters. To ensure maintaining the relationship between input and output streams during debarking, it is important to consider every single piece of wood as a traceable unit. To that end, a cost-favorable marker is required. A suitable solution was developed within the project "IndisputableKey" (2010): a prototype ink-printer device that can

be integrated into the sawing blade of a harvester to print (at a very low cost of only €0.002 cents per log) two-dimensional barcodes or data matrices on the end surface of a log. The ink printing allows the log's position up to the chipper to be determined at all times.

In the chipper, the product state changes, requiring another kind of traceability markers from this point on. Wood chips are bulk goods. It is necessary to attach the marker in the output stream. In the project "IndisputableKey" (2010), RFID tracers made from biodegradable artificial wood were also developed; these are suitable for pulp production and dissolved in a cooker without impairing the pulp's properties. The same method can be used for slabs, edgings, and wood chips from sawmills.

Starting with the cooker, the wood undergoes continuous processes with harsh conditions (high temperature and pressure, and many chemically active substances) and high dynamics (segregation). Based on these two properties, two methods are used: offline methods and process data. Tracers are used to perform experiments and to describe the process with the appropriate mathematical model. The process data are input data for the model, to account for the dynamics of the system. Many parameters can nowadays be measured and checked continuously by sensors in the ongoing process. From this variety, those parameters have to be selected which show the changes during the processes. In the following table, the variables suitable for use as a process data traceability method are summarized.

The model for the use of kappa number and brightness data for the purpose of fiber traceability was developed by Lundqvist & Kubulnieks (1995). Based on online time data for the state of chemical treatment, it is possible to create the pulp data using models to calculate and remove the time delays according to RTD. Unfortunately, up to this time, there are no studies to confirm the proposed solution for the paper machine.

In the last step, finite rolls of paper are created from the endless paper web, again the continuous and batch processes are mixed. In this case, traceability markers can be used to identify the traceability unit. For example, the Vilant company offers an RFID-based solution for finished rolls. During the core cutting stage, RFID tags are automatically attached to the role with an applicator in the cutter. At the same time, the tag is assigned a specific ID number to control the process via the mill system, e.g. at the roll packaging (Vilant, 2010).

It has been shown that a variety of methods is already in place and can be used along pulp and paper making to improve traceability. Based on the process characteristics three different types of methods (offline methods with subsequent use of process data and traceability marker) can be used. The methods described here make it possible to implement automatic traceability and with that react quickly to deviations and identify the potentials for the process and quality improvement.

Table 4: Process parameters for traceability in pulp and paper manufacturing (Mercangöz & Doyle III, 2006; Leviskä, 1999)

Process step	Variable	Description
Digester	Kappa Number	Lignin concentrations of the pulp before bleaching (the ratio of lignin mass to the total solid mass, multiplied by 654); Measurement of UV absorption in the 280 nm wavelength region; Value changes from 160 to 30
Bleaching	Bright-ness	Brightness of the pulp from bleaching to stock preparation (the ability of the pulp sample to reflect monochromatic light compared to a known standard); Value changes from 15-30% to 89-91%
Paper making	Basis weight	Support variable during the processes in the headbox (at the beginning of paper machine) Measurements based on absorption of radio-active Sr 90, Kr 85 or 147-um radiation (β-absorption sensors)
	Moisture	Main variable in the paper machine: Measurements based on absorption of infrared radiation or microwave principle; Value changes from 92% to 5-15%
	Thickness	Support variable during the processes in the calender (at the end of paper machine): Mechanical or laser measurements

5   Conclusions

A range of characteristics of the continuous processes makes it difficult to implement the traceability concept in this area (see Table 1). Nonetheless, there are a number of traceability methods that can be used in continuous processes (see Figure 1). There is no method that simultaneously satisfies all requirements based on specific process characteristics. However, the combination of several methods makes it possible to achieve traceability throughout the process steps. The choice of method is based on the properties of the process step in which the traceability to be achieved. Table 3 provides a basis for deciding. The example of the pulp and paper industry has shown that two of three online methods can already be used for the purpose of improving traceability (see Figure 3). The use of process data requires conducting experiments with tracers (offline method).
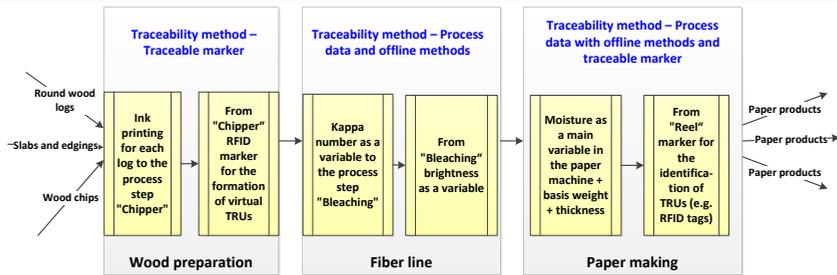
Figure 3: Integrated pulp and paper manufacturing process with choice of traceability methods

Improving the traceability along the supply chain opens new opportunities for process improvements. The information on the quality of raw materials can help to achieve more accurate production planning. For example, the effectiveness of the digestion process and the bleaching reaction (time, values of kappa number, and brightness) depends on moisture content and chip size. To achieve the desired values of deviations, manipulations are used by affecting the temperature and chemical composition of the flows. On the other hand, there is the possibility of information already available to customers providing e.g. the quality test results. In addition, internal processes can be improved if each paper roll is equipped with a RFID tag, such as packaging and shipping. Moreover, new opportunities for improving the quality control open up. Any deviation can be assigned timely and accurately to a virtual or natural TRU. This enables the effects of the disturbance to be greatly reduced.

It was also noted that not all proposed methods can be implemented immediately. A particular challenge is posed by traceability in the paper machine. Although the process data are available, there are still no mathematical models that can work with this data. The algorithms have yet to be elaborated that can also calculate the results sufficiently quickly because the paper machine creates up to 30 m of paper per second. In addition, further investigation of methods based on wood heterogeneity is required.

This work extends the existing theoretical knowledge about traceability methods in continuous processes, especially in the pulp and paper industry. In the next step, it is necessary to evaluate this knowledge worked out empirically from the practical point of view.

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Sustainable Supplier Relationship Management: A resource-based Perspective

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Abstract

At the latest with Meadows et al. and the Club of Rome in the early 1970's, the signal of the finiteness of resources has been sent (Meadows 1974). Resource scarcity is and remains a current and urgent issue. The careful use of resources is essential for the preservation of society. Moreover, it is also necessary to maintain and improve economic systems. In particular, companies can use resources carefully and maintain economic systems through a sustainable resource management. Production and offering of goods and services requires a supplier network regularly. The structure of the supply chain has a significant impact on the consumption of resources. A resource-efficient establishment of supply networks would be favorable. However, in practice, selecting and managing suppliers for such networks are generally based on economic-monetary parameters in the foreground, not the environmentally, sustainable perspective.

Supply networks engage numerous companies, processes, and technologies. Supply Chain Management (SCM) covers the process chains in a supply network and allows for long-term cooperation between all participants all the way to the customer (Cooper, Lambert & Pagh 1997). It ensures that under consideration of total efficiency, optimal solutions can be implemented for investments and costs, such as transportation and information flow.

Tasks and resource usage in the supply chain have been identified in having a significant impact on the natural environment. Bloemhof-Ruward et al. describe that the wastes and emissions caused by the supply chain have become the main source of current environmental problems (Bloemhof-Ruwaard et al. 1995). Following this, companies are increasingly "greening" their supply chain by integrating environmental issues into supply chain management (Nikbakhsh 2009). This so-called Green Supply Chain Management (Green SCM) has developed as a strategic asset for

companies to achieve cost-optimization in the supply chain as well as reputation on the market as eco-friendly and environment-responsible company. But current Green SCM measures and activities are not enough to accomplish a long-term sustainability in these complex supply chain structures. This paper addresses this issue by integrating ecological thinking into SCOR, an industry standard reference model for supply chain management. Along the five key processes of the SCOR model, we discuss aspects of resource-relevant process steps and provide a conceptual framework of a resource-based supplier relationship management for further research approaches. The findings of the paper contribute to the sustainable resource management and enables organizations to take action for securing their own long-term interest. A sustainable development of economic systems will only be possible through the conscious and efficient use of resources in the future.

Keywords

Supply chain management, resource management, SCOR

1 Motivation

Environmental changes like global warming (Stern 2011) or resource finiteness *(DERA Rohstoffinformationen* 2012) have been topics that have attracted interests all over the world. To face these challenges, legislations and environmental requirement to companies have been put forward by government and environmental organization. In addition, rising energy and resource costs forces companies to find new ways to reduce energy and resource consumption to remain competitive in the market. In order to be able to produce and offer goods and services, a supply network started by primary product suppliers, whose products come from raw materials, is required and needs to be applied efficiently. Supply networks are a typical inter-organizational system, engaging numerous companies, processes, and technologies. Supply Chain Management (SCM) covers the process chains in a supply network and allows for long-term cooperation between all participating vendors and service suppliers all the way to the customer (Cooper, Lambert & Pagh 1997). Tasks and resource usage in the supply chain have been identified in having a significant impact on the natural environment. Bloemhof-Ruward et al. describe that the wastes and emissions caused by the supply chain have become the main source of current environmental problems (Bloemhof-Ruwaard et al. 1995). Following this, companies are increasingly "greening" their supply chain by integrating

environmental issues into supply chain management (Nikbakhsh 2009). This so-called Green Supply Chain Management (Green SCM) has developed as a strategic asset for companies to achieve cost-optimization in the supply chain as well as reputation on the market as eco-friendly and environment-responsible company. But current Green SCM measures and activities are not enough to accomplish a long-term sustainability in these complex supply chain structures. By looking at the current state of research in the area of sustainable supply chain management, the investigation of long-term aspects, which are typically covered in the strategic aspects of supply chain management, are clearly underrepresented (Wittstruck & Teuteberg 2010). Therefore, the question arises, how this research gap can be addressed for further improvements.

The paper is structured as follows: in Section 2, we explain the research approach. In Section 3, we provide the current state of research on the relevant foundations of this research. We present a current introduction to Supply Chain Management and Green SCM as well as an overview of the concept of SCOR as an established reference model for supply chain management. In section 4, we investigate SCOR in terms of resource-related activities in all process steps. This leads to the identification of resource and energy relevant activities and task when using SCOR for the implementation of Green SCM as a blueprint. In Section 5, we apply the Green SCOR model to the issue of Green SCM. We discuss some findings from the model's application in Section 6. The paper closes with a brief summary and an outlook on future research in Section 7.

2   Research Method

The research uses a design science approach. Design science is a research method to solve organizational problems by creating and evaluating IT artifacts (Hevner et al. 2004). For this research, we have adapted the design science research methodology from Kuechler & Vaishnavi (2008). The first process step, problem recognition, has been addressed in the introduction. In the second process step, we recommend the adaption of the SCOR model as a reference model industry standard for supply chain modeling. In research step 3, development, we investigate SCOR for the applicability as a foundation for the development and enhancement of environmental-oriented, strategic supply chains. For this, we identify activities in SCOR, which are highly related to resources and energy issues. For the evaluation, we follow the guidelines for design science research according to Hevner et al. (2004). In our research, we selected an experimental evaluation approach in terms of controlled experiments to demon-

strate the usability of the proposed model. In the conclusion, we reflect the findings and discuss refining its further application.

3 Research Background

3.1 Supply Chain Management

In 1961, Forrester (Forrester 1996) considered material flow and the reduction of total inventory before these issues were blanketed under the term "supply chain management" (SCM). SCM was purely concerned with the external logistical integration of customers and suppliers (see also Bowersox & Closs 2005). Logistics research focused on minimizing total cost, while SCM was concerned with long-term profitability of serving customers and their customers (Lamey 1996). Finally, the traditional focus of logistics was often intra-organizational, while SCM became inherently inter-organizational (Larson & Rogers 1998). Hence (Cooper, Lambert & Pagh 1997) used the term "supply chain" to represent an alignment of firms. They defined SCM as: "The integration of business processes from original suppliers to the end-user that provide products, services, and information that adds value for customers." Introducing the term "network" into the SCM arena has extended the SCM concept into more strategic areas, which covers long-term aspects of the customer-supplier relationship. Through a supply network's perspective a focal company views its whole supply network in order to compare performance in its multiple supply chains, to identify potential competitive problems and opportunities, and to identify overall process improvements trough supply chain style thinking.

3.2 Green SCM

Green SCM has its foundation in the scientific discussion on Green IT and Green IS. Murugesan defines Green IT as "… the study and practice of designing, manufacturing, using and disposing of computer, servers and associated subsystems … efficiently and effectively with minimal or no impact on the environment." (Murugesan 2008). Green IS puts a broader scope on the intersection between IT and the ecological impact, which includes the usage of information systems to improve sustainability within an economy (Watson 2008). Green SCM is a combination of SCM and Environmental Management, and it forms the sub-area of Sustainable SCM (SSCM). In 1987, the committee World Commission on Environ-

ment and Development (WCED) defined the concept of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development 1987) It has three main aspects: environmental, social, and economical. Mainly for the ecological aspects, Green SCM addresses these issues endeavors to handle incurred environmental damage and impacts, ideally before they occur (Nikbakhsh 2009). Green SCM deals with the command challenges of SCM and additionally with aspects of environmental sustainability and challenges of resource optimization. Green SCM can be framed as "…integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life." (Srivastava 2007). Green SCM measures give companies cost and risk advantages such as benefits in productivity, property value, and environment. Thus, raw materials and energy costs can be lowered, low emission production can be designed, and the company's image can be improved, which can lead to higher product sales and a high societal acceptance (Nikbakhsh 2009).

3.3   SCOR Model

There exist several business process frameworks to structure supply chain management processes in literature (see for example Hewitt Hewitt 1994 or Cooper et al. Cooper, Lambert & Pagh 1997). The framework chosen a holistic approach is the SCOR (Supply Chain Operations Reference) model (Poluha 2005). This model was designed by the Supply Chain Council as a reference model for describing business processes in the Supply Chain *(Supply Chain Operations Reference (SCOR) model* 2010). It draws on both corporate and external business processes and has established itself as a reference model for the market. SCOR has four levels of description. Level 1 is the process level and thus represents the highest level, whose scope is the organization and the content of its supply chain. There are five processes considered: Plan (the interplay of supply and demand), source (procurement of products, components and services), make (the manufacturing of products, intermediate products, and services), deliver (the supply of products and services to the customer) and return (to receive a faulty product or a return of primary products or raw materials to the supplier). On the second level, the core processes are divided into process categories. The detailing of the processes takes place in level 3. The viewing plane 4 is the implementation level, which is not included in the original model due to its company-specific considerations.

4 Greening the SCOR Model

There is only a very narrow scientific knowledgebase on the linkage between issues from Green IS and SCOR. On Green SCOR, there is the work of Cash & Wilkerson (Cash & Wilkerson 2003). They are investigating SCOR on environmental issues, but the work is based on SCOR version 5 and combines best practices in environmental management into SCOR. Therefore, it is rather a practical approach, which is based on an outdated SCOR version. Qianhan et al. developed a Green SCOR model which was based on several industry cases in the Chinese automotive industry (Xing Qianhan, Wang Jing & Zhu Rongyan 2010). They extended to SCOR model, but did not reflect on the existing activities in the SCOR model. In 2008, the Supply Chain Counsel itself released Green SCOR as a new module for SCOR version 9.0 for managing the environmental footprint in supply chain management (Wilkerson 2008). Three activities in the area of waste disposal and 12 metrics have been added to the original SCOR model. These extensions, which are still valid in version 10 of SCOR, lead only to a small fraction of environmental understanding in a holistic view on supply chain management. The question, how the current release of SCOR may be adapted to the requirements for environmental issues in the supply chain remains open. To close this gap, the SCOR model release 10.0 is investigated on its relationship to environmental issues. For this, all activities on SCOR level 3 have been investigated und split in activities which are independent of any resource activities and those, which are related to resource activities. For an overview of the result of the investigation, see Table 1:

Table 1: Resource-relevant activities in the Supply Chain Operations Reference Model (SCOR)

SCOR section	# activities	# resource-relevant activities	Percentage
Plan	**20**	**10**	**50%**
	Resource-relevant activities: sP1.2: Identify, Prioritize, and Aggregate Supply Chain Resources; sP1.3: Balance Supply Chain Resources with Supply Chain Requirements; sP2.2: Identify, Assess, and Aggregate Product Resources; sP2.3: Balance Product Resources with Product Requirements; sP3.2: Identify, Assess, and Aggregate Production Resources; sP3.3: Balance Production Resources with Production Requirements; sP4.2: Identify, Assess, and Aggregate Delivery Resources; sP4.3: Balance Delivery Resources with Delivery Requirements; sP5.2: Identify, Assess, and Aggregate Return Resources; sP5.3: Balance Return Resources with Return Requirements		
Source	**7**	**5**	**71%**
	Resource-relevant activities: sS3.1: Identify Sources of Supply; sS3.5: Verify Product; sS3.2: Select Final Supplier(s) and Negotiate; sS3.6: Transfer Product; sS3.4: Receive Product		
Make	**8**	**4**	**50%**

SCOR section	# activities	# resource-relevant activities	Percentage
	Resource-relevant activities: sM3.1: Finalize Product Engineering; sM3.5: Package; sM3.4: Produce and Test; sM3.8: Waste Disposal		
Deliver	15	7	47%
	Resource-relevant activities: sD3.3: Enter Order, Commit Resources, and Launch Program; sD3.10: Pack Product sD3.6: Route Shipments; sD3.12: Ship Product; sD3.7: Select Carriers and Rate Shipments; sD3.14: Install Product; sD3.8: Receive Product from Source or Make		
Return	27	9	33%
	Resource-relevant activities: sSR1.1: Identify Defective Product Condition; sSR1.5: Return Defective Product; sSR2.1: Identify MRO Product Condition; sSR2.5: Return MRO Product; sSR3.1: Identify Excess Product Condition; sSR3.5: Return Excess Product; sDR1.4: Transfer Defective Product; sDR2.4: Transfer MRO Product; sDR1.4: Transfer Excess Product		

The Plan processes cover the planning activities which are necessary to operate a supply chain. The planning process enfolds all process steps of the SCOR model and can be regarded as overall planning activities for the whole supply chain. On level 3, planning consists of 20 activities *(Supply Chain Operations Reference (SCOR) model* 2010). Ten activities are directly related to resource management (see Table 1). The Source processes describe the ordering (or scheduling) and receipt of goods and services. In SCOR, the source processes are divided into three sourcing strategies in relation to their production strategies: sourcing of a stocked product, sourcing of a make-to-order product, and sourcing of an engineer-to-order product. Due to the highest ratio of environmental issues in the activities, the activities for the engineer-to-order product are investigated. In this sourcing strategy, seven activities are defined on SCOR level 3. Five of them are related to resource management (see Table 1). The Make processes cover all activities dealing with the conversion of materials. Material conversion is a much broader application than classic production or manufacturing. In the sense of SCOR, make covers conversions like repair, recycling, maintenance, remanufacturing, and many more. As already seen in the sourcing process, the production process is also subdivided into three different production strategies: make-to-stock, make-to-order, and engineer-to-order. In alignment with the sourcing process, the engineer-to-order activities will be investigated. On SCOR level 3, there are eight activities in the make process. Four of them are directly related to resource management (see Table 1). The Delivery processes describe the activities associated with the creation, maintenance, and fulfillment of customer orders. In SCOR, the delivery processes are subdivided into four distinct delivery strategies on description level 2: delivery for stocked products, make-to-order products, engineer-to-order products, and retail products. The first three strategies are quite overlapping in their activities, while the

delivery of retail products differs significantly from the others. In alignment with the sourcing and making strategies, an investigation will be done for the delivery activities for the engineer-to-order products. In this delivery strategy, 15 activities are defined on SCOR level 3 with seven among them directly related to resource management (see Table 1). The Return processes describe the activities associated with the reverse flow of goods back from the customer. In SCOR, return is more about the coordination and documenting the return of products. Activities like repairing, recycling and remanufacturing take place in the make-section of SCOR. Return in SCOR is subdivided into six different return strategies, depending on the type of return reason. There are three different reasons considered: returning a defective product, returning an MRO (maintenance, repair and operations) product, and returning an excess product. All of them have a strong overlapping in their activities. For a holistic view on the return process, all of the return strategies are investigated. On SCOR level 3, there are 27 activities in the return processes. 9 of them are directly related to resource management (see Table 1).

5   The case of a Green SCM Case Study

The concept of Green Supply Chain Management (Green SCM) is widely discussed in industrial practice (see Dao, Langella & Carbo 2011; Sheu, Chou & Hu 2005). Most discussions on Green SCM result in the proposition of initiatives which should be undertaken to achieve the potential goals on a broad Green SCM approach. The question remains, whether the proposition of the initiatives is really a holistic approach or whether they put a focus on specific issues of the supply chain based on different reasons. To demonstrate this, we selected a published study on Green SCM from Bearingpoint (Wohlfahrt & Vogt, n. d.). This study is based on a survey of 450 companies on a European level. Based on this survey, the study proposes 22 initiatives developing towards a Green Supply Chain. These 22 initiatives are divided in 15 intra-organizational and 7 inter-organizational initiatives.

Figure 1: Applied findings on a selected Green SCM initiative

One area, which is very broadly covered, is the area of delivery. Eight initiatives from the complete concept can be identified as relevant tasks for the area of delivery. This is remarkable from two viewpoints. First, delivery is fully covered by the proposed Green SCM initiative. This is aligned with most other proposed Green SCM initiatives from a practical side of view, because there seems to be broad experience and methods to develop ecological-friendly tasks. But second, all eight initiatives are inter-company issues. But delivery is also a local issue with complex intra-company processes, especially in the production industry. The discussion on this is missing in the Green SCM concept. The area of Return is not covered at all. This is also quite remarkable since the return processes are responsible to transfer material back into the economic cycle. But the proposed initiative does not cover these aspects at all. All of the nine resource-related activities remain open to improvement.

6 Discussion

The previous section has shown that the proposed GreenSCOR model provides a holistic view on a resource-oriented, sustainable supply chain. In general, the model may act as a tool for investigating resource-oriented concepts in an inter-organizational context for their sustainability. Therefore, the proposed model can be regarded as a first step towards a reference model for a resource-oriented sustainable supply chain model, which may act as a blueprint for the development and extension of classical supply chains to sustainable one. Due to its resource-oriented focus, the emphasis of the proposed model lies in the management of tangible goods and classic production processes. In several industries, there is a broad discussion about the substitution of tangible goods through service-based solutions. One outstanding example of this development is in the area of cloud computing. Cloud computing has made it so the IT department is no longer running its own infrastructure, but is rather sourcing IT services from external providers and orchestrating them to run complex business applications. This has a tremendous impact on sourcing, developing, and maintaining processes and a completely new perspective on resources in this area (see for example Bensch & Schrödl 2012). The question is how this development may be reflected in the proposed Green SCOR model? In a first approach we assume, that the distinction between make and delivery has to be redesigned. In the service industry, we see a principle called uno actu, which means that in the service industry the making of a service and the consumption of a service may occur simultaneously. This principle

changes the meaning of delivery and might create a much closer relationship between make and delivery in a revised model.

7   Summary

The aim of this paper was the development of a supply chain management model which emphasis environmental aspects from a strategic perspective. To achieve this, the reference model of a SCOR has been selected as a modeling foundation. SCOR has been investigated on activities which are closely related to resource and energy issues. SCOR in its current version 10.0 contains 77 activities on description level 3, of which 35 of them could be identified as environmental significant. Emphasis on these 35 activities leads to "Greened" SCOR as a blueprint for the establishment of strategic supply chains with emphasis on minimized environmental impact and provides a new framework for the development and establishment of sustainable supply chain management structure. The proposed model has been applied to a selected case for Green SCM. It could be shown that the proposed approach for Green SCM lacks generality and covers only parts of the relevant aspects. The discussion of the proposed model shows that it has the potential also for extending into a more service-based industry. In this sense, the proposed model acts as a blueprint for current issues in strategic supply chain management with environmental focus and as foundation for the future development of a generic approach towards product-independent supply chain management development.

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Inter-organizational systems adoption in regional networks of the wood industry

Towards a factor-based model

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Abstract

The utilization of inter-organizational systems (IOS) in regional wood networks promises to create significant advantages in terms of operational efficiency, especially, since cascade utilization requires a high degree of information sharing. Thus, low adoption rates of IOS seem surprisingly.

This study sets out to investigate facilitators and inhibitors of IOS adoption in regional wood networks. By drawing on the technology-organization-environment model and network governance theory, this paper develops a factor-based research framework encompassing three dimensions: technology, organization and network relationships, and environment. Within each dimension factors are summarized from existing literature and translated to the field of regional wood networks. The model is intended to be the fundament for future qualitative and quantitative research.

Keywords

Regional networks, IT adoption, inter-organizational systems

1 Introduction

In recent years, the use of wood has garnered increasing attention from the public, economic, and political sectors. First, heightened environmental awareness has led to the rising popularity of wood as an ecological alternative for oil-based products. Second, since wood is usually produced and

processed by small- and medium-sized companies in regional networks, increasing wood utilization reinforces rural areas (Peters et al., 2010). Wood processing is usually characterized by inter-organizational cascade utilization, i.e., utilization of byproducts such as sawdust for chipboards and multiple reuses such as energetic recovery. In this context, misallocation results in waste of resources. For example, Uusijärvi (2012) estimate that 10% of the wood raw materials and production resources are lost as waste which, e.g., leads in Europe to a yearly loss of 25 million cubic meters of wood waste in Europe (Uusijärvi et al., 2010). Therefore, close inter-organizational operational coordination and complementary cooperation (Hong, 2002) is a central challenge.

As with other industries, a set of standards have been developed in order to support both IT-based coordination and cooperation; ELDAT, FHP, IFIS, PapiNet are a few that aim towards electronic integration of contractual, invoice, and delivery data exchange in the wood industry. Despite wide acknowledgement of benefits gained through inter-organizational systems (IOS) in other industries (Johnston & Vitale, 1988, Saeed et al., 2005) and the high need for information integration in cascades utilization, there is still low diffusion in the wood industry (Hewitt et al., 2011).

During the past decades, academia has paid considerable attention to answering questions related to the adoption and non-adoption of information systems (IS). As a result, various prominent theories attempting to explain which factors influence technology diffusion for the individual (Davis et al., 1989, Venkatesh et al., 2003) and organizational levels have arisen (Tornatzky & Fleischer, 1990). While there is also a stream of research that sheds light on why organizations adopt inter-organizational IS, the basic assumption is a focal firm having dyadic relations to other organizations (e.g., Iacovou et al., 1995, Chan et al., 2012, Cao & Gan, 2013). Factors concerning networks as in the case of cascade utilization are, to the best of our knowledge, only marginally considered. However, research on inter-organizational networks explicitly stresses that the perspective of "networks as a whole" is essential for understanding the influence of social and political forces in decision making (Provan et al., 2007).

In this paper, we examine factors affecting the adoption of IOS in regional wood networks. The resulting model is the foundation for further research effort which will examine the relevance of each factor with empirical qualitative case studies.

This study addresses two gaps in current theory. First, the specific issue of IOS non-adoption in regional wood networks has not yet been sufficiently addressed in literature. The majority of existing efforts describe non-adoption, rather than examining the reasons for it (Hewitt et al., 2011). The results of this study provide first insights into facilitators and

inhibitors of IOS adoption. Second, we contribute to IOS adoption research by shifting the focus from a dyadic perspective to a network point of view. Drawing upon the technology–organization–environment model, we borrow from network governance theory to account for network factors.

The remainder is structured as follows. In the next section, we review IOS adoption in general and IS adoption studies on the wood industry. We then postulated a research model for the adoption of IOS in regional wood networks which encompasses technological, network, and environmental factors. The paper closes with a conclusion and an outline of further research in this direction.

2 Related literature

2.1 Reviewing adoption of IOS

The past decades of IS research have brought forth various frameworks explaining IS adoption. Most of them take a so-called factor-based stance (Kurnia & Johnston, 2000). Following a situational control perspective, it is assumed that implementation decisions or actions are influenced by the characteristics of technologies, potential adopters, and further internal and external factors (Markus & Robey, 1988). In contrast to process-oriented approaches which focus on interactions rather than singular causes, factor-based models follow an arguably straightforward logic, allow generalization through established empirical methodologies, and can be readily translated (Kurnia & Johnston, 2000). Accordingly, factor approaches enjoy great popularity in the field of IOS adoption studies.

Most studies on IOS adoption focus on analysis at the organizational level and range from manufacturing resource planning and EDI implementations to e-business applications, including business-to-business and collaborative commerce (e.g., Premkumar & Ramamurthy, 1995, Chong et al., 2009). In this context the technology–organization–environment model (TOE) is widely acknowledged and builds the theoretical foundation for a variety of these studies. The technological context refers to the availability of the new technologies and the ability to adopt new systems into the existing environment. Organizational factors include internal characteristics covering formal and informal linking structures of an organization, its communication processes, organizational size, and the organization's slack. External factors encompass the context beyond organizational borders, such as sector characteristics, competitors, and policy makers. Building

upon the three perspectives of the TOE, a variety of studies concentrate on EDI-related IOS adoption. Premkumar et al. (1995) studied EDI adoption using organizational and environmental predictors, such as top management support, organizational compatibility, competitive pressure, customer support, and customer expertise. Huang et al. (2008) studied factors for Internet-EDI adoption and also find empirical evidence for organizational and environmental variables including application knowledge and network externalities. Since EDI implementations usually follow a hub and spoke structure with a powerful focal firm in the middle, all of these studies concentrate on dyadic relationships. When examining the adoption of IOS in the context of regional networks, factors relating to the network as a whole become important. Research on inter-organizational networks explicitly stresses the importance of examining network factors from a macro perspective (Provan et al., 2007). We will argue that enabling and hindering factors emerging from relations among network members in regional networks can contribute to the understanding of IOS adoption in the wood industry.

2.2 Reviewing IS adoption in the wood industry

Little research has been undertaken thus far to explain IS adoption with a branch-specific focus on the wood industry. In general, studies indicate a low rate of IS diffusion in this context (Arano & Spong, 2012, Karuranga et al., 2005, Vlosky & T. Smith., 2003), which corresponds with generally low investments in IS (Arano, 2008). Karuranga et al. (2005), e.g., report that less than 5% use IS for IT in operational planning, supply planning, inventory management, process control, and buying/selling. Not surprisingly, as the economic value of IS is well understood, results from Perkins (2009) from the hardwood lumber manufacturing industry empirically demonstrate the importance of technological integration through information systems; companies with a high level of IT integration had a significant higher degree of business performance than low-technology firms. A study of Arano & Spong (2012) on e-commerce adoption presents inhibitors for adoption. The top three concerns of non-adopters are the security of sensitive information, implementation costs, and the availability of technical resources. Stennes et al. (2006) also conducted an empirical study in the forest-products context and find that firm output, export activity, and firm type are significant predictors of companies that had opted for e-commerce implementation. A comprehensive review of 16 publications dealing with the forest products industry can be found in Hewitt et al. (2011). However, from the mainly descriptive literature provided in this field, it remains unclear which deeper explanations determine IOS adop-

tion, whether they be technological, organizational, environmental, or network-related causes.

3 Development of an adoption model

The three perspectives of the TOE framework build the foundation for the study of factors determining the adoption of IOS in regional networks of the wood industry. We argue this decision with the strong theoretical fundament provided by the broad literature on TOE and IOS that has been published within the past two decades. While the terms technology and environment from the TOE can be directly translated to our context, the term organization requires more attention.
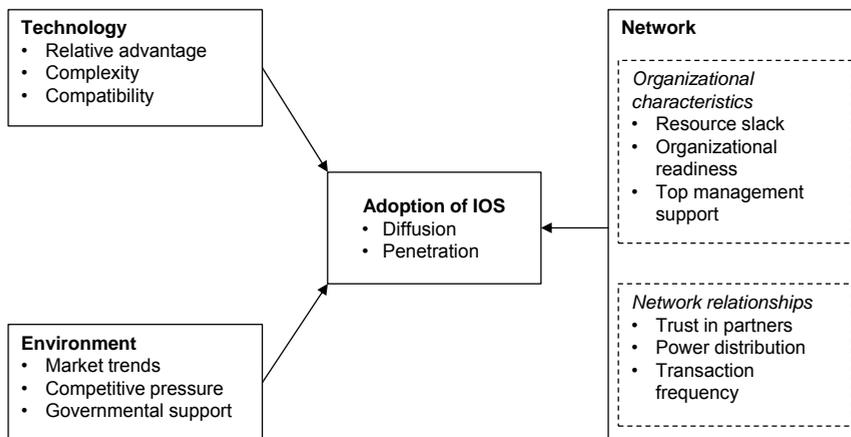
Figure 1: The technology-network-environment model

Organization generally refers to the unit of analysis, which is regional network in this study. Regional networks differ from the classical understanding of organizations with hierarchical structures and clear decision making. Formal accountability of network members to network-level goals is typically not provided; conformity to rules and procedures is purely voluntary (Provan & Kenis, 2007). Unlike clear authority relationships, which are based on a formal hierarchy in intra-organizational governance, networks are characterized by unstable and polycentric power distribution with a low degree of formalization (Alter & Hage, 1993). Moreover, because the existence of common goals does not exclude differing goals, networks struggle with balancing these conflicts (Winkler, 2006). Due to these differences, our model incorporates two perspectives on network factors. First, we consider classical organizational characteristics, which found wide support in former adoption studies. Second, we borrow from inter-

organizational relationship theory and network governance theory (Jones et al., 1997) and include factors emerging from intra-network-relationships.

3.1 Adoption of IOS

The object of interest in this study is the adoption of IOS in regional networks of the wood industry. Therefore, in contrast to the broad literature on firm-centric IOS adoption, we want to present and understand facilitators and inhibitors of IOS adoption that explain adoption within the whole network. Moreover, rather than understanding adoption as a singular question of "adopted" or "not adopted," our conceptualization investigates adoption within two dimensions (as suggested by Zhang et al. (2009)). First, we want to know the extent to which IOS have reached implementation among partners within regional wood networks. This can be understood as diffusion of IOS. Second, our concept of adoption includes the aspect of penetration, i.e., the extent to which the network and its partners rely on IOS.

3.2 Technology

The general role of technological characteristics has already been discussed by introducing Rogers's DOI model. We argue that different degrees of perceived technology fit also lead to different adoption decisions in regional wood networks. Following Tornatzky & Kleins's (1982) suggestions from a review on DOI literature, this model incorporates three factors, i.e., relative advantage, complexity, and compatibility. First, relative advantage has perhaps the strongest scientific support among the proposed factors. Roger (2003) points out that diffusion processes always start with a subjective evaluation of the organizational future benefits that are provided by an innovation. In addition, Iacovou et al. (Iacovou et al., 1995) argue that the benefit is generally associated with an increasing internal efficiency, but it also effects or even enables business opportunities that hold the potential to be transformed into competitive advantages. Correspondingly, IOS are also more likely to be adopted if they are perceived to be beneficial to existing solutions. Second, Rogers (2003) argues that the degree of complexity in terms of the relative difficulty to understand IS relates negatively to adoption decisions. IOS are complex socio-technical systems involving a dispersed structure of stakeholders. In a network context, the implementation of IOS requires the consideration of different IT structures and IT resources. As shown in other research on IOS (Huang et al., 2008, Premkumar & Ramamurthy, 1995), different degrees of perceived complexity can therefore also influence IOS adoption decisions in regional wood networks. The third and final factor, namely compatibility, describes

the fit of an IOS with existing IT infrastructures and work procedures (Tornatzky & Klein, 1982). Again, heterogeneous networks with a heterogeneous IT landscape may make IOS implementation even more complex.

3.3 Organizational characteristics

Fleischer (1990) argues that organizational preparation is important for the success of innovations. This model incorporates financial readiness, organizational readiness, and top management support as three widely-acknowledged factors influencing adoption decisions.

The implementation of IOS is not only a complex task but also requires a considerable amount of financial and organizational resources. Financial readiness covers the first aspect and proposes that the network must have the financial resources required, and involved network members must be willing to invest in them jointly. Results from Arano & Spon (2012) already indicate the importance for the wood industry; they find high expenditures to be an influential inhibitor for the adoption of IS innovations.

Organizational readiness refers to whether the organization has the attributes necessary to accommodate the IOS, such as technological experience, appropriate IS staff, and IT infrastructure. Studies on IS diffusion in the context of the wood products industry show a generally low degree of IS diffusion (Hewitt et al., 2011). Consequently, prior experiences with IS implementations leading to internal IT knowhow are few. This reinforcing mechanism might lead to non-adoption of complex IOS. Since organization in the context of regional networks refers to the entirety of all network members, it is important that all members show readiness. The implementation of IOS is a long-term project with high organizational and financial involvement. In line with IS project management literature and a range of adoption literature, a high degree of top management support is a widely accepted precondition for implementation success.

3.4 Network relationships

Networks constitute a "distinct form of coordinating economic activity (Powell, 1990)." When following the transaction cost perspective, network governance is located in the middle of market governance and hierarchical governance (Jones et al., 1997). Obviously, this form of coordination also affects decision making related to information systems in supporting the collaboration. By means of incorporating transaction cost economics with social network theory, network governance theory offers approaches to explanation that can be translated to this context (Jones et al., 1997). In general, relationships in networks usually rely on socially implicit contracts

rather than formal or legally binding contracts (Alter & Hage, 1993; Jones et al., 1997). With network governance theory building the theoretical frame for the analysis, we identify the following three factors affecting IOS adoption decisions: trust in partners, power distribution, and transaction frequency.

Informal relations and control mechanisms in networks are supported by social contracts based on norms of reciprocity and trust (Alter & Hage, 1993). Trust can be understood as "the willingness to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action, irrespective of the ability to monitor or control that other party (Mayer & Schoorman, 1995)." Relating this understanding to network relationships and decisions for IOS, trust determines the expectations of a partner's reliability, competence, and openness (Ibrahim & Ribbers, 2009). A high density of trust among network members leading to positive expectations can influence attitudes towards IOS and, thus, IOS adoption. In contrast to the few other IOS adoption studies examining the role of trust, this conceptualization follows a more generalized trust approach. Instead of defining trust as interpersonal trust, where one trustor trusts a more or less specific trustee/trust object, for understanding network-level interactions it is important whether trust is reciprocated among network members (Provan & Kenis, 2007). More precisely, whether there is a wide or narrow distribution of trust across members.

The second factor relevant for IOS adoption is the existence of powerful members within the network. Powerful members in terms of organizational resources or imbalanced lateral dependencies can be an influential source when it comes to common decision making. For instance, although perceived benefits through implementation of an ELDAT interface do not seem to be convincing for some small raw timber wood suppliers in a regional network, the powerful position of a saw mill is influential enough to force the common adoption decision. Similar observations haven been made in the automotive industry, where car manufacturers push component suppliers to adopt EDI (Premkumar & Ramamurthy, 1995). Accordingly, imbalanced power distribution might support IOS adoption in regional networks.

The last factor of the network aspect is the transaction frequency. Network governance theory proposes that the more often members exchange with one another, the higher the social embeddedness and exchange of tacit knowledge (Jones et al., 1997). In turn, strong social ties among network members and a high degree of knowledge exchange are the foundation for developing initial ideas for planning and implementing common innovations (Tsai & Ghosahl, 1998). Moreover, a high transaction frequency may provide increased incentives to improve IT-supported coordination between partners, thus influencing IOS adoption.

3.5 Environment

Since our unit of analysis is the regional network as a whole, environmental factors refer to the outside of this compound. This model incorporates three environmental factors, i.e., market trends, external competitive pressure, and government support.

Market trends regarding new technologies refer peer behavior, which has proven to be a good predictor for adoption (Cao & Gan, 2013). For example, if some networks start to implement B2B integration through PapiNet and visibly improve their inter-organizational processes, it is reasonable that other networks would also get a basic idea of the new technology. In turn, this could be a starting point for considering its own implementation. Both theoretical considerations and empirical results reveal the influence of market trends on the willingness and openness to adopt new technologies (Chong et al., 2009).

The basic approach concerning the impact of market competition on innovation diffusion originates from Porter & Millar's (1985) research. They argue that innovation adoption enables firms to change the rules of competition and consequently facilitates the development of new competitive advantages. IOS adoption research translated this idea to their domain and established good empirical support (Huang et al., 2008). In line with this argumentation, it is proposed that great external competitive pressure demands IOS adoption.

Lastly, governmental support is particularly important. Since there is a public interest in promoting wood, e.g., as a sustainable substitute for oil-based products, there is a wide range of governmental initiatives providing financial and organizational incentives. Access to governmental support can be an incentive to adopt IOS and, thus, influence adoption.

4 Conclusion and outlook

This study sets out to investigate the adoption of IOS in regional wood networks. The utilization of IOS promises to create significant advantages in terms of operational efficiency, especially, since cascade utilization of wood requires a high degree of information sharing. Thus, the low adoption rates of IOS among regional wood networks seem surprisingly.
By drawing on the TOE model and network governance theory, this paper developed a factor-based research framework encompassing three dimensions: technology, organization and network relationships, and environment. Within each dimension factors were summarized from existing literature and translated to the field of regional wood networks.

In doing so, this article addresses gaps in the current literature that are inherent to the adoption of IOS in regional wood networks. However, theorizing from prior literature as we have done it in this study is only a first step into the investigation of facilitators and inhibitors. Additional research efforts are necessary to, first, validate the proposed model and, second to examine the magnitude of each single factor. We suggest following a method triangulation approach. In a first step, a qualitative inquiry strengthens the content validity of each single factor. This should be followed by an empirical survey which enables quantitative validation of the model as a whole and allows determining the relevance of single factors.

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Mathematical Optimization in the Presence of Uncertainties

Using Minimum Quantities to Guarantee Resource Efficiency in Combinatorial Optimization Problems

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Abstract

In this note, we summarize some results of our recent work on network flow and packing problems with minimum quantities.

Keywords

Minimum quantities, network flows, packing problems

1 Introduction

An important aspect of resource efficiency is achieving a sufficient utilization of resources that are used within a production process. This motivates to study optimization problems in which a minimum amount of load is guaranteed for each resource that is used in a solution. One way to reach this goal is to specify a *minimum quantity* for the use of each resource, which means that, in any feasible solution, the utilization of the resource is either zero or at least the given minimum quantity. In order to give an impression of the algorithmic consequences of such minimum quantity constraints on combinatorial optimization problems, we summarize some of our recent results that show how minimum quantity constraints influence the complexity and approximability of network flow problems and packing problems, which are two important problem classes in combinatorial optimization. A more detailed presentation of these results can be found in (Thielen & Westphal, 2013; Krumke & Thielen, 2011) (for network flow problems) and (Krumke & Thielen, 2013) (for packing problems).

2 Network Flow Problems with Minimum Quantities

The first class of problems we consider are network flow problems where the flow on each arc in the network is restricted to be either zero or above a given lower bound (a *minimum quantity*). The problems we study are the following minimum quantity variants of the classical maximum flow problem and the minimum cost flow problem:

Definition 1 (Maximum Flow Problem with Minimum Quantities (MFPMQ))**.**

INSTANCE:	*A directed graph $G = (V, R)$, a source $s \in V$, a sink $t \in V$, positive arc capacities $u : R \rightarrow \mathbb{N} \cup \{+\infty\}$, and nonnegative minimum quantities $\lambda : R \rightarrow \mathbb{N}_0$ such that $\lambda(r) \leq u(r)$ for all $r \in R$.*
TASK:	*Find a feasible s-t-flow $f : R \rightarrow \mathbb{N}_0$ of maximum flow value $val(f) := \sum_{r \in \delta^+(s)} f(r) - \sum_{r \in \delta^-(s)} f(r)$ in G.*

Definition 2 (Min Cost Flow Problem with Minimum Quantities (MCFPMQ))**.**

INSTANCE:	*A directed graph $G = (V, R)$, a source $s \in V$, a sink $t \in V$, positive arc capacities $u : R \rightarrow \mathbb{N} \cup \{+\infty\}$, arc costs $c : R \rightarrow \mathbb{N}_0$, nonnegative minimum quantities $\lambda : R \rightarrow \mathbb{N}_0$ such that $\lambda(r) \leq u(r)$ for all $r \in R$, and a flow value $F \in \mathbb{N}$.*
TASK:	*Find a feasible (s, t)-flow $f : R \rightarrow \mathbb{N}_0$ of flow value F in G such that the flow cost $\sum_{r \in R} f(r) \cdot c(r)$ is minimized.*

In the above definitions, a *feasible s-t-flow* is a function $f : R \rightarrow \mathbb{N}_0$ that satisfies the flow conservation constraints and respects the minimum quantities and upper capacities on the arcs.

Both MFPMQ and MCFPMQ are strongly NP-hard to approximate on general graphs but pseudo-polynomial time dynamic programming algorithms are known for series-parallel graphs (where the problems are still weakly NP-hard to solve). Moreover, there exists a $(2 - \frac{1}{\lambda})$-approximation algorithm for MFPMQ for the case that there is an identical minimum quantity λ on all arcs. In the case that the graph is series-parallel *and* the minimum quantity is identical on all arcs, MFPMQ can be solved in polynomial time by a dynamic programming algorithm.

3 Packing Problems with Minimum Quantities

As a second class of problems, we consider packing problems. In this context, a minimum quantity constraint restricts the amount of space used in a container (bin) to be either zero or above a given minimum quantity (which may depend on the container). One of the most prominent packing problems in combinatorial optimization is the generalized assignment problem (GAP), whose minimum quantity variant is defined as follows:

Definition 3 (GAP with Minimum Quantities (GAP-MQ))**.**
INSTANCE: m *bins with capacities* $B_1, \ldots, B_m \in \mathbb{N}$ *and minimum quantities* $q_1, \ldots, q_m \in \mathbb{N}$ *(where* $q_j \leq B_j$ *for all* $j = 1, \ldots, m$*), and* n *items. For each item* i *and bin* j*, a size* $s_{i,j} \in \mathbb{N}$ *and a profit* $p_{i,j} \in \mathbb{N}$*.*
TASK: *Find a packing of a subset of the items into the bins such that the total space used in each bin* j *is either zero (if bin* j *is not opened) or at least* q_j *and at most* B_j *and the total profit is maximized.*

Unless $\mathsf{P} = \mathsf{NP}$, no polynomial time approximation algorithm exists for GAP-MQ even for restricted profit values and only one bin. Moreover, even the special case of unit-size items does not admit a polynomial time approximation scheme. However, there exists polynomial time $(1, 2)$-approximation algorithm for GAP-MQ. For every instance of the problem, this dual approximation algorithms computes a solution violating the minimum quantities and bin capacities by at most a factor $\frac{1}{2}$ and 2, respectively, and whose profit is at least as large as the profit of the best solution that satisfies the minimum quantities and bin capacities strictly.

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Efficient Graph Algorithms for Network Analysis

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Abstract

We provide improved algorithms for the Graph Center (GC) problem and the Graph Bottleneck (GB) problem. We show that both the 1-center GC problem and the GB problem can be solved in $O(n^\omega \log n)$ time, where $\omega < 2.373$. We also introduce a new problem called the Shortest Paths for All Flows (SP-AF) problem, which effectively combines the well known Shortest Paths problem and the Bottleneck Paths problem. We define a new semi-ring called the distance/flow semi-ring, and show that our new semi-ring definition can be utilized to solve the new SP-AF problem.

Keywords

Network analysis, facility location, bottleneck paths, shortest paths, fast algorithms

1 Introduction

We provide efficient algorithms for two major problems in network analysis. One is the Graph Center (GC) problem and the other is the Graph Bottleneck (GB) problem. The GC problem is relevant for facility location, while the GB problem is relevant for transportation and logistics.

The GC problem is to identify a pre-determined number of center vertices such that the distances or costs from (or to) the centers to (or from) other vertices is minimized. Let us take an example of transporting wood trunks from forests to sawmills. The distance here is defined by the shortest distance from the forests to the sawmills. The problem is then to determine the center vertices (i.e. sawmills) so that the average distance from each forest is minimized.

The bottleneck of a path is the minimum capacity of edges on the path. The Bottleneck Paths (BP) problem is to compute the paths that

give us the maximum bottleneck values between pairs of vertices. The Graph Bottleneck (GB) problem is to find the minimum bottleneck value out of bottleneck paths for all possible pairs of vertices. Continuing with the example of sawmills and forests, we define the edge capacities as the maximum number of tonnes that can be transported on the roads. Then the BP problem is to find the paths from the forests to the sawmills that can be used to transport the maximum amount of wood trunks at the same time. The GB problem is to find the bottleneck in this model network.

We give two similar algorithms that are based on binary search to solve the 1-center GC problem and the GB problem on directed graphs with unit edge costs. We achieve $\tilde{O}(n^{2.373})$ worst case time complexity for both the 1-center GC problem and the GB problem, where n is the number of vertices in the graph[1]. This is better than the straightforward methods of solving the two problems in $O(n^{2.575})$ (Zwick, 2002) and $O(n^{2.688})$ (Duan & Pettie, 2009) time bounds, respectively. Note that the 2-center GC problem is investigated by (Takaoka, 2010).

We then combine the Bottleneck Paths (BP) problem with the well known Shortest Paths (SP) problem to compute the shortest paths for all possible flow values. We call this problem the Shortest Paths for All Flows (SP-AF) problem. If the flow demand is fixed (e.g. from a forest to a sawmill), computing a single shortest path that can accommodate the flow demand is sufficient. However, the flow demand maybe uncertain, and may vary greatly. It is therefore beneficial to compute the shortest paths for all possible flow amounts. In introducing this new problem, we define a new semi-ring called the distance/flow semi-ring, and show that the well known algorithm by (Floyd, 1962) can be used over the distance/flow semi-ring to solve the All Pairs Shortest Paths for All Flows (APSP-AF) problem. Further discussions of the SP-AF problem can be found in the paper by (Shinn & Takaoka, 2013).

2 Preliminaries

Let $G = \{V, E\}$ be a directed graph where V is the set of vertices and E is the set of edges. Let $|V| = n$ and $|E| = m$. We assume that the vertices are numbered from 1 to n. Let $(i, j) \in E$ denote the edge from vertex i to vertex j. Let $cost(i, j)$ and $cap(i, j)$ be the cost and capacity of the edge (i, j), respectively. For the GC and GB problem in Sections 3 and 4, respectively, we deal with graphs with unit edge costs, hence $cost(i, j) = 1$ for all $(i, j) \in E$. $cap(i, j)$ can be any non negative real number. Let c be the maximum value of $cap(i, j)$.

Let $Z = X \star Y$ denote the Boolean matrix multiplication of matrices

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[1]$\tilde{O}$ is a notation used to omit all polylog factors from the asymptotic time complexity.
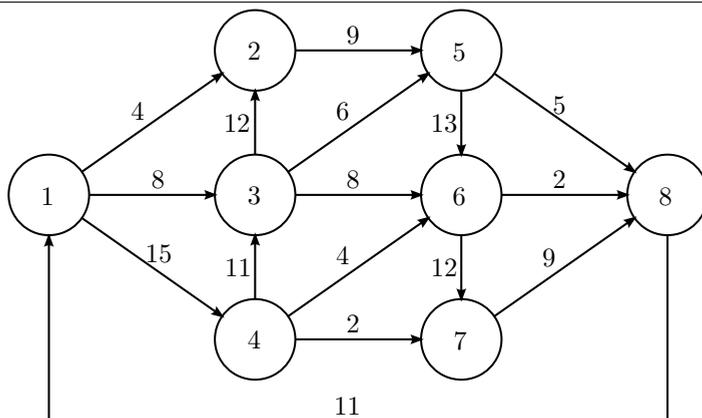
Figure 1: An example of a strongly connected directed graph with unit edge costs, with $n = 8$ and $m = 16$. Capacities are shown beside each edge.

$X = \{x_{ij}\}$ and $Y = \{y_{ij}\}$, where $Z = \{z_{ij}\}$ is given by:

$$z_{ij} = \bigvee_{k=1}^{n} \{x_{ik} \wedge y_{kj}\}$$

3 The 1-center GC problem

The GC problem is closely related to the All Pairs Shortest Paths (APSP) problem. Let us assume that the APSP problem has been solved for the given graph, that is, the matrix D^* has been solved with the shortest distance from vertex i to vertex j being d_{ij}^*. Then the 1-center is given by vertex i that gives the minimum Δ in the following equation, where the value of Δ is the distance from the center to the farthest vertex:

$$\Delta = \min_{i=1}^{n} \{\max_{j=1}^{n} d_{ij}^*\}$$

The aim of our algorithm is to compute the center without computing D^*, that is, without solving the APSP problem, which is costly. As mentioned in Section 1, the current best time bound for solving the APSP problem is $O(n^{2.575})$ by (Zwick, 2002).

Let the threshold value t be initialized to $n/2$. For simplicity we assume n is a power of 2. Let a Boolean matrix B be defined by its element b_{ij} as follows: $b_{ij} = 1$ if there is an edge (i, j), and 0 otherwise. We let $b_{ii} = 1$ for all i. Let B^{ℓ} be the ℓth power of B under Boolean matrix

multiplication. We observe that for the matrix B^ℓ, $b_{ij}^\ell = 1$ if and only if j is reachable from i via a path whose path length is at most ℓ. Let $C = B^\ell$. Let us compute:

$$P(C) = \bigvee_{i=1}^{n} \{ \bigwedge_{j=1}^{n} c_{ij} \}$$

from which we can derive the fact that $\Delta \leq \ell$ if and only if $P(C) = 1$. We can repeatedly halve the possible range $[\alpha, \beta]$ for Δ by adjusting the threshold value of t through the binary search. Algorithm 1 solves the GC problem in $\tilde{O}(n^{2.373})$ worst case time complexity.

Algorithm 1 Solve the 1-center GC problem

1: Compute B^2, B^4, ..., $B^{n/2}$ by repeated squaring
2: $\alpha \leftarrow 0$; $\beta \leftarrow n$
3: $C \leftarrow I$ /* I is the unit Boolean matrix */
4: **while** $\beta - \alpha > 1$ **do**
5:     $t \leftarrow (\alpha + \beta)/2$
6:     $r \leftarrow (\beta - \alpha)/2$
7:     **if** $P(C \star B^r) = 1$ **then**
8:         $\beta \leftarrow t$
9:     **else**
10:         $\alpha \leftarrow t$
11:         $C \leftarrow C \star B^r$
12: $C \leftarrow C \star B^r$
13: Find row i such that $c_{ij} = 1$ for all j /* Vertex i is the graph center */

14: **procedure** $P(C)$
15:     **return** $\bigvee_{i=1}^{n} \{ \bigwedge_{j=1}^{n} c_{ij} \}$

Lemma 3.1. *At the beginning of each iteration of the while-loop at line 4 of Algorithm 1, $\alpha < \Delta \leq \beta$.*

Proof. Proof is based on induction on the repetition of the while-loop. We first prove that at the beginning of each iteration of the while-loop, $C = B^\alpha$. At the 0th repetition, $C = B^0$ and $\alpha = 0$. Suppose the lemma is true for α. If $P(C \star B^r) = 1$, C and α are unchanged. If $P(C \star B^r) = 0$, α becomes t and C becomes B^t. Now the lemma is true after the initialization of α and β. Suppose the lemma is true at the beginning of an iteration. If $P(C \star B^r) = 1$, $\alpha < \Delta \leq \alpha + r = t$ and β is set to t. If $P(C \star B^r) = 0$, $t < \Delta \leq \beta$ and α is set to t. $\square$

Theorem 3.1. *Algorithm 1 solves the GC problem on graphs with unit edge costs in $\tilde{O}(n^\omega)$ time, where $\omega < 2.373$ (Williams, 2012).*

Proof. Upon termination of the while loop, we see $\alpha + 1 = \beta$, $\Delta = \beta$ and $C = B^\alpha$. Thus line 13 of the program successfully computes the graph center. The computation of line 1 for the powers of B takes $O(n^\omega \log n)$, where $O(n^\omega)$ is the time taken for multiplying two n-by-n Boolean matrices. Obviously the iteration in the while loop is done $O(\log n)$ times. Thus the total time is $O(n^\omega \log n) = \tilde{O}(n^\omega)$. $\qquad\square$

Note that Algorithm 1 is based on the "to" distance. If we use the "from" distance, i and j will be swapped in $P(C)$. If we consider both distances, we take the $\wedge$ operation of the two formulae.

For a graph with integer edge costs bounded by c, we can transform G to have $O(cn)$ vertices and unit edge costs (Alon et al., 1991) such that the 1-center GC problem can be solved in $\tilde{O}((cn)^\omega)$ time.

4   The GB problem

Let Θ be the bottleneck value of the entire network. The straightforward method to compute Θ would be to solve the All Pairs Bottleneck Paths (APBP) problem and find the minimum among the bottleneck paths. The current best time bound for solving the APBP problem is $\tilde{O}(n^{2.688})$ by (Duan & Pettie, 2009). We avoid solving the APBP problem to compute Θ.

Example 4.1. *The value of Θ for the graph in Figure 1 is 9, which is the capacity of edges $(2, 5)$ and $(7, 8)$.*

Let the threshold value t be initialized to $c/2$, where c is the maximum capacity. Let Boolean matrix B be defined by its element b_{ij} as follows: $b_{ij} = 1$ if $cap(i, j) \geq t$, and 0 otherwise. Let us compute the transitive closure, B^*, of B. Then, from the equation:

$$b_{ij}^* = \Sigma\{b_{ik_1} b_{k_1 k_2} \cdot \cdot \cdot b_{k_r j} \mid \text{all possible paths } (i, k_1), (k_1, k_2), ..., (k_r, j)\}$$

we observe that $b_{ij}^* = 1$ if and only if $b_{ik_1} = 1$, $b_{k_1 k_2} = 1$, ..., $b_{k_r j} = 1$ for some path. From this we derive the fact that $\Theta \geq t$ if and only if $b_{ij}^* > 0$ for all i and j. We can repeatedly halve the possible range $[\alpha, \beta]$ for Θ by adjusting the threshold value of t through binary search.

Obviously the iteration over the while-loop in Algorithm 2 is performed $O(\log c)$ times. Thus the total time complexity becomes $O(n^\omega \log c)$. If c is large, say $O(2^n)$, the algorithm is not very efficient, taking $O(n)$ halvings of the possible ranges of Θ. In this case, we sort edges in ascending order of $cap(i, j)$. Since there are at most m possible values of capacities,

---

Algorithm 2 Solve the GB problem

1: $\alpha \leftarrow 0$; $\beta \leftarrow c$
2: **while** $\beta - \alpha > 0$ **do**
3: $\quad t \leftarrow (\alpha + \beta)/2$
4: $\quad$ **for** $i \leftarrow 1$ to n; $j \leftarrow 1$ to n **do**
5: $\quad\quad$ **if** $cap(i,j) > t$ **then**
6: $\quad\quad\quad b_{ij} \leftarrow 1$
7: $\quad\quad$ **else**
8: $\quad\quad\quad b_{ij} \leftarrow 0$
9: $\quad$ Compute B^* /* This takes $O(n^\omega)$ time */
10: $\quad$ **if** $b_{ij}^* > 0$ for all i and j **then**
11: $\quad\quad \alpha \leftarrow t$
12: $\quad$ **else**
13: $\quad\quad \beta \leftarrow t$
14: $\Theta \leftarrow \alpha$

---

where m is the number of edges, doing binary search over the sorted edges gives us $O(n^\omega \log m) = O(n^\omega \log n)$ time bound[2]. We note that the actual bottleneck path can be obtained with an extra polylog factor using the witness technique by (Alon et al., 1992). We omit the correctness proof of Algorithm 2 since it is essentially the same as the proof of Lemma 3.1.

5 Algebraic treatment for graph paths problems

Let S be a closed semi-ring, that is, $S = (S, +, \cdot, 0, 1)$. The operations $+$ and $\cdot$ are associative, $+$ is commutative, and $\cdot$ distributes over $+$. 0 is the unit element with $+$ and 1 is the unit element with $\cdot$. For $a \in S$, the closure of a, a^*, is defined by $a^* = 1 + a + a^2 + \ldots$.

Let us define matrices over semi-ring S. Let O and I correspond to 0 and 1 in the semi-ring. Let $M(S)$ be the set of all matrices of size n-by-n for a fixed n. Let I be the identity matrix and O be the zero matrix. The multiplication and addition of two matrices are defined in the conventional way. For $A = \{a_{ij}\}$, $B = \{b_{ij}\}$ and $C = \{c_{ij}\}$, let C = A + B. Then c_{ij} is defined by $c_{ij} = a_{ij} + b_{ij}$. Let $C = A \cdot B$. Then c_{ij} is defined by:

$$c_{ij} = \sum_{k=1}^{n} \{a_{ik} \cdot b_{kj}\}$$

and the system $M(S) = (M(S), +, \cdot, O, I)$ becomes a closed semiring.

---

[2]$O(m \log n)$ can be achieved by determining strongly connected components in $O(m)$ time (Tarjan, 1972) rather than computing the transitive closure in each iteration.

Let R_1 be the set of non-negative real numbers. R_1 is intended to represent edge costs. Let min and $+$ on R_1 correspond to $+$ and $\cdot$ of the semi-ring. Then $R_1 = (R_1, min, +, \infty, 0)$ becomes a closed semi-ring, called the distance semi-ring, also known as the tropical semi-ring (Richter-Gebert et al., 2003). The system $M(R_1) = (M(R_1), +, \cdot, O, I)$ becomes a closed semi-ring, where addition is the component-wise addition and for $C = A \cdot B$, c_{ij} is defined by:

$$c_{ij} = \min_{k=1}^{n}\{a_{ik} + b_{kj}\}$$

The meaning of A^ℓ is to give for the (i, j) element the shortest distance from vertex i to vertex j that uses ℓ edges. Thus the closure A^* gives the shortest distances for all pairs of vertices. As the shortest distance from any i to any j can be determined by the paths of at most $n - 1$ edges, we have $A^* = I + A + A^2 + ... = I + A + A^2... + A^{n-1}$. A^* is the solution to the All Pairs Shortest Paths (APSP) problem.

Let R_2 be the set of non-negative real numbers. R_2 is intended to represent edge capacities. Let max and min on R_2 correspond to $+$ and $\cdot$ of the semi-ring, called the max-min semi-ring. Then $R_2 = (R_2, max, min, 0, \infty)$ becomes a closed semi-ring. The system $M(R_2) = (M(R_2), +, \cdot, O, I)$ becomes a closed semi-ring, where addition is the componentwise addition and for $C = A \cdot B$, c_{ij} is defined by:

$$c_{ij} = \max_{k=1}^{n}\{\min\{a_{ik}, b_{kj}\}\}$$

The meaning of A^ℓ is to give for the (i, j) element the maximum bottleneck values of all paths from vertex i to vertex j that uses ℓ edges. Thus the closure A gives the bottleneck values for all pairs of vertices. As the bottleneck value from any i to any j can be determined by the paths of at most $n-1$ edges, we have $A^* = I + A + A^2 + ... = I + A + A^2 + ... + A^{n-1}$. A^* is the solution to the All Pairs Bottleneck Paths (APBP) problem.

6 The distance/flow semi-ring

So far we have defined the distance semi-ring and max-min semi-ring independently. In this section we combine them and make a composite semi-ring called the distance/flow semi-ring. Note that the concept of semi-rings is widely known. Our contribution here is in the definition of a new type of semi-ring that has practical applications.

We define the df-pair, (d, f), where d and f are from R_1 and R_2, respectively. That is, d represents distance and f represents flow. We define two orders on df-pairs.

Definition 6.1. *Let (d, f) and (d', f') be two df-pairs. Then the merit order $\leq_m$ and the natural order $\leq_n$ are defined as:*

$$
\begin{aligned}
(d, f) \geq_m (d', f') &\Leftrightarrow d \leq d' \wedge f \geq f' \\
(d, f) \leq_n (d', f') &\Leftrightarrow d \leq d' \wedge f \leq f'
\end{aligned}
$$

The meaning of the merit order is that a *df*-pair is more desirable if it has a higher f for the same or lower value of d. If $(d, f) <_n (d', f')$, the *df*-pairs are incomparable under the merit order. Note that these two orders are partial orders on the direct product of integer sets.

Definition 6.2. *The addition and multiplication on df-pairs (d, f) and (d', f') are defined as:*

$$
(d, f) + (d', f') =
\begin{cases}
(d, f) & \text{if } (d, f) >_m (d', f') \\
(d', f') & \text{if } (d, f) <_m (d', f') \\
\{(d, f), (d', f')\} & \text{if } (d, f) <_n (d', f') \\
\{(d', f'), (d, f)\} & \text{if } (d, f) >_n (d', f')
\end{cases}
$$

$$
(d, f) \cdot (d', f') = (d + d', \min \{f, f'\})
$$

Note that the addition of *df*-pairs can result in a set of *df*-pairs that are incomparable under the merit order, and sorted in natural order. Intuitively speaking, addition of two *df*-pairs is to take a better route from two parallel connections from a vertex to another vertex and take both if they are incomparable. Multiplication is to compute the new *df*-pair for a serial connection. We sometimes omit the signs "{}" for singletons.

The domain $R_1 \times R_2$ is not closed under the + operation. Thus we need to extend the domain to the power set of incomparable *df*-pairs, that is, the set of all subsets of incomparable *df*-pairs. We firstly define the + operation on sets of incomparable *df*-pairs. Let x and y be sets of incomparable *df*-pairs, sorted in natural order. Let $z = x + y$, where z can be computed as follows: We start with $x \cup y$, and remove all *df*-pairs from the union that are smaller than any other *df*-pair in the merit order. If multiples of equal *df*-pairs exist we remove all but one. Then z is the resulting set of incomparable *df*-pairs, sorted in natural order. $x + y$ can be calculated in $O(|x| + |y|)$ time with Algorithm 3. In this algorithm, the operation $a \Leftarrow x$ means that the element a is removed from the set x, where a is the first *df*-pair and x is the set of incomparable *df*-pairs sorted in natural order. If $x = \{\}$, $a \Leftarrow x$ results in $a = null$.

Theorem 6.1. *Algorithm 3 computes $x + y$ in $O(|x| + |y|)$ time, where x and y are both sets of incomparable df-pairs sorted in natural order.*

Proof. We prove that the set of *df*-pairs, z, accumulates incomparable *df*-pairs in natural order. Observe that *df*-pairs lower in merit order are

Algorithm 3 Add two sets of *df*-pairs

1: $z \leftarrow \{\}$
2: $a \Leftarrow x$, $b \Leftarrow y$
3: **while** $(a \neq null)$ and $(b \neq null)$ **do**
4:     **if** a and b are incomparable **then**
5:         **if** $a <_n b$ **then**
6:             Append a to z, $a \Leftarrow x$
7:         **else**
8:             Append b to z, $b \Leftarrow x$
9:     **else if** $a >_m b$ **then**
10:         $b \Leftarrow y$
11:     **else if** $b >_m a$ **then**
12:         $a \Leftarrow x$
13:     **else** /* $a = b$ */
14:         Append a to z, $a \Leftarrow x$, $b \Leftarrow y$
15: **if** $a \neq null$ **then**
16:     Append a to z, Append x to z (if $x \neq \{\}$)
17: **if** $b \neq null$ **then**
18:     Append b to z, Append y to z (if $y \neq \{\}$)

discarded at lines 10 and 12. We discard *df*-pairs until a and b are incomparable or $a = b$, at which point we append one *df*-pair to z (at lines 6 or 8 or 14). This ensures that all resulting *df*-pairs in z are incomparable. When appending a *df*-pair to z we ensure that the smaller *df*-pair (in natural order) is appended (line 5). This ensures that all *df*-pairs in z are sorted in natural order. $O(|x| + |y|)$ is obvious since at least one of x or y becomes shorter in each iteration. □

Now we define the $\cdot$ operation on sets of incomparable *df*-pairs. Let x and y be sets of incomparable *df*-pairs, sorted in natural order. Let $z = x \cdot y$, where z can be computed as follows: Let $x \times y = \{a \cdot b | a \in x \wedge b \in y\}$. From $x \times y$, we extract all incomparable *df*-pairs. If duplicate *df*-pairs exist in the extracted set, we keep one and discard the rest. Then z is the resulting set sorted in natural order. A straightforward method to compute $x \cdot y$ would take $O(|x| * |y|)$ time. We can reduce the time complexity to $O(|x| + |y|)$ with Algorithm 4.

Theorem 6.2. *Algorithm 4 computes $x \cdot y$ in $O(|x| + |y|)$ time, where x and y are both sets of incomparable df-pairs sorted in natural order.*

Proof. Suppose we have some accumulation of incomparable *df*-pairs in natural order. If $a.f < b.f$, a can no longer combine with remaining *df*-pairs in y to generate an incomparable *df*-pair, hence a is discarded (line

---

Algorithm 4 Multiply two sets of df-pairs

1: $z \leftarrow \{\}$
2: $a \Leftarrow x$, $b \Leftarrow y$
3: **while** $(a \neq null)$ and $(b \neq null)$ **do**
4:     Append $a \cdot b$ to z
5:     **if** $a.f < b.f$ **then**
6:         $a \Leftarrow x$
7:     **else if** $b.f < a.f$ **then**
8:         $b \Leftarrow y$
9:     **else**
10:         $a \Leftarrow x$, $b \Leftarrow y$

---

6). Similar reasoning applies to the case of $a.f > b.f$. If $a.f = b.f$, both are discarded. $\qquad\square$

Now let us extend the distance/flow semi-ring to matrices. Let M be the set of all possible n-by-n matrices where each element of the matrix is a set of incomparable df-pairs sorted in natural order. Then the zero matrix, O, has $\{(\infty, 0)\}$ as all its elements. The unit matrix, I, is defined as the matrix with $\{(0, \infty)\}$ for the diagonals and $\{(\infty, 0)\}$ for all other elements. The multiplication and addition of these matrices are defined in the usual way using operations $+$ and $\cdot$, respectively, as defined earlier. Obviously $(M, +, \cdot, O, I)$ forms a closed semi-ring.

7 The SP-AF problem

Suppose there exists multiple parallel paths of varying distances and bottlenecks from a source vertex to a destination vertex. We may only be able to push a small amount of flow through a shorter path because the path may have a relatively small bottleneck value. A longer path may support a bigger flow. Clearly it is useful to determine all shortest paths for varying flow amounts. Let t be the number of distinct edge capacities. $t = m$ if all edge capacities are distinct. We refer to the distinct edge capacities as *maximal flows*. Then the Shortest Paths for All Flows (SP-AF) problem is to compute the shortest paths for all maximal flow values for pairs of vertices.

Using the distance/flow semi-ring as defined in Section 6, we can provide a formal definition for the SP-AF problem as the problem of computing all incomparable df-pairs for pairs of vertices, preferably sorted in natural order. Then each df-pair corresponds to a path between the vertices. The All Pairs Shortest Paths for All Flows (APSP-AF) problem is to solve the SP-AF problem for all possible pairs of vertices on the graph.

We define the n-by-n matrix $A = \{a_{ij}\}$ by $a_{ij} = (cost(i,j), cap(i,j))$, for all vertex pairs (i,j) in $V \times V$. Then the closure $A^* = I + A + A^2 + ... = I + A + A^2 + ... + A^{n-1}$ is the solution to the APSP-AF problem. If we perform repeated squaring on $(I + A)$, we can compute A^* in $O(tn^3 \log n)$ time. We can solve the APSP-AF problem in $O(tn^3)$ time by generalizing the well known APSP algorithm by (Floyd, 1962), as shown in Algorithm 5.

Algorithm 5 Solve the APSP-AF problem

1: A = A + I
2: **for** $k = 1$ to n **do**
3:     **for** $i = 1$ to n; $j = 1$ to n **do**
4:         $a_{ij} = a_{ij} + a_{ik} \cdot a_{kj}$

Theorem 7.1. *Algorithm 5 computes the closure A^* in $O(tn^3)$ time.*

Proof. The time is obvious as line 4 takes $O(t)$ time. Correctness proof follows. We prove that the best incomparable df-tuples are obtained from paths that go though vertices $1, 2, ..., k-1$ at the beginning of the kth iteration. The basis is $k = 1$. A is initialized by $A + I$, which means $a_{ii} = \{(\infty, 0)\}$, and $a_{ij} = (cost(i,j), cap(i,j))$ for $i \neq j$. Suppose the hypothesis is correct for k. Then at line 4, the best tuple without going through k and going through k are merged and the best df-pairs are chosen. □

8 Concluding remarks

We showed an asymptotic improvement on the time complexity of the 1-center GC problem. The center under the average distance measure is to minimize $\Delta = \min_{i=1}^{n} \sum_{j=1}^{n} d_{ij}^*$. Our algorithm can also be applied for this variation of the GC problem. Using a similar approach, we also improved the asymptotic time complexity of the GB problem. The key to our achievement was circumventing the computation of APSP and APBP, for the problems of GC and GB, respectively, with a clever use of the simple binary search method.

We then combined the SP problem and the BP problem to introduce the new SP-AF problem, where the distance/flow semi-ring plays an important role. We showed that it is straightforward to generalize the APSP algorithm to solve the APSP-AF problem using the sets of incomparable df-pairs. Improvements in time complexities for the SP-AF problems, such as the single source problem, will be on the research agenda for the future.

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Resource Efficiency in Veneer Production: Optimization of a Complex Cutting Problem

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Abstract

In the veneer cutting industry trunks are peeled into thin veneer strips which are cut into fitting pieces, glued together and pressed into bentwood pieces for seats, backrests, etc. In this work, a model for optimizing the inherent cutting problem with respect to resource efficiency is presented. Especially the inhomogeneous quality of the wood renders existing models for classic cutting stock problems useless and calls for a new modeling approach. By means of the model presented in this paper, the problem is solved to optimality for real-world instances in reasonable times and generates applicable solutions.

Keywords

Optimization, cutting stock, heterogeneous material, IP formulation

1   Introduction

The problem considered in this work is an application from the veneer cutting industry. Here, trunks are peeled into thin veneer strips which are cut into fitting pieces, glued together and pressed into bentwood pieces for seats, backrests, armrests, chair legs, etc. The production process of these veneers is to be optimized with respect to a minimal cutoff of the used wood.

Currently, the production process is planned manually. On the one hand, this enables the planner to utilize his experience and certain rules of thumb, especially with respect to the wood quality, which is an important aspect of the problem. On the other hand, with an increasing number of orders the problem becomes hardly comprehensible and understandable and consequently, optimization tools have the potential to increase the quality of the production process significantly, especially with respect to

long term planning periods. We develop a model for the problem at hand that both computes an optimal solution in reasonable time and incorporates all restrictions and specifics of the productions process.

1.1 Outline

The rest of this paper is organized as follows. In the remaining part of this section, the problem is presented explicitly and classified with respect to cutting stock problems. In Section 2, the real-world cutting problem is modeled. In Section 3, instances with practical relevance are tested and the results are presented. Finally, in Section 4, we summarize our results and point out further work.

1.2 The Cutting Problem

In the following, the cutting problem is described in more detail. The manufacturer receives N orders $\{1, \dots, N\}$ from different customers. Each order i is characterized by length l_i, width w_i, thickness t_i and quality q_i of the requested veneer pieces. Length, width and thickness are given in millimeters, the quality ranges from very bad (quality 10) to very good (quality 1). For the quality, certain wood characteristics such as wood color, vain or knotholes are taken into account. Furthermore, each order is specified by the number of required pieces n_i and a deadline d_i. The main goal of the manufacturer is to find cutting patterns for each day that fulfill all orders with deadline at this day and minimize the cutoff of the used wood. Further objectives are described in Section 2.2.

For a better understanding of the problem and the notion of a cutting pattern, the production process is described in the following. As a first step, depending on the orders, the trunks are cut to lengths and the bark is removed. Subsequently, the trunk is peeled into a thin veneer strip which is then cut down to the required veneer pieces. In this phase, only vertical cuts, i.e. in the width dimension, can be made. Consequently, the length of the pieces cannot be changed. If necessary, the length is manually cut to size in an additional working step. In order to plan the production process, it has to be decided which trunk lengths are used and how the veneer strips are cut down to pieces, both in the width and the length dimension. Each length corresponds to a cutting scheme and due to certain characteristics of the production process, the number of different cutting schemes per day is limited to $C_{\max}$. Furthermore, there is a limit of $p_{\max}$ on the amount of wood that can be processed at each day.

The difficulty of the problem is increased by two further aspects. First of all, the quality of the wood is uncertain. Before the trunk is peeled into a thin veneer strip, the distribution of the different qualities can only be estimated. Different approaches to deal with this uncertainty

are conceivable, such as robust (see for example Ben-Tal et al (2009)) or online optimization (see for example Borodin & El-Yaniv (1998)) . As these are rather theoretical concepts and in this work the optimization of the real-world cutting problem has priority, a known probability distribution of the wood quality is assumed. In fact, the manufacturer provided an estimated probability distribution, based on historical values. Furthermore, orders can always be satisfied with veneer pieces of a higher quality than requested. Obviously, satisfying requests with higher qualities than requested is a loss in profit for the manufacturer and is therefore to be minimized.

Secondly, the manufacturer has the possibility to cut down the veneer pieces to the appropriate size manually. For example, there is an order for 100 pieces of length 800 mm and width 350 mm and another order for 200 pieces with length 300 mm and width 390 mm. The manufacturer could schedule to cut 200 pieces of length 800 mm and width 390 mm, and cut down the width from 390 mm to 300 mm for the first order and the length from 800 mm to two pieces with length 300 mm for the second order. Of course, the manual cutting costs additional working time, therefore the number of pieces that are manually cut is limited for each day.

In Table 1, three exemplary orders and an appropriate cutting pattern are given. Note that, due to the distribution of the wood quality in the

Table 1: Oders and Cutting Pattern for Length 800 mm

	order					cutting pattern				
order	l_i	w_i	t_i	q_i	n_i	l_i	w_i	t_i	q_i	n_i
1	400	390	1.5	2	50	800	390	1.5	1,2	25
2	400	470	1.5	4	200	800	470	1.5	3,4	100
3	800	490	1.1	5	200	800	490	1.1	5	200
						800	450	1.1	>5	400

trunk, certain amounts of each quality have to be used. Therefore, there is an additional line in the cutting pattern, covering all qualities worse than five. Furthermore, qualities one and two are used for order one, as well as qualities three and four are used for order two. Finally, orders one and two are cut with length 800 mm and then cut down manually to 400 mm. Therefore, only half the number of pieces of orders one and two is needed.

This example is supposed to give a brief glimpse of the planning problem of the manufacturer. The real-world problem is comprised of several hundreds of available orders with up to 50 different lengths and widths, 4 thicknesses and 10 qualities.

1.3 Classification of the Cutting Problem

The problem presented in this work is basically a cutting stock problem. The ordered veneer pieces (the small items) are characterized by length and width, leading to a two-dimensional problem. Furthermore, all small items have to be assigned to a selection of large objects, i.e. the tree trunks of different lengths. The thickness of the veneer strip is also a characteristic of the large objects. Finally, there are several different large objects and many small items of many different figures. Therefore, according to Dyckhoff's typology for cutting and packing problems Dyckhoff (1990), the problem is classified as 2/V/D/M. But, in addition, we have to deal with inhomogeneous large items, i.e. each large item consists of different qualities, deadlines, adding a temporal dimension to the problem, and certain production restrictions.

According to the classification of cutting and packing problems by Wascher (2007) we are faced with a two-dimensional input minimization problem where all small items (strongly heterogeneous) have to be accommodated by several large objects for which one dimension is considered as a variable, resulting in an open dimension problem. Essentially, it is a two-dimensional strip packing problem. Still, we have to deal with the aforementioned additional aspects of the problem, making it significantly more difficult. To the best of our knowledge, the cutting problem as described above is not discussed in the literature. The basic cutting stock problem on a strip, which is the core of our problem, is for example considered by Benati (1997) and Zhiping et al (1997).

2 Modeling of the Cutting Problem

Consider N orders $\{1, \ldots, N\}$ characterized by length l_i, width w_i, thickness t_i, quality q_i, the number of required pieces n_i and a deadline d_i. Now, the goal is to determine cutting patterns for the next n^d days, starting from day d', minimizing the cutoff. We assume that all orders i are due at day d' or later, i.e., $d_i \geq d'$. Furthermore, the deadline of all orders with deadline later than day $d'+n^d$ will be set to day $d'+n^d$. The primary goal is to satisfy all orders i with deadline $d_i < d' + n^d$ before their deadline. All other orders with deadline $d_i = d' + n^d$ can be used to minimize the cutoff and to increase the workload of the production.

The sets of all lengths L, widths W, thicknesses T, qualities Q and relevant days D are given by

$$L = \bigcup_{i=1}^{N} l_i \ , W = \bigcup_{i=1}^{N} w_i \ , T = \bigcup_{i=1}^{N} t_i \ , Q = \bigcup_{i=1}^{N} q_i \ \text{ and } D = \bigcup_{i=1}^{N} d_i.$$

Furthermore, the last day, i.e. $d'+n^d$, is not to be planned, so we define

the set of working days D^w as $D^w = D \setminus \{d' + n^d\}$.

2.1 Variables and Constraints

First of all, binary variables

$$z_{l,w,t,q,d^1,d^2} \in \{0,1\} \quad \text{for all } l \in L,\ w \in W,\ t \in T,\ q \in Q,$$
$$d^1, d^2 \in D^w,\ d^2 \geq d^1,$$

representing the fulfillment of orders are introduced. If z_{l,w,t,q,d^1,d^2} equals one, order i with $l_i = l$, $w_i = w$, $t_i = t$, $q_i = q$, $d_i = d^1$ is accomplished on day d^2. For $d^2 = d^1$, the order is fulfilled before or at the deadline, for $d^2 > d^1$ the order is fulfilled after the deadline. We require each order to be fulfilled at most once, i.e., for all $l \in L$, $w \in W$, $t \in T$, $q \in Q$ and $d^1 \in D^w$ we have

$$\sum_{d^2 \geq d^1} z_{l,w,t,q,d^1,d^2} \leq 1. \tag{1}$$

If an order is not accomplished at all or after its deadline, corresponding penalty terms are added to the objective function as described in Section 2.2. It is chosen to model the fulfillment of orders as soft constraints in order to be able to optimize sets of orders that are not all compliable within their deadlines simply due to limits in the production capacity.

Further, we introduce variables

$$x_{l,w,t,q,d} \in \mathbb{R} \quad \text{for all } l \in L,\ ,w \in W,\ t \in T,\ q \in Q,\ d \in D^w,$$

representing the number of new veneer pieces with length l, width w, thickness t and quality q produced on day d without an additional manual cutting step.

For the modeling of the variables $x_{l,w,t,q,d}$, the probability distribution of the wood quality is required. Denote by $p_{l,q,t}$ the probability of quality q with respect to length l and thickness t. Note that the distribution depends on the length and the thickness. The manufacturer provided us with the necessary estimates for the distributions. Now, we introduce the variables

$$y_{l,t,d} \in \mathbb{R} \quad \text{for all } l \in L,\ t \in T,\ d \in D^w,$$

representing the total width cut from length l with thickness t on day d and model the new pieces $x_{l,w,t,q,d}$ by

$$\sum_{w \in W} w \cdot x_{l,w,t,q,d} \leq y_{l,t,d} \cdot p_{l,q,t}. \tag{2}$$

The new pieces $x_{l,w,t,q,d}$ are either correctly sized and in the right quality or will manually be cut down or used for an order with lower quality, respectively. In order to model this situation we introduce transformation variables

$$\tau^{l^2,q^2}_{l^1,q^1,w,t,d} \in \mathbb{R} \quad \text{for all } l^1, l^2 \in L,\, q^1, q^2 \in Q,\, w \in W,\, t \in T,$$
$$d \in D^w,\, l^1 \geq l^2,\, q^1 \leq q^2,$$

for the number of pieces that are manually cut down from length l^1 to length l^2 with $l^2 \leq l^1$ or used for a request of lower quality, i.e., $q^1 \leq q^2$. On the first day d', the newly cut pieces $x_{l,w,t,q,d}$ are distributed among all possible transfer variables, i.e., for all $l^1 \in L$, $w \in W$, $t \in T$ and $q^1 \in Q$, we have

$$\sum_{l^2 \in L, q^2 \in Q} \tau^{l^2,q^2}_{l^1,q^1,w,t,d'} = x_{l^1,w,t,q^1,d'}. \tag{3}$$

Imagine stacks for each configuration (length, width, thickness, quality) from which the orders have to be satisfied. The stacks change over time since new pieces are produced and added to the corresponding stack and some pieces are manually cut down and therefore change their stack (see also Figure 1). The transfer variables model this *stack-transfer-concept* which is the basis for a compact model for our complex problem.
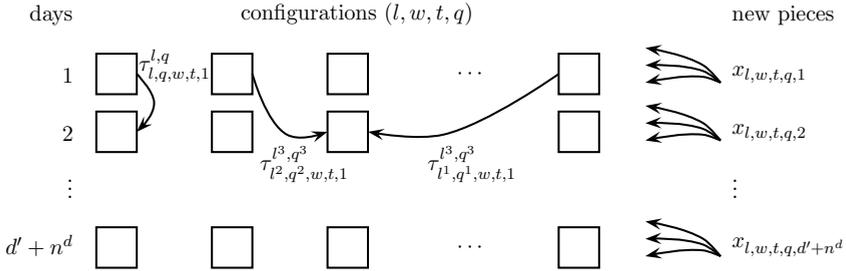
Figure 1: Stack-Transfer-Concept

On the following days, the stack for a certain configuration (the left hand side of constraints (4)) is composed of the stack for that configuration of the previous day and the newly produced pieces for that configuration reduced by the satisfied orders (the right hand side of constraints (4)), i.e., for all $l^1 \in L$, $w \in W$, $t \in T$ and $q^1 \in Q$, we have

$$\sum_{l^2 \in L, q^2 \in Q} \tau^{l^2,q^2}_{l^1,q^1,w,t,d} = \sum_{l^2 \in L, q^2 \in Q} \tau^{l^1,q^1}_{l^2,q^2,w,t,d-1} \cdot \left\lfloor \frac{l^2}{l^1} \right\rfloor \tag{4}$$
$$- \sum_{i \in I} n_i \cdot z_{l,w,s,q,d_i,d-1} + x_{l,w,t,q,d},$$

where

$$I = \{i \in \{1, \dots, N\} \mid l_i = l, \ w_i = w, \ t_i = t, \ q_i = q, \ d_i < d - 1\}.$$

On the last production day, i.e., $d' + n^d - 1$, we have to make sure that all produced pieces can be assigned to any of the regular orders or orders with deadlines set to $d' + n^d$:

$$\sum_{l^2 \in L, q^2 \in Q} \tau^{l^1, q^1}_{l^2, q^2, w, t, d' + n^d - 1} \cdot \left\lfloor \frac{l^2}{l^1} \right\rfloor \tag{5}$$

$$- \sum_{i \in I} n_i \cdot z_{l, w, s, q, d_i, d' + n^d - 1} \leq n_i + o_{l, w, t, q},$$

where the variable $o_{l, w, t, q} \in \mathbb{R}$ for all $l \in L$, $w \in W$, $t \in T$, $q \in Q$, represents the overproduction of the configuration l, w, t, q. This variable is needed for the penalization of the overproduction in the objective function, see Section 2.2.

Finally, we make sure that all orders are fulfilled by the binary variables z_{l, w, t, q, d^1, d^2}. The stack for a certain configuration on some day d^2 has to be large enough in order to fulfill the order for that configuration, otherwise the variable z_{l, w, t, q, d^1, d^2} has to be set to zero:

$$\sum_{l^2 \in L, q^2 \in Q} \tau^{l^1, q^1}_{l^2, q^2, w, t, d} \cdot \left\lfloor \frac{l^2}{l^1} \right\rfloor \geq \sum_{i \in I} n_i \cdot z_{l, w, s, q, d_i, d}. \tag{6}$$

If z_{l, w, t, q, d^1, d^2} is set to zero, a penalty is included in the objective function, see Section 2.2.

Furthermore, certain restrictions with respect to the production capacity have to be considered. On each day, at most $p_{\max}$ cubic meters may be processed and the manufacturer aims for a production at full capacity. Consequently, we introduce the variable $g_d \in \mathbb{R}$ for all $d \in D^w$ for the gap between the actual production and the capacity and have, for all $d \in D^w$,

$$g_d + \sum_{l \in L, t \in T} y_{l, t, d} \cdot l \cdot t = p_{\max}. \tag{7}$$

In order to ensure a minimal production $p_{\min}$ at each day, we have, for all $d \in D^w$,

$$g_d \leq p_{\max} - p_{\min}. \tag{8}$$

Additionally, on each day $d \in D^w$ the number of used lengths, i.e., the number of cutting patterns, is limited by $C_{\max}$. In order to model this situation, we introduce binary variables $c_{l, d} \in \{0, 1\}$ for all $l \in L$, $d \in$

D^w, taking value one if length l is cut on day d, and zero otherwise. For all $l \in L$, $d \in D^w$, we model $c_{l,d}$ by

$$\sum_{t \in T} y_{l,t,d} \leq c_{l,d} \cdot M, \tag{9}$$

where M is given by $M = p_{\max}/\left(\min_{l \in L} l \cdot \min_{t \in T} t\right)$, i.e., the maximum width cut for length l, and restrict the number of cutting patterns for each day $d \in D^w$ by

$$\sum_{l \in L} c_{l,d} \leq C_{\max}. \tag{10}$$

It remains to bound the number of manually cut down pieces by $\mathcal{T}_{\max}$ in order to comply with the production capacity. Define

$$\widetilde{L} := \left\{ \left(l^1 \in L, w \in W, t \in T, q^1 \in Q, l^2 \in L, q^2 \in Q\right) \mid l^1 \neq l^2\right\}.$$

Then, for all $d \in D^w$, we require

$$\sum_{\widetilde{L}} \left(\tau_{l^1,w,t,q^1,d}^{l^2,q^2} \cdot \left\lceil \frac{l^1}{l^2} \right\rceil - 1 \right) \leq \mathcal{T}_{\max}. \tag{11}$$

By the constraints described in this section the main aspects of the cutting problem are modeled. Note that the real-world problem is complicated by even more conditions, such as the integration of a warehouse that allows to cut beyond the number of ordered pieces, or the requirement of a minimum length in the first cutting phase, such that certain orders have to be cut down manually. But these additional conditions would exceed the limitations of this work. However, the computational results in Section 3 are with respect to the full real-world problem.

2.2 Objectives

The objective for the model is comprised of several aspects such as the minimization of (a) the cutoff c_1, (b) delayed or unfulfilled orders c_2, (c) the use of high quality pieces for lower quality orders c_3, and (d) the number of manually cut down pieces c_4. In the following, we will describe aspects (a) and (b) in more detail. First of all the cutoff of the used wood is to be minimized. The total cutoff c_1 is given by the total amount of processed wood minus the fulfilled orders

$$\sum_{l,t,d} y_{l,t,d} \cdot l \cdot s - \sum_{\substack{i \in \{1,\ldots,N\} \\ \text{s.t. } d_i \in D^w}} \left(n_i \cdot l \cdot w \cdot t \cdot \sum_{d^2 \geq d_i} z_{l,w,t,q,d_i,d^2} \right)$$

minus the veneer pieces that are cut at the last production day for orders with deadline $d' + n^d$

$$\sum_{l^1,w,t,q^1} \left(\sum_{l^2,q^2} \left(\tau^{l^1,q^1}_{l^2,w,t,q^2,d'+n^d-1} \cdot \left\lfloor \frac{l^2}{l^1} \right\rfloor \right) \right.$$

$$\left. - \sum_{i \in I_1} n_i \cdot z_{l^1,w,t,q^1,d_i,d'+n^d-1} \right) \cdot l \cdot w \cdot t,$$

where

$$I_1 = \{i \in \{1,\ldots,N\} \mid l_i = l^1, \ w_i = w, \ t_i = t,$$
$$q_i = q^1, \ d_i \le d' + n^d - 1\},$$

plus the total overproduction $\sum_{l,w,t,q} o_{l,w,t,q} \cdot l \cdot w \cdot s$.

Secondly, we want to minimize delayed or unfulfilled orders. A delayed order is penalized proportional to the number of days the order is late, and, if the order is not fulfilled at all during the planned period, the penalty is $n^d + 1$. Thus, c_2 is given by

$$\sum_{\substack{i \in \{1,\ldots,N\} \\ \text{s.t. } d_i \in D^w}} \left(\sum_{d^2 > d_i} \left((d^2 - d_i) \cdot z_{l,w,t,q,d_i,d^2} \right) \right.$$

$$\left. + (n^d + 1) \cdot \left(1 - \sum_{\substack{d^2 \in D^w \\ \text{s.t. } d^2 \ge d_i}} z_{l,w,t,q,d_i,d^2} \right) \right).$$

The objective function is then given by

$$\min \sum_{i=1}^{4} \omega_i \cdot c_i,$$

where the weighs ω_i, $i = 1,\ldots,4$ are chosen with respect to the preferences of the manufacturer. In interaction with constraints (1)-(11), the mixed integer programming formulation for the cutting problem described in this paper is given.

3 Computational Results

The model for the cutting problem presented in Section 2 is implemented with FICO Xpress Mosel Version 3.4.0 and solved with the FICO Express

Optimizer Version 23.01.05. The model is tested on real-world instances. For example, a generic instance consists of 466 orders leading to 47 lengths, 37 widths, 4 thicknesses and 9 qualities. For a single day, the model was solved to optimality in 146 seconds. Note that in the case of a single day still all available orders are considered, but only for the first day cutting patterns are generated. For two days, the model is solved to optimality in 314 seconds and for three days in 635 seconds. In practice it is not reasonable to plan ahead more than at most three days, due to eventually necessary adjustments due to the uncertainty in the wood quality. However, for 6 days the model is solved to optimality in 4881 seconds.

The optimization model fulfills all production requirements and is still able to puzzle cutting patterns together that consider orders from the whole order set. This leads to an improvement over the manual planning for which the set of considered orders is limited to a certain extend. Due to a lack of data, a direct comparison of generated solutions to the manual process is not possible. Still, the generated solutions feature approximately 10 % cutoff, whereas, according to the manufacturer, the manual production process exhibits about 20 % cutoff.

4   Conclusion and Further Work

In this work, a mixed integer programming model for a complex cutting problem from the veneer production is presented. The way of modeling allows for solving the real-world problem to optimality with respect to certain resource efficiency measures and and generates applicable solutions in reasonable time. Furthermore, the solution approach facilitates the optimization of large planning periods, which are hardly comprehensible and manually not manageable.

The uncertainties in the wood quality are treated with the help of estimated probability distributions. In this work, we abstained from the application of uncertainty concepts, due to the sheer difficulty of the problem. For an application of robust multi-objective optimization to a simplified version of this problem we refer to Ide & Tiedemann (2013). It could also be interesting to apply further uncertainty concepts, such as stochastic or online optimization.

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An Application of Minmax Robust Efficiency in the Wood Processing Industry

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Abstract

Robust optimization is an important tool to deal with uncertainties in the formulation of mathematical optimization models. Different concepts of robustness have been provided in the literature, one of which is the concept of minmax robust efficiency for uncertain multi-objective optimization problems. In this paper we apply the concept of minmax robust efficiency to a problem found in the wood processing industry. We repeat the concept of minmax robust efficiency, present the application problem and discuss the uncertainty in the problem formulation. We then apply the concept of minmax robust efficiency to this uncertain multi-objective formulation and calculate robust efficient solutions. We conclude the paper with the discussion of the benefit of these solutions.

Keywords

Multi-objective optimization, robustness, uncertainty, application, modeling

1 Introduction

In real-world applications of optimization, the best solution is not always helpful if disturbances or other changes to the input data occur. Such changes in fact occur frequently and can result in non-optimality or even infeasibility of the optimal solution.

For instance, in forestry, the quality of the used wood is subject to fluctuations which cannot be determined beforehand. Often it is only possible to determine the quality during the production process itself, which makes it necessary to take these uncertainties into account already during the planning of the production process.

Different approaches to deal with uncertain input data are commonly known throughout the literature, such as stochastic optimization (for an overview see e.g. (Birge & Louveaux, 2011)). The approach we follow in this paper is robust optimization. The aim of robust optimization is to find solutions which remain feasible and of good quality in all scenarios. A scenario in this context is a realization of the uncertain input data.

For single-objective optimization problems several definitions of robustness, i.e., when a solution is seen as robust against such uncertainties, have been analyzed thoroughly, see for instance (Ben-Tal, et al., 2009; Kouvelis & Yu, 1997). One of these concepts is the concept of minmax robustness, introduced in (Soyster, 1973) and intensively researched in (Ben-Tal, et al., 2009). Here a solution is called robust if it is feasible for every scenario and minimizes the objective function in the worst case.

In application of mathematical optimization and especially in the application we present in this paper, there is often more than just one objective to consider. Several definitions of robustness for multi-objective optimization have been presented in the literature, see for instance (Branke, 1998; Deb & Gupta, 2006).

In this paper we follow the concept of minmax robustness which has been extended to the concept of minmax robust efficiency for multi-objective optimization problems in (Ehrgott, et al., 2013). We apply this concept to a real-world problem in the veneer cutting industry.

The structure of the paper is the following: After clarifying the notation (Section 1.1) and repeating the concept of minmax robust efficiency (Section 1.2), we introduce the application problem and present the optimization model in Section 2. In Section 3 we then apply the concept of minmax robust efficiency and discuss the value of the minmax robust efficient solutions in practice.

1.1   Notation

First of all we need to define an uncertain multi-objective optimization problem.

Here, our assumption is that the uncertain data contaminating the problem structure is given by an *uncertainty set $\mathcal{U} \in \mathbb{R}^m$*, thus a set of scenarios $\xi \in \mathcal{U}$ representing the various possible realizations of the uncertain data. To define this uncertainty set $\mathcal{U}$ is a crucial step in formulating the model as we will see in Section 2.

Now, for every possible realization of the uncertain parameters, we obtain a single (deterministic) multi-objective optimization problem $\mathcal{P}(\xi)$, $\xi \in \mathcal{U}$ which we denote in the following way:

Notation 1.1. *Given a set of feasible solutions $\mathcal{X} \in \mathbb{R}^n$, a vector-valued objective function $f : \mathcal{X} \times \mathcal{U} \mapsto \mathbb{R}^k$, an uncertainty set $\mathcal{U}$, and a scenario*

ξ ∈ U, we denote the multi-objective optimization problem of minimizing $f(x, ξ)$ *over* $\mathcal{X}$ *by*

$$\mathcal{P}(ξ) \quad \min f(x, ξ)$$
$$s.t. \quad x \in \mathcal{X}.$$

Note that, due to the lack of a total order on $\mathbb{R}^k$, the minimization of a vector-valued objective function is dependent on the definition of dominance. In this paper we stick to the definition which goes back to (Pareto, 1896) and has been extensively studied throughout the literature. For an overview see (Ehrgott, 2005). Here a solution $x \in \mathcal{X}$ is said to be *efficient*, if there does not exist an $\overline{x} \in \mathcal{X}$ such that $f(\overline{x})$ is at least as good as $f(x)$ in every component and better in at least one component. x is said to be *weakly efficient* if there is no $\overline{x} \in \mathcal{X}$ such that $f(\overline{x})$ is better than $f(x)$ in every component and *strictly efficient* if there is no $\overline{x} \in \mathcal{X}$, $\overline{x} \neq x$ such that $f(\overline{x})$ is at least as good as $f(x)$ in every component.

The solution to a multi-objective minimization problem is the so-called *Pareto-Front*, i.e., the set of all (strictly/weakly) efficient solutions.

With Notation 1.1 we can now define an uncertain multi-objective optimization problem $\mathcal{P}(\mathcal{U})$:

Definition 1.2 (Uncertain multi-objective optimization problem). *Given a set of feasible solutions* $\mathcal{X} \in \mathbb{R}^n$, *a vector-valued objective function* $f : \mathcal{X} \times \mathcal{U} \mapsto \mathbb{R}^k$, *and an uncertainty set* $\mathcal{U}$, *an uncertain optimization problem* $\mathcal{P}(\mathcal{U})$ *is defined as the family of optimization problems* $(\mathcal{P}(ξ), ξ \in \mathcal{U})$.

1.2 Minmax Robust Efficiency

After defining an uncertain multi-objective optimization problem, we need a definition of what is called a "good" solution to $\mathcal{P}(\mathcal{U})$. As $\mathcal{P}(\mathcal{U})$ in fact is a family of multi-objective optimization problems, this interpretation of what is called "good" is not trivial.

The interpretation we use throughout the paper is an extension of the concept of minmax robustness, originally introduced in (Soyster, 1973) and extensively studied in (Ben-Tal, et al., 2009). This concept was originally designed for single-objective functions and has later been extended to multi-objective optimization problems in (Ehrgott, et al., 2013). Here, the following definition is presented:

Definition 1.3 (Minmax Robust Efficiency). *Given an uncertain multi-objective optimization problem* $\mathcal{P}(\mathcal{U})$, *for every* $x \in \mathcal{X}$ *we define* $f_{\mathcal{U}}(x) := \{f(x, ξ) : ξ \in \mathcal{U}\}$. *A solution* $x \in \mathcal{X}$ *is called* **minmax robust efficient** *if there is no* $\overline{x} \in \mathcal{X}$ *such that*

$$f_{\mathcal{U}}(\overline{x}) \subseteq f_{\mathcal{U}}(x) - \mathbb{R}^k_{\geq}.$$

Here $\mathbb{R}^k_{\geq}$ is the (open) positive orthant of $\mathbb{R}^k$, containing the 0.

Several algorithms for calculating minmax robust efficient solutions have been provided in (Ehrgott, et al., 2013).

2 Problem formulation

After introducing the notation we now present the optimization problem we will later on apply the concept of minmax robust efficiency to.

2.1 Problem description

The problem considered is a real-world application from a partner in the veneer production industry. The production process is the following: The tree trunks are cut into different lengths and the resulting trunk-pieces are peeled into thin veneer strips (average thickness around 1.5 mm). These veneer strips then are optically tested for quality, cut into veneers of various sizes, afterwards dried, glued together, and pressed into bentwood pieces for seats, backrests for chairs, etc..

Now, the process of choosing the length of the tree trunks and cutting the veneer strips into veneers is to be optimized with respect to a minimal cutoff of the used wood and a minimal loss of wood of high quality which occurs if either the wood is not used at all or used to satisfy demands of lower quality. A detailed (single-objective) formulation of the problem can be found in (Ide & Tiedemann, 2013). Since the aspect of uncertainty adds a lot of complexity to the problem, we use a simplified formulation of the problem. The simplified problem can be stated as follows:

Let orders $1, \ldots, N$ be given, each defined by length l_i, quality q_i and number of items n_i. For simplification of the program width and thickness of the items are considered standardized. For instance an order i could be 400 items of length 960 mm in quality 4 (the qualities are given in classes from 1 to 10, 1 being the best quality). The veneer cutting machine strips the wood directly from the tree trunk which has been sized beforehand to a certain length.

Now, the output of the optimization program is a composition of orders into schedules which the machine can use later on. A schedule is defined by a length $l \in \mathcal{L} := \cup_{i \in \{1, \ldots, N\}} l_i$, and a set of orders $\mathcal{I}$ with $l_i \leq l$ for all $i \in \mathcal{I}$. The cutting machine then will peel veneer strips from the tree trunks until the schedule is finished and every order is satisfied. During the cutting process it can determine the quality of the veneer strip and accordingly satisfy the different orders.

Thus, the machine "sees" the whole veneer strip, determines the quality distribution in the veneer strip and partitions the strip into the

different orders. Even though a (very good) heuristic is used in practice for the last step we assume the machine to solve this partition problem optimally.

Briefly said, the process is the following: A schedule is prepared, the machine uncovers the quality distribution of the veneer strip, chooses the length of the tree trunk and the width of the veneer strip and partitions this strip into pieces which are automatically assigned to the orders. All wood which is not used to satisfy an order will count as cutoff and will therefore contribute a penalty to the objective function. Furthermore, the wood of high quality (i.e., qualities 1, 2, and 3) which is not used to satisfy a demand of high quality will give a penalty on the second objective function as this wood is very valuable and should not be "wasted".

2.2 Deterministic formulation

The problem can be formulated in the following way:

Input: A set of orders $\mathcal{I} = \{1, \ldots, N\}$, every order i with length l_i, quality q_i and number of items n_i, $\mathcal{L} := \cup_{i \in \mathcal{I}} l_i$, $\mathcal{Q} := \cup_{i \in \mathcal{I}} q_i$, and a distribution $p \in \mathbb{R}_{\geq 0}^{10 \times |\mathcal{L}|}$ of the qualities in the veneer strip of length l ($\sum_{q=1}^{10} p_{q,l} = 1$ for every $l \in \mathcal{L}$).

Decision variables: $x \in \mathbb{Z}^{|\mathcal{I}| \times |\mathcal{L}|}$, where $x_{i,l}$ indicates, how many pieces of order i are satisfied by the schedule of length l.

$y \in \mathbb{B}^{|\mathcal{L}|}$, where y_l indicates, whether there is a schedule of length l or not.

Objective functions: In order to follow the formulation of the objective functions, note that the length of the veneer strip the machine will later on produce in order to satisfy the orders assigned to the current schedule can be modeled with an additional decision variable $w \in \mathbb{R}^{|\mathcal{L}|}$, where w_l indicates the width of the veneer strip cut in schedule l (measured in standard units which is the width of one veneer). With the additional constraint

$$\sum_{i \in \mathcal{I}: q_i \leq q} x_{i,l} \leq w_l \cdot \sum_{q' \in \mathcal{Q}: q' \leq q} p_{q',l} \quad \forall\, q \in \mathcal{Q}, l \in \mathcal{L},$$

w_l would be modeled correctly. With this formulation it is clear that

$$w_l = \max_{q \in \mathcal{Q}} \left(\frac{\sum_{i \in \mathcal{I}: q_i \leq q} x_{i,l}}{\sum_{q' \in \mathcal{Q}: q' \leq q} p_{q',l}} \right)$$

for all $l \in \mathcal{L}$. In order to make it more clear that the uncertainty only lies in the objective functions we use the latter equivalent formulation.

Minimize cutoff:

$$f_1(x,p) := \sum_{l \in \mathcal{L}} l \cdot \max_{q \in \mathcal{Q}} \left(\frac{\sum_{i \in \mathcal{I}: q_i \leq q} x_{i,l}}{\sum_{q' \in \mathcal{Q}: q' \leq q} p_{q',l}} \right) - \sum_{i \in \mathcal{I}} l_i \cdot n_i$$

The cutoff lost in the program can be determined by the length of the veneer strip the machine has to peel from the tree in order to get enough wood to satisfy the orders assigned to the current schedule minus all produced veneers.

Minimize lost high quality wood:

$$f_2(x,p) := \sum_{l \in \mathcal{L}} \left(l \cdot \max_{q \in \mathcal{Q}} \left(\frac{\sum_{i \in \mathcal{I}: q_i \leq q} x_{i,l}}{\sum_{q' \in \mathcal{Q}: q' \leq q} p_{q',l}} \right) \cdot \sum_{q \in \{1,2,3\}} p_{q,l} \right)$$
$$- \sum_{i \in \mathcal{I}: q_i \leq 3} l_i \cdot n_i$$

Qualities 1, 2, and 3 are of high value and should not be wasted or used to satisfy orders of lower quality.

Now the composed objective function is

$$\min \begin{pmatrix} f_1(x,p) \\ f_2(x,p) \end{pmatrix}.$$

Note that here p is an input parameter and therefore constant. The following constraints have to be met:

Constraints:

$$\sum_{l \in \mathcal{L}} x_{i,l} = n_i \quad \forall\, i \in \mathcal{I} \tag{1}$$

$$x_{i,l} = 0 \quad \forall\, i \in \mathcal{I}, l < l_i \tag{2}$$

$$\sum_{l \in \mathcal{L}} y_l \leq 2 \tag{3}$$

$$\sum_{i \in \mathcal{I}} x_{i,l} \leq y_l \cdot \sum_{i \in \mathcal{I}} n_i \quad \forall\, l \in \mathcal{L} \tag{4}$$

$$x_{i,l} \in \mathbb{Z}_{\geq} 0 \tag{5}$$

$$y_l \in \mathbb{B} \tag{6}$$

(1) means that all items are produced (where it is possible to cut a veneer from a higher length down to a smaller length). (2) means that produced veneers can only be used on orders, where the length is at most the one produced. (3) limits the number of total schedules. This number usually is limited since changing of the cutting length of the machine is very time consuming. (4) - (6) define the decision space of the variables.

3 Minmax robust efficiency applied to the optimiziation model

Now, after formulating the deterministic optimization problem we apply the concept of minmax robust efficiency. Obviously, to do so we first need to determine the uncertain parameters in the formulation.

3.1 Uncertainties in formulating the problem

The uncertainties in the problem formulation are due to fluctuations of the qualities of the used wood. As the machine only uncovers the true quality of the veneer strip at the moment of production, this quality distribution is unknown at the moment of creating the schedules. In practice this uncertainty is not considered, and, instead of a deterministic formulation, estimated probability distributions obtained by experience would be used as in (Ide & Tiedemann, 2013).

In this paper, we consider the distribution of the qualities to be uncertain, i.e., we work with an uncertainty set $\mathcal{U}_p$ consisting of different scenarios of distribution. With this uncertainty set we formulate the minmax robust version of the deterministic formulation given in Section 2.2.

3.2 Formulating the robust version of the problem

Formulating the robust version of our problem from Section 2.2 now is fairly simple:

Input: Instead of a single distribution p the input is the whole uncertainty set $\mathcal{U}_p$. The rest of the input remains unchanged.

Decision variables: remain unchanged.

Objective functions: We re-formulate the objective function as proposed in (Ehrgott, et al., 2013) in the following way:

$$\min_{} \ \max_{p \in \mathcal{U}} \ \begin{pmatrix} f_1(x,p) \\ f_2(x,p) \end{pmatrix}$$

Constraints: All constraints remain unchanged since they are not affected by the uncertain parameters.

Note that the solutions to this problem we want to obtain are the minmax robust efficient solutions as presented in Section 1.2.

3.3 Modeling the uncertainty set

Modeling the uncertainty set is a crucial point in the formulation of the uncertain multi-objective optimization problem. As the concept of minmax robust efficiency only considers solutions which are feasible in every scenario, the different scenarios have a high impact on the feasible set of the robust version and therefore on the minmax robust efficient solutions. E.g., if one would assume that there is a scenario where a veneer strip only consists of qualities worse than or equal to 3, there would not be any feasible solution to the robust version at all if there is an order of quality 1 or 2.

But also if the set of feasible solutions to the robust version is not empty, with too strict uncertainty sets the robust version can become arbitrarily bad. Thus, one has to be very careful when modeling the uncertainty set.

The uncertainty set we use was developed together with the practice partner providing the application problem using experience values of quality distributions. To mention the uncertainty set itself would exceed the limitations of this paper therefore we give a rough idea of how the quality distributions look like in Figure 1. Here, the quality distribution for length 390 mm is given, meaning that e.g. in Scenario 1 20 percent of the veneer strip will be of quality 5.
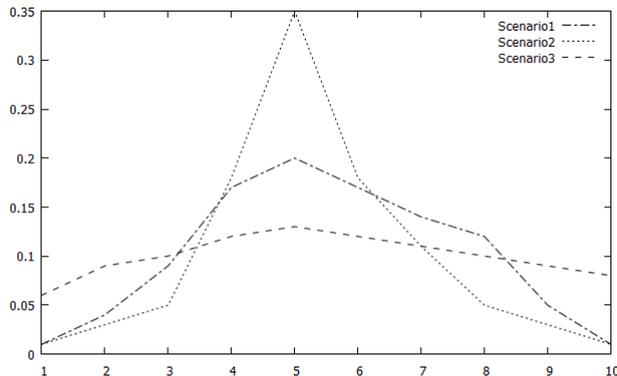
Figure 1: Quality distributions for length 390 mm

3.4 Computational results

Calculating minmax robust efficient solution was done using the weighted-sum-scalarization-method presented in (Ehrgott, et al., 2013). Here, the two objective functions are weighted with a scalar $\lambda \in \mathbb{R}^2_+$ and added and

the worst-case of this sum is to be minimized:

$$\min_{} \max_{p \in \mathcal{U}} \ \left(\lambda_1 \cdot f_1(x,p) + \lambda_2 \cdot f_2(x,p) \right), \qquad (\mathcal{WS}(\lambda))$$

such that x satisfies Constraints (1) - (6) from Section 2.2. This will yield minmax robust efficient solutions as presented in Section 1.2. We compare the results in the following way:

For different weights $\lambda \in \mathbb{R}^2_+$ we calculate a minmax robust efficient solution x^{rob}_λ obtained by optimizing $(\mathcal{WS}(\lambda))$. Furthermore we calculate for every scenario $p \in \mathcal{U}$ an optimal solution x^p_λ to the according deterministic multi-objective optimization problem via the deterministic weighted-sum-scalarization with weight λ. Then for each $p \in \mathcal{U}$ we compare the two objective values

$$\max_{p' \in \mathcal{U}} \ \left(\lambda_1 \cdot f_1(x^{rob}_\lambda, p') + \lambda_2 \cdot f_2(x^{rob}_\lambda, p') \right)$$

(not depending on p) and

$$\max_{p' \in \mathcal{U}} \ \left(\lambda_1 \cdot f_1(x^p_\lambda, p') + \lambda_2 \cdot f_2(x^p_\lambda, p') \right).$$

We chose this comparison strategy for reason: Usually in application one has knowledge about the past and therefore works with the scenario which seems most likely. Since we do not know which scenario is seen as most likely we assume all scenarios to be equally realistic. Therefore, we calculate the optimal solutions to the different scenarios since those are the solutions likely to be used in application.

The data sets used are real-world data provided by our practice partner and involve 59 instances of order sets and a set of 5 different $\lambda \in \mathbb{R}^2_+$. We then calculated the average and the maximum gain of x^{rob}_λ against x^p_λ for all 59 instances. Since the minimal gain is zero for most of the instances, it is omitted.

We obtained the following results for the different weights λ:

Table 1: Gain of x^{rob}_λ against x^p_λ in percentage

λ	$\begin{pmatrix} 1 \\ 0.1 \end{pmatrix}$	$\begin{pmatrix} 1 \\ 0.5 \end{pmatrix}$	$\begin{pmatrix} 1 \\ 1 \end{pmatrix}$	$\begin{pmatrix} 0.5 \\ 1 \end{pmatrix}$	$\begin{pmatrix} 0.1 \\ 1 \end{pmatrix}$
avg gain	1.11	0.79	0.68	0.58	0.37
max gain	35.66	34.31	33.69	32.65	7.94

The results show that on average the gain of using minmax robust efficient solutions does not seem to matter very much. Still, the application is in a high price-range and therefore saving a small percentage of the budget means quite a reasonable gain. More interesting are the results

on the maximal gain. Using a minmax robust efficient solution over an optimal one can lead to a significant gain of around 35 percent.

Furthermore, one of the reasons for the quite low average values is that a lot of the optimal solutions to the different scenarios are also minmax robust efficient solutions themselves. If we neglect those instances for which this is the case and only have a look at the instances for which not all solutions to the different scenarios are also minmax robust efficient, we obtain the following results:

Table 2: Gain of x_λ^{rob} against x_λ^p for revised instances in percentage

λ	$\begin{pmatrix} 1 \\ 0.1 \end{pmatrix}$	$\begin{pmatrix} 1 \\ 0.5 \end{pmatrix}$	$\begin{pmatrix} 1 \\ 1 \end{pmatrix}$	$\begin{pmatrix} 0.5 \\ 1 \end{pmatrix}$	$\begin{pmatrix} 0.1 \\ 1 \end{pmatrix}$
avg gain	5.45	3.87	3.32	2.64	1.45

These results strengthen the concept of minmax robust efficiency as they show that the gain of using minmax robust efficient solutions is quite significant.

4 Conclusion and further work

As we can see in the results, the concept of minmax robust efficiency provides a useful tool when dealing with uncertain multi-objective optimization problems.

The downside of these solutions obviously is that they are only hedging against a worst case and are therefore quite "pessimistic". This issue has been addressed a lot of times in the literature on robust optimization (compare e.g. (Ben-Tal, et al., 2009), (Kouvelis & Yu, 1997)).

Therefore, a next step would be to extend other, more optimistic concepts of robustness to multi-objective optimization. These concepts might also be helpful in the context of this application, even though the practice partner explicitly asked to hedge against a worst case, which is why we chose this concept.

Another next step is to apply this concept also to the (more complicated) model presented in (Ide & Tiedemann, 2013) in order to be able to use the minmax robust efficient solutions also in practice.

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Modeling of Production and Logistic Systems

Eco-Industrial Areas Modeling Proposal

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Abstract

This contribution describes a preliminary analytical model of an industrial area where Industrial Ecology strategies are developed. The formulation of the model is supported on a conceptual framework based on the analysis of eco-industrial areas as complex adaptive systems, which was defined in previous work of the authors. According to the conceptual model requirements, the agent based modeling (ABM) is the technique selected for this proposal. Based on the ABM technique, the different types of agents are defined through their properties and behavioral rules, which govern the relationships among agents and with their environment. The cooperative relationships are studied considering the creation of exchange networks of wastes and byproducts as strategy of industrial symbiosis. Moreover, the environment of the system is defined based on the analysis of the influential factors, and their influence over the system.

Keywords

Industrial areas modeling, industrial symbiosis, agent based model

1   Introduction

Industrial areas degradation and economic crisis are relevant problems for the industrial development, territorial planning and environment. The principles of Industrial Ecology (IE) theory and the strategies of Industrial Symbiosis (IS) are geared to transform the traditional industrial activity towards a more sustainable system (Gibbs & Deutz, 2007; Boons, 2008). The IE theory suggests the development of cooperative relationships among nearby enterprises closing the loops of the linear chains, as resemblance of natural ecosystems (Lambert & Boons, 2002; Graedel & Allenby, 2003). This transformation towards eco-industrial systems aims to get

more efficient systems and endure its operation. The strategies of IS promotes the cooperation of companies through the creation of exchange networks of materials, by-products, water and energy (Chertow, 2000). Due to the decrease of resources consumption and wastes generation, the development of exchange networks on an industrial area increases the efficiency in the use of materials, water and energy.

These strategies should be integrated in each phase of the life cycle of the eco-industrial areas: planning, design, building, operation and deconstruction. Nonetheless, this study is focused on the operational phase which is the longer stage. The integration of these new strategies on operational stage gives more unexpected and emergent behavior of the industrial system. So, the implementation, development and maintenance of collaborative relationships based on IS require a meditated process of evaluation. This idea sets the background of the conceptual framework to model the operation of eco-industrial parks suggested in a previous work (Romero & Ruiz, 2013). In order to advance to next stages of modeling process (Izquierdo et al., 2008, Sterman, 2000), this communication aims to contribute to the preliminary model formalization. Therefore, the main characteristics of the conceptual framework (Romero & Ruiz, 2013) are summarized on section 2.1. According to the conceptual model requirements, the agent based modeling (ABM) is the technique selected for this proposal (section 2.2). Based on the ABM technique, section 2.3 defines the preliminary model of eco-industrial areas through the companies' properties and behavioral rules, which govern the relationships inside the eco-industrial area and with their environment.

2   Methodology

Firstly, the main characteristics and properties of the conceptual model are presented in order to set up the background of the analysis. Then, a brief review of ABM technique is included to justify as a suitable method to support the analytical model representation. Finally, the formalization of the model is enounced according to agent's properties and behavioral rules, relationships and the environmental impacts.

2.1   Conceptual Framework

The paper of Romero & Ruiz (2013) covers the formulation of the conceptual model, which corresponds to the first stage of the modeling process (Sterman, 2000; Izquierdo et al., 2008). First part of the paper was focused on the study of complex adaptive systems (CAS). Typical charac-

teristics of CAS such as nonlinear relationships, emergence, adaptability or self-organization, are identified on the EIP's operation. Then, from the analysis of the strengths and weaknesses of several experiences developed by two mechanisms of IS -planned eco-industrial parks (PEIPs) and EIPs that developed through self-organizing symbiosis (SOS)-, some characteristics that have an influence on the operational properties of EIPs were deduced. Based on this analysis, five key properties to be modeled by the conceptual framework were deduced, as table 1 sums up.

Table 1: Properties of the conceptual model (Adapted from Romero & Ruiz, 2013).

Conceptual Model Properties	Deduced from
Functionality	The use of a methodology to implement the strategies of IE and IS (common strength of PEIPs and SOS).
Long term life	The agreement of companies and trust in relationships (common strength of PEIPs and SOS).
Reliability	Consensus between authorities and companies (strength of PEIPs).
Theoretical support	Identification of IE principles in eco-industrial models (common weakness of PEIPs and SOS).
Adaptability	The consideration of environment for EIP development (relevant CAS property).

The paper finally represented these properties by three main considerations of the conceptual model, as table 2 shows: (1) system and element objectives, which represent the properties of functionality and theoretical knowledge; (2) system surroundings, whose delimitation favors the adaptability of the model; and (3) internal and external relationships of the elements of the system, which represent the properties of reliability and life span. These considerations build the conceptual framework that enables a better understanding of system's operation.

Table 2: Modeling considerations that represent the conceptual model properties (Adapted from Romero & Ruiz, 2013).

Conceptual Model Properties	Modeling considerations
Functionality Theoretical support	System and elements' objectives
Adaptability	System's environment
Reliability Long term life	External (elements-environment) and Internal (element-element)system's relationships

As a result, the proposed conceptual model is described in figure 1. The eco-industrial area is built up by a group of individual companies whose aim is to achieve specific economic goals through production of goods. Besides satisfying these individual goals, the membership to an eco-industrial area looks for the improvement of the overall performance through the establishment of cooperative relationships. The cooperative IS strategies are fairly diverse, such as material, water and energy exchange networks or the shared use of utilities, services or information systems (Chertow, 2004), although this model is only focused on the first one. Furthermore, the definition of the surrounding environment is also necessary to understand the system's adaptation to external changes. The environment is build up by three nested systems which represent natural, economic and social surroundings. The respective flows of each system circulate through the eco-industrial area and might affect its performance.
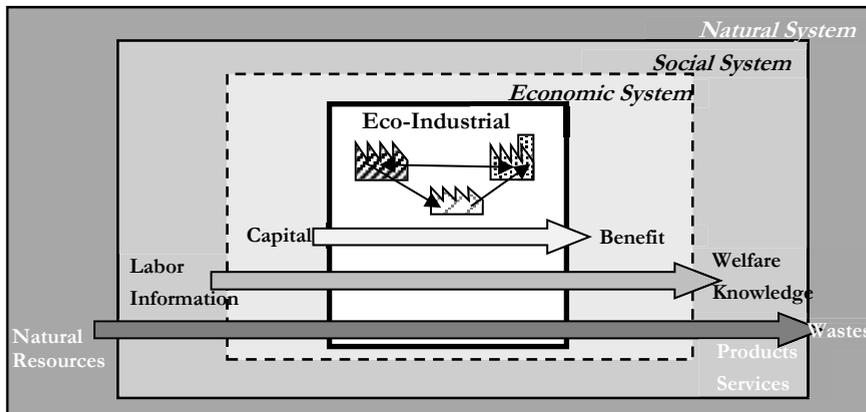
Figure 1: Eco-industrial area and nested environment that represents the conceptual model (Adapted from Romero & Ruiz, 2013).

2.2 Modelling Paradigm

Agent based method is chose as suitable paradigm for the formalization of the conceptual model. ABM method models systems formed by individual entities which are characterized by certain attributes. These entities or agents are autonomous and heterogeneous with their own objectives and behavioral rules and are able to interact among themselves and with their surroundings (Scholl, 2001; Borschev & Filippov, 2004; Izquierdo et al., 2008; Barbati et al., 2012). The interactions among agents cause the global emergent behavior of the system. Based on the work of Schieritz & Milling (2003), table 3 summarizes main features of ABM approach:

Table 3: Main features of ABM method.

Features	ABM. Agent Based Modeling
Model representation	Population formed by autonomous, heterogeneous and independent agents with their own objectives, properties, and social ability to interact between them and with their surroundings.
Inductive Approach	The bottom-up approach inference from the agents' behavior to the system behavior. The behavior of the system emerges.
Handling on time	Temporal variable is discrete.
Formal representation	The behavioral rules of the agents are defined by logic sentences or even more complicated learning algorithms.
Graphical representation	
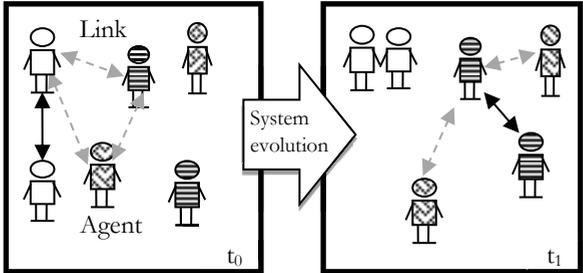
Bonabeau (2002) proposes some conditions that suggest the use of ABM, *"when the interactions between agents are complex, nonlinear, discontinuous or discrete; when space is crucial and the agents' position are not fixed; when the population is heterogeneous; when the topology of the interactions is heterogeneous and complex; or when the agents exhibit complex, including learning and adaptation"*. Except for the

fixed location of the companies, our conceptual model shares these main conditions. Firstly, the interactions between agents are complex. Besides working in a competitive market, the companies of the eco-industrial area also cooperate. This increases the complexity of relationships. The interactions studied in the model are supported by the opportunities to exchange materials among companies based on industrial symbiosis strategies. Secondly, the population is heterogeneous as resemblance of the real system represented. The agents that form the industrial area are individual companies with their own objectives,such as the maximization of their economic benefits. These agents are defined by specific properties that represent the heterogeneity of the population and by behavioral rules that represent the independence of the agents. Thirdly, the topology of interactions is heterogeneous. Based on the strategies of each company the cooperative networks are developed and system behavior emerges. Simulation objective is focused on the maximization of overall economic and environmental benefits. Finally, the agents exhibit adaptation. The agents assimilate the external changes through the modification oftheir structures and properties according to the new surroundings' conditions.

2.3   Analytical Model Proposal

The representation of the system as an agent-based model is supported on their elementary components, or agents. The main characteristics that represent an agent, based on Wooldridge & Jennings (1995), are autonomy, social ability, reactivity, and proactiveness. These characteristics are represented by the properties, objectives and behavioral rules of agents, which provide the independence and goal-directed behavior. According to our conceptual framework, each agent of the model is identified with a company of the real industrial area. Therefore, the characterization of agents should resemble the properties of a real company.
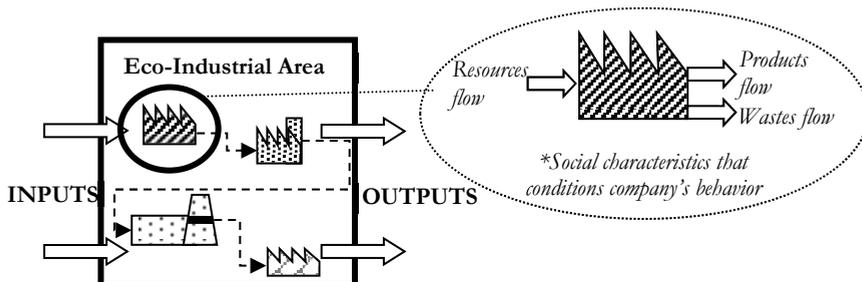
Figure 2: Characterization of agents of the conceptual model based on ABM paradigm.

As the detail of figure 2 shows, the proposed agent's properties are those inputs and outputs related to material flows that circulate through the company, as well as other properties that condition the company's behavior and represent its social abilities. The properties of agents related to material flows are directly associated with the productive process of each company. These properties are defined as vectors that gather the qualitative and quantitative data of resources, products and wastes (table 4). The qualitative data defines the type of flows consumed and generated by each agent. Considering the example of an agent representing a paper mill, the qualitative data are corresponded with flows of resources such as wood, water and additives, paper as product flow and waste flows such as fiber wastes and fiber sludge. Based on these qualitative flows, the data referred to quantity and economic prices of each flow are also specified. These flow-related properties are used on the evaluation of cooperative relations.

Table 4: Agents' properties flow-related.

Properties flow-related	
Resources (R)	Formed by n_R elements. The type (Rt_i), quantity (Rq_i) and cost (Rc_i) are defined for each element.
Products (P)	Formed by n_P elements. The type (Pt_i), quantity (Pq_i) and cost (Pc_i) are defined for each element.
Wastes (W)	Formed by n_W elements. The type (Wt_i), quantity (Wq_i) and cost (Wc_i) are defined for each element.

However, the decision making of agents is based not only on quantitative features such as economic savings or environmental impacts but also considers social aspects related to the appraisal of companies or the business strategy for the long or medium term. The three social properties suggested are related with different types of agents that form the system population, called as "traditional", "ecologic" and "strategic" companies as table 5 sums up. First property proposed is trust level (Tr), which represents the trust offered by a company to establish commercial agreements. The second property, efficiency level (Ef), represents the image of the environmental company. The third property, innovation level (In), represents the initiative of the company to develop new strategies.

Table 5: Agents' properties social related.

Properties social related	
Trust level (Tr)	Scalar between (0, 2). Agents with values of trust level greater than 1 are characterized as "traditional companies".
Efficiency level (Ef)	Scalar between (0, 2). Agents with values of efficiency level greater than 1 are characterized as "ecologic companies".
Innovation level (In)	Scalar between (0, 2). Agents with values of innovation level greater than 1 are characterized as "strategic companies".

Agents are able to interact and build up relationships in order to satisfy their objectives. This contribution is focused on the analysis of cooperative relationships that formalize material exchanges. These exchange relationships arise when a resource of one company can be substituted by a waste of another company. The first condition to assess cooperative actions is to check the substitutive ability of the flows of each agent. For this purpose, the model integrates a knowledge database that registers flow substitutions of several existing industrial symbiosis experiences. Based on this knowledge database, the types of resources of the model's companies are checked with replaceable resources of the database. Respectively, the associated types of wastes of the database are checked with the types of wastes of the model's companies. Once the replaceable resource and the substitute waste are detected on the model, the quantitative and economic properties of the respective agents are evaluated.

The trade-off is achieved when the companies' economic, environmental and social objectives are satisfied based on their behavioural rules. According to the type of agents, their behaviours are conditioned as follows: (1) "traditional company" chooses the exchange which gets the greater economic profits; (2) "ecologic company" chooses the exchange which causes the lower environmental impacts; and (3) "strategic company" chooses the exchange which gets the best social position. After the trade-off, agents update their properties to the new situation including the type, quantity and cost of the new item exchanged in their flow-related properties.

Additionally, the evolution of the system should be consistent with the premises of the IS. So, the development of cooperative relationships among companies looks for the improvement of economic (GEP_{EIP}) and environmental (GEI_{EIP}) objectives of the overall system, which should be greater than the improvement achieved by the economic (EP_{Ai}) and envi-

ronmental (EI_{Ai}) progresses of individual companies, as equations (1) and (2) represent.

$$\max\left(GEP_{EIP}\right) > \sum_{i=1}^{N} \max\left(EP_{A_i}\right) \qquad (1)$$

$$\min\left(GEI_{EIP}\right) < \sum_{i=1}^{N} \min\left(EI_{A_i}\right) \qquad (2)$$

Besides the internal relationships, the agents should also adapt to impacts caused from the surrounding environment. The surroundings is defined as three nested systems (natural, social and economic) which affects the system modifying the circulating flows (natural resources and industrial wastes, human capital, financial capital and manufactured capital). In Romero & Ruiz (2013) a categorization of the influential factors that might affect the system were proposed. These influential factors are analyzed in order to relate them with the affected agent's properties, as table 6 gathers. Future research is geared to prioritize the more relevant factors to implement their effects computationally.

Table 6: Influential factors and affected agent's properties (Expanded from Romero & Ruiz, 2013).

Description of the influential factor subcategory	Agent's property
Natural environment (Environmental). Capacity of the natural environment to absorb the impacts generated from the system.	Resources quantity (Rq_i), Wastes quantity (Wq_i)
Resources (Environmental). Related with the inputs from the natural environment to the system.	Resources type (Rt_i), Resources quantity (Rq_i)
Wastes (Environmental). Related with the outputs from the system to natural environment.	Wastes type (Wt_i), Wastes quantity (Wq_i)
Legislative and political (Social). Legal or political initiatives from the society to promote specific behaviors inside the system.	Resources cost (Rc_i), Wastes cost (Wc_i)
Organizational (Social). Behavioral and relational patterns which are supported by normative of the system.	Trust level (Tr_i), Efficiency level (Ef_i)
Formative (Social). Operational patterns which rise from educative doctrines.	Innovation level (In_i)

Market (Economic). Factors which condition the development of the productive activities according to the economic profit and market demand.	Products quantity (Pq_i)
Innovation and competitiveness (Economic). Business practices geared to improve companies' performance so as to achieve economic profits.	Products type (Pt_i)
Infrastructural (Technical). Infrastructures and services geared towards the implementation of more sustainable systems.	Efficiency level (Ef_i), Resources cost (Rc_i), Wastes cost (Wc_i)
Technological (Technical). Production means more efficient which take part in the operation of the activities.	Products cost (Pc_i)
Procedural (Technical). Work methods or practices for more sustainable activity developing.	Eficiency level (Ef_i)

Therefore, internal changes as well as external impacts cause the modification of the system. These changes directly affect on agents flow-related and social properties, and thus the agents' structure should be adapted to the new situation. After a change of one property, the rest of the properties of the agent should be checked and recalculated in order to maintain the consistency. So, the development of new relationships makes the system evolves.

3   Conclusions

According to the suggested conceptual framework that models the operation of eco-industrial areas, this communication advances to the model description based on the ABM paradigm. The final aim of the work is to achieve a computational model which evaluates the evolution of the cooperative exchange networks developed on an operating industrial area. So, besides completing the analytical model formalization, future lines of work are related with next stages of the modeling process: computational implementation, verification, validation and testing. Due to its versatility, the software NetLogo is evaluated as an adequate computational tool for the model implementation. The analytical model should be implemented on the computational tool in order to proceed with inference process. The verification, validation and testing stages should be supported on a case study, such as Kalundborg symbiosis network. The data of the companies

that form the network will be used to verify and validate the model. After these stages, the model will be able to evaluate data of traditional industrial areas and to support their conversion to eco-industrial areas.

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Design Of Synergy Network Of Industrial Symbiosis Between Large Companies Of An Industrial Complex

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Abstract

Industrial symbiosis (IS) presents the implementation of synergies that represent a progress in terms of sustainable development, so that should be ensured the coexistence of a benefit, not only economic but also social and environmental. In previous experiences of network design and analysis, focus is mainly on savings and economic potential of the synergies implementation. While economic viability is a necessary condition, the life cycle approach provides environmental and also economic information that should be quantified in every option of the network design.

This project starts from the preliminarily identified synergies between large companies of the production and manufacturing sector, located in an industrial complex in northern Spain. Based on an analogy between the concept of supply chain and industrial synergy, the analysis of the identified synergies is carried out by multicriteria selection methods that will return the ones that will be part of the initial synergy network. In this point the technical feasibility of each particular case is verified, analysing the economic and environmental feasibility of each synergy, and the whole eco-industrial system they form. For this purpose, techniques and tools of process and flow analysis will be used, with life cycle perspective.

The resulting network model must combine new investment opportunities and services with an economic and environmental benefit substantially higher that the baseline.

Keywords

Industrial synergy, industrial symbiosis, network.

1   Introduction

The concept of Industrial Symbiosis (IS) is part of a new field of recent study called Industrial Ecology (IE). This new discipline, works mainly with the existing material and energy flows across different systems, including from the finished goods to the factories that produce them, and at different scales such as regional, national and even a global level point of view. As described by Graedel & Allenby (2003), IE "*is a systemic vision which seeks to optimize the whole material cycle from their virgin extraction, through the finished material, the component, the final product, the product obsolescence and its final disposal*". On the basis of IE, IS incorporates many elements that emphasize the idea of completing cycles within an industrial process and the reuse of materials from a broad perspective of the system concept. More particularly, IS focuses on these flows through networks of businesses and other organizations within the local and regional economy as a means to focus industrial development from an environmentally sustainable standpoint. IS involves traditionally separated sectors given their different activities within a community approach, providing a competitive advantage through a physical exchange of materials, energy, water and/or sub products. The key of IS is on the collaboration and synergistic possibilities offered by geographic proximity of the entities involved (Chertow, 2004). IS term was coined in the small town of Kalundborg, Denmark, where spontaneously, had emerged a dense network of interactions between the entities that formed the town's industrial park (Domenech and Davies, 2011). There are cases like Ulsan (Won et al., 2006), in which these networks were developed intentionally, that implements the theoretical IS knowledge and proves possible to achieve a more sustainable industrial activity while improving economic development at the same time.

A life cycle perspective ensures a broader approach that is not limited only to the processes that occur within an installation or plant, but will consider the full set of environmental impacts that occur in each stage of development, and the industrial use given to each of the materials involved. Focusing on the case of IS, the life cycle approach is useful when evaluating opportunities for developing symbiosis and the existence of possible synergies, where the situation of the life cycle of a product makes the residual flows can be considered useful for other use within the life cycle of another product.

The aim of this work is to design a methodology for creating synergy networks in an industrial complex following a defined structure and extrapolated to any event contemplated. This research uses the context of a previous study (INGEPRO, 2012) to create an appropriate methodology for the design of a feasible preliminary synergy network. The cited project

(INGEPRO, 2012) preliminarily identified the synergies available between large production and manufacturing companies, located in an industrial complex in the city of Torrelavega, in Northern Spain. The network design is supported on from a shortlist of synergies within an industrial area, which have been identified on the previous study (INGEPRO, 2012).

Based on the phase's structure made by Fernández et al. (2010), this work includes the steps of selection of synergies technically feasible and economic and environmental analysis of alternatives. The ultimate goal pursued by the generated method is to reach an initial design of an industrial synergy network technically feasible and economically viable to ensure environmental and social benefit, achieving a more sustainable development of the complex activity. From this method, we try to simulate the effects and advantages obtained, intentionally and quantified, and establish a fixed line of work that facilitates the creation of an industrial symbiosis network in an industrial area.

2 Theoretical Methods

2.1 Industrial Symbiosis Synergies

Industrial symbiosis (IS) proposes the implementation of synergies that advance in terms of sustainable development, so that should ensure the coexistence of a benefit, not only economic but also social and environmental. In previous experiences and network design study, the focus is primarily on savings and economic potential of the implementation of synergies. While affordability is necessary, the approach yields information life cycle environmental and economic, which should be quantified in the design options of the network.

The nature of these innovative industrial networks is supported on the concept of "synergy". According to the Royal Academy of the Spanish Language, synergy means the improvement obtained through a partnership between two or more companies seeking a profit greater than that obtained individually. This association is favored by geographical proximity between the members participating in the synergy.

The collaborative relationship between companies should be aimed at reducing environmental impacts by reducing natural resource consumption and waste generation. Moreover, this relationship should bring economic benefits or cost reductions that encourage the establishment of the relationship. From previous experiences and projects such as (Outters, 2006) or the one developed in Geneva (Massard & Erkman, 2007), the

previous collaboration opportunities are classified in two major groups called mutualization and substitution activities.

Substitution synergy: The consumption of an inflow of a company is replaced by a residual output from another company, to produce a reduction of resources consumption and environmental impacts generation. This implementation of substitution synergies strengthens cycle closing, increasing flow recirculation within the system.

Mutualization synergy: The integration of the whole infrastructure and services required for the system companies, which can be used together, reducing the demand for resources.

Genesis Synergy: The creation of new activities and relocation of the existing ones in the system given the existence of business opportunity. These advantages concerning the transfer of the production facility must compensate the costs and risks assumed by the company by changing its spatial location (Sterr & Ott, 2004). New activities will be implemented in the system only if they contribute to a greater sustainability of the whole. This third type implements both substitution and mutualization synergies.

2.2 Supply Chain and synergy network analogy

Fernández et al. (2010) presents in her work a system model for study which holds only to industrial activities in the considered area where the complex is located, simplifying and making more feasible the analysis. In this paper we use the same system for the study of the methodology of IS networks design.

From the model of behavior of the system under study presented by Fernández et al. (2010), which includes any industrial activity area, we can find many similarities with the behaviour that shows a supply chain in any of the activities implicated in an industrial complex. These suggest an analogy between the two concepts that offers a new approach for analyzing the methodologies and strategies within the IS.

Blanchard (2010) defines supply chain as: "*The sequence of events that cover the entire lifecycle of a product or service from conception until it is consumed*". Within this broad definition, there are less complex models representing the same way the concept of supply chain.

The Council of Supply Chain Management Professionals (CSCMP) also provides a description of the term in the same line. Considers that the Supply Chain includes many companies, starting with unprocessed raw materials and ending with the final consumer using the finished products. All suppliers of goods and services and all clients are included in the chain as a link, like material and computer exchanges in the logistics process,

from acquisition of raw materials to delivery of finished products to the end user.

Due to the breadth of the concept, there is a wide range of models of supply chain. The Supply Chain Operations References or SCOR model (figure 1), which was approved by the Supply Chain Council (SCC), has been developed by the consulting firm PRTM and has become a reference for the management of the supply chain. It is a model that covers from the supplier's supplier to customer's customer (Supply Chain Council, 2010).
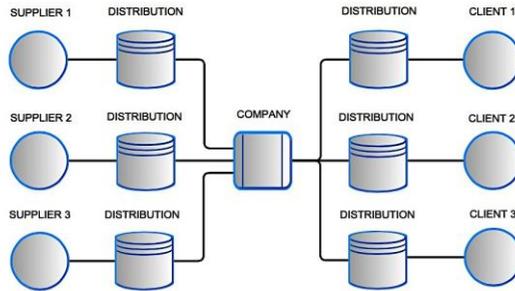
Figure 1: SCOR model

The model designed to define an industrial synergy also maintains the analogy with the SCOR model proposed by the SCC. In this paper, the supply chain model is simplified to a subset of the initial SCOR model (figure 1). This model includes from the supplier company to delivery to the customer or destination, omitting any event beyond such limits thereby adjusting the boundaries of the system under study.

Given the analogy between the concepts of supply chain and IS network, it can be can designed a theoretical model of industrial synergy that represents the wide variety of them that can occur in a network given the three types considered in this work. Model structure may include any possible case so that all of them are represented by a single idea that suits each case as necessary (figure 2).

Each of the elements or entities in both models also maintains a direct analogy in concept. The origin within the synergy model maintains a direct relationship with a supply chain provider concept. In both cases both entities provide a flow of resources or products that will be further processed or directly distributed to their respective destinations.
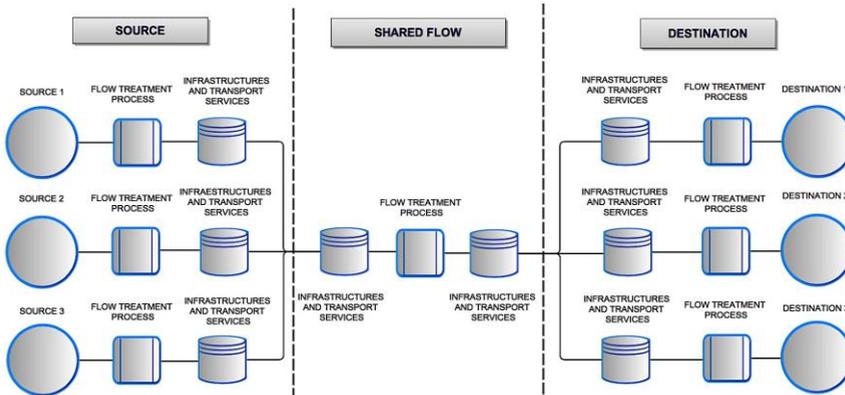
Figure 2: Synergy model

The customer or receiver of the finished products within the supply chain concept corresponds to the destination entity considered in the model of industrial synergy. These entities act as sinks of the final product and are where the flux ends. The production work within a supply chain maintains a direct analogy with the processes used for the adaptation of a flow in an industrial synergy. They can be a series of successive processes to achieve the desired product nature. The flexibility of the model enables to omit some elements that even may not be necessary and are omitted when working with the model. Finally the distribution labour, not only of the finished product to the customer, but also of any flow movement along the supply chain, have their equivalence in concept with transport infrastructure and services that are represented in the synergy model. In this case all product or flow movements are covered by a single entity to simplify the concept, and in addition add versatility when establishing the parameters that define the personality of the entity.

3 Methodology for Networks Analysis

3.1 Preliminary selection of synergies

Based on the preliminary synergies get from the identification stage, a selection task of the synergies that will form the symbiosis network is performed. The selection uses linear weighting (scoring) so that under previously established criteria should be considered as priorities for its simplicity and feasibility. The six criteria are summarized in table 1.

Table 1: Synergy preference criteria

SYNERGY PREFERENCE CRITERIA			
Supply capacity		**Availability of technology**	
Low or non-existent investment	1	Mature technology of easy application	1
Shared technology investment	0.75	Mature technology of complex application	0.75
Acquisition of new facilities collectively	0.5	Low mature technology	0.5
Individual investment	0.25	Developing technology	0.25
Flow Purity		**Infrastructure, Facilities and Services Needed**	
Fully compatible	1	Infrastructure and services available	1
Similar flows	0.75	Infrastructure and services of new shared creation	0.75
Low compatibility flows	0.5	Individual infrastructure need and simple creation services	0.5
Incompatible flows	0.25	Individual infrastructure need and complex creation services	0.25
Forecasting of technological and industrial investment		**Coefficient of specific weight of exchanged flow over the total production (CSW$_j$)**	
Complete supply coverage	1	Key flow for production	1
High supply coverage (>80%)	0.75	High priority of synergy implementation	0.75
Medium supply coverage (>50%)	0.5	Medium priority of synergy implementation	0.5
Low supply coverage (<50%)	0.25	Low priority of synergy implementation	0.25

The weighting of the criteria is identical in all cases (1 point), using a priority selection scale for each of the four alternatives of 0.25 to one, being 0.25 the case that less meets each criterion and 1 for each case that best meets your specifications.

The last criterion, coefficient of specific weight of exchanged flow over the total production refers to the importance of implementing a synergy for a

particular flow comparing the amount of exchanged flow with the global activity of the company. The coefficient is calculated by equation (1):

$$CSW_j = \frac{(Q_j/Pr_j)}{\max CSW} \qquad (1)$$

Where *CSW* is the coefficient of specific weight, *Q* the amount of flow exchanged and *Pr* the total production of the company, both measured in tons per year. The values are normalised in order to simplify the comparison between companies in a relative way.

The chosen synergies will be those with the highest score from the ones selected in previous studies. The score will be calculated by equation (2):

$$S_j = \sum_i w_j \, r_{ij} \qquad (2)$$

Where *S* is the final score of each synergy, *w* the weighting of each criterion that in this case is 1 for all of them, and *r* the score of each of the options set for each criterion.

The 26 preliminary synergies detected on the previous study are evaluated based on the selective criteria. This assessment enables to prioritize the most relevant for next evaluations. Once the rating of each synergy is done, the technical feasibility of the selected synergies is evaluated. This evaluation comprises both an economic and environmental study, which guarantees the sustainability approach of the synergies network to be designed.

3.2   Economical feasibility of the synergies network

The evaluation of the economic feasibility of implementing each synergy individually and as a whole network should be supported on the estimation with an order of magnitude definition of the capital and operating and maintenance costs in each case, calculating the savings that will suppose the new synergy management compared with the case which was performed prior to its implantation. From the annual savings identified, it can be estimated the payback period of the initial investment that the companies involved will have to face.
In order to estimate the costs associated with the implementation of a synergy, two distinct parts to its calculation are proposed. First a part of processing or treatment of the synergy flow is considered and then another

part of transportation and transfer of the flow between each of the entities involved. In the first part, the Module Costing Technique, which was developed by Turton et al. (2003) and based on previous works, is used. The equipment module costing technique is a common technique to estimate the cost of a new plant. It is generally accepted as the best for marking preliminary cost estimates. From this method, both the capital costs and the costs of operation and maintenance of the new facilities are obtained. In the second part, the transport cost estimation has been considered for two types of flow, fluid flow and solid flow. For the transport of fluids in pipes, the calculation is simplified for piping and pumping stations. According to Parker (2004) the whole capital costs of the construction of a pipeline for the transport of fluids can be estimated. The U.S. Army Corps of Engineers (2011) estimated the initial cost for the erection of a new pumping station. For the operation and maintenance costs of this infrastructure, the Miriam Vale Shire Council (2007) raises its estimate for both pipelines and pumping station from percentages of the capital cost, over 1% and 2.5% respectively. In the transport of solids case, the cost is estimated for road transport, basing this calculation on the prices offered by the software ACOTRAM (data of 2008), which is a Wizard Transportation Costing offered by the Ministry of Public Works and Transport of the Government of Spain. In case of occurrence of the generation of a new activity associated with the implantation of synergy, not contemplated in the module costing technique, the costs associated with this activity should be estimated in a specific way. An example is the generation of WWTP for treatment of urban wastewater. In this case the Barnstable County Wastewater Cost Task Force (2010) estimates both the capital and operation and maintenance costs for the case of a wastewater treatment station from the study of previous cases.

As a result of this economical analysis, those synergies which does not fulfill the profitability requirements are discard from the methodology. The ones proved to be economically viable continue being analyzed in order to study their environmental impact.

3.3   Environmental feasibility of the synergies network

The objective of this analysis is to compare the environmental impact of the selected synergies that has been tested economically viable. For this purpose a life cycle analysis of the operation with the implementation of synergy case is carried out and compared with a life cycle analysis of the base scenario in which the synergy is not implemented. The carbon footprint is used as an indicator to compare both scenarios.
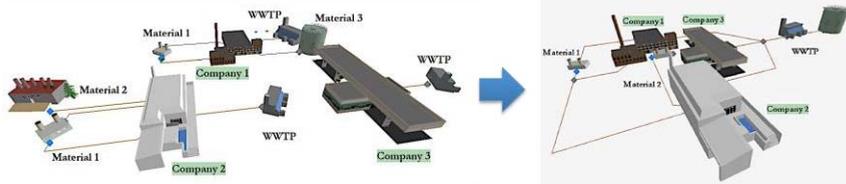
Figure 3: Example of initial case and the implementation of the synergy network

The calculation of the total emission of gases of an entity is impossible in practice due to the large number of variables that should be contemplated and the required data for this purpose, coupled with the fact that carbon dioxide can be created naturally within an activity without need for human factors. Wright et al. (2010) have suggested a more practicable definition: "*A measure of the total amount of carbon dioxide (CO_2) and methane (CH_4) emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as carbon dioxide equivalent (CO_2e) using the relevant 100-year global warming potential (GWP100).*"

Based on this indicator, any synergy would be environmentally feasible when the carbon footprint of the new flow management after the synergy implantation is reasonably lower than the one left by the previous management. It must be considered the carbon footprint of the construction process of the new facilities and their life cycle assessment, so that the recovery time of the initial environmental impact (in carbon footprint measuring) before the implementation of synergy in the production process can be quantified.

Finally, after passing the whole analysis, those synergies that guarantee their sustainability formed the preliminary IS synergy network to be implemented in first place like in the example shown in figure 3.

4   Conclusion

Based on the prior identification of synergies in an industrial area, a methodology to prioritize a set of them and select those technically feasible for implementation is defined. For this purpose a working model for an industrial synergy has been designed based on the analogy of the supply chain model. As an ultimate goal of this work, a synergy network should be projected from the selection made following the proposed method.

At this point, future lines of research should be considered. First the methodology developed might be debugged to improve the selection process and the analysis, in order to get the most optimal synergy network after the application of the methodology. Another line to consider is the

possibility of designing work methods for the expansion of the preliminary obtained network. Thus, the design process becomes dynamic allowing its enlargement, correction or optimization using different techniques, ensuring continuous improvement in the companies involved and increasing their competitiveness and sustainability.

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Integrated facility location and network design for bioenergy villages

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Abstract

Bioenergy villages offer cutting-edge solutions to the question of how to supply a community with energy independent of external resources. The planning of bioenergy villages using biomass as main source of electricity and heat calls for the simultaneous consideration of facility location, capacity planning, and network design for the heating grid. A linear mathematical model is presented, that economically optimizes the local bioenergy production and distribution system and considers various parameters such as biomass availability, the number of heat customers, or heat loss in the system.

Keywords

Bioenergy village, network flow problem, facility location, mixed integer linear program (MILP), district heating

1 Introduction

During the last few years, European energy policy started changing towards a sustainable, carbon neutral energy supply (European Commission, 2009, 2011c). This included measures to increase the general energy efficiency, a reduction of the overall energy consumption and further development of renewable energy resources, to reduce the dependency on fossil fuels and the emission of greenhouse gases (European Commission, 2011a,b). One potentially important source of renewable energy is biomass, which can be converted to biogas in a fermentation process. This type of renewable energy is especially promising, because it is capable of providing baseload power, but can also be used to cover the peakloads, due to the possibility of biogas storage (Ostergaard, 2012). Furthermore, biogas can be used to fuel decentralized combined heat and power stations (CHPs),

in order to produce electricity and heat for local heating systems, reaching energy efficiencies of above 80% (Nowak & Arthkamp, 2012).

Bioenergy villages use biogas to provide an independent supply of heat for local heating (Ruppert, 2008). The electricity generated by the CHPs can be fed into the national grid and a local heating network supplies customers with heat. However, to contribute to a sustainable energy supply, it is necessary to distribute the generated heat from the CHP efficiently (Uhlemair, 2012). The planning and realization of bioenergy villages poses various challenging problems. Considering the general energy production system, critical issues include: The number of installed power plants, their capacity, and the locations of these facilities (Delzeit, 2008; Plata, 2008). Problem-specific parameters such as the availability or allocation of biomass have to be considered as well. The planning of the distribution system poses the questions of which heat customers to connect to the grid and how to design the course of the heating network, while considering heat loss, profitability, and the requirements of the Renewable Energy Act among other factors (Uhlemair et al., 2012b). Only the simultaneous consideration and optimization of these aspects in a suitable model allows for an efficient, decentralized heat supply.

In the following, we model the local heating system as a network flow problem, before we optimize the plant location and heating network structure of a village in the context of a case study. Finally, we discuss and summarize the results in the last section.

2 Modeling of the source location and network flow problem

Bioenergy villages have an independent supply of electricity and heat from a CHP station fuelled with biogas and can therefore help to reach a sustainable energy supply. Liquid manure and crops, which are cultivated from the agricultural land around the village, are the feedstock for the generation of biogas in an anaerobic digestion plant. The electricity is fed into the national electricity grid and the heat is inducted into a local hot water grid supplying the villagers with heat (Ruppert, 2008; Uhlemair et al., 2012b).

Planning and realizing an efficient, decentralized heating system poses a great challenge and the following questions on production planning and logistics arise: What is the optimal course of the heating network and which potential heat customers should be connected to this network? Regarding the production system, the number of CHP plants, the location planning, and the optimal capacity planning have to be considered.

To model the planning situation of a bioenergy village, a specific approach in graph theory is used. These network flow problems are com-

monly used to model problem situations in which any kind of commodities have to be transported from source to sink through a given network (Ford & Fulkerson, 1962). The models can be used in a variety of real-world applications such as the planning of oil pipelines connecting a given set of offshore platforms and onshore wells to a port (Brimberg, 2000) or the evaluation of energy and electricity networks (Quelhas et al., 2007). In the planning situation of bioenergy villages, not only the flow of the heat and the network are optimized, but the locations of the biogas plants are considered as well. This can be modeled as a source location network flow problem optimizing both the flow through the network and the location of the flow sources. Ford & Fulkerson (2010) used this kind of model to optimize the evacuation of public buildings, determining both the optimal escape routes and the location of assembly points for evacuation. Melkote & Daskin (2000) present an efficient integrated model for facility location and network design, which can be easily solved to optimality even for larger instances. However, these models do not consider weighted and Steiner nodes, which are nodes that can be connected to the grid, but are not required. To adequately model the planning of bioenergy villages, it is necessary to introduce weighted links, nodes and Steiner nodes, accounting for the contrary cost structure of construction costs for the heating network and revenue from selling heat to the connected nodes.

The application of this model to the network planning in bioenergy villages implicates a certain planning situation. A certain set of potential heat customers is given (represented by the nodes of the network) and they can be connected via a set of potential network segments (links in the network). The net present value (NPV) is used to economically assess customers and network segments, modeled as weights of nodes and links. The heat, which is to be distributed, is generated in one or more CHPs. While connected households will generate revenue due to their heat demand, the construction of network links and combined heat and power plants will cause costs. The optimization problem to be solved then consists of determining the optimal capacity and location of the plant, the number of connected heat customers and the optimal heating network design.

2.1 Graph theory and modeling of the network construction problem

Heating networks can be theoretically described using graph theory. The notation of the network planning and construction problem with weighted Steiner nodes is introduced as follows (Uhlemair et al., 2012b):

A connected, directed graph $G = (V, E)$ with the set of nodes of $V = \{v_0, v_1, \ldots, v_n\}$, representing potential heat customers, and the set of edges of $e_j \in E$ is assumed. Edge e_j represents a segment of the heating network and link construction costs l_j are given as edge weights for every edge. d_i

is the heat demand at every node $v_i \in V$ and r_i is a given revenue factor, specifying the amount of revenue generated from every unit of heat sold to customer $v_i \in V$. Thus, defining the node weights as $d_i \cdot r_i$ represents the total revenue generated at every node $v_i \in V$.

$B \subseteq V$ is a subset of V and includes the profitable heat customers $V' \subseteq V$. $E' \subseteq E$ are the segments of the optimal course of the grid, and V' and E' must be determined. When using definitions from graph theory, this problem of determining the most cost efficient heating network, which arises during the planning process of a bioenergy village, can be described as follows: A tree $G' = (V', E')$, that connects all nodes in B and where $\sum_{i:v_i \in V'} r_i \cdot d_i - \sum_{j:e_j \in E'} l_j \cdot e_j$ is maximal must be found.

In the following subsection, this basic network construction problem is modeled as a mixed integer linear program (MILP) and extended to include the optimal network flow and the source location.

2.2 MILP modeling of the source location

It is possible to model the source location network flow problem as a MILP, allowing for computer-based solving of this problem. First, several assumptions have to be made to model the problem. Each node represents a potential heat customer and each edge represents a potential network segment. The supply facilities (CHP plants) can be located at every node in the directed network, which is a customer-to-server system. The input parameters of the problem are the transportation costs t_{ij} and the link construction costs l_{ij} for every edge $(i,j) \in E$, the heat demand d_i and the facility construction costs c_i for every node $i \in V$, a revenue factor r_i, for every unit of heat sold at node i, the total network demand $M := \sum_{i \in V} d_i$ and the graph incidence matrix $A \in \mathbb{R}^{|V| \times |E|}$. The decision variables are

$$x_i = \begin{cases} 1, & \text{if node } i \text{ is connected to the grid,} \\ 0, & \text{else.} \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{if link } (i,j) \text{ is constructed,} \\ 0, & \text{else.} \end{cases}$$

$$z_i = \begin{cases} 1, & \text{if a facility is constructed at node } i, \\ 0, & \text{else.} \end{cases}$$

$$f_{ij} = \text{amount of flow on edge } (i,j).$$

$$ds_i = \text{demand served by a facility at node } i.$$

The problem can then be stated as follows:

$$\max \quad \sum_{i \in V} r_i \cdot d_i \cdot x_i - \sum_{(i,j) \in E} t_{ij} f_{ij} - \sum_{(i,j) \in E} l_{ij} y_{ij} - \sum_{i \in V} c_i z_i \qquad (1)$$

$$s.t. \qquad (2)$$

$$\sum_{j \in V} f_{ij} - \sum_{j \in V} f_{ji} + ds_i = d_i x_i \quad \forall i \in V \qquad (3)$$

$$ds_i \leq M z_i \quad \forall i \in V \qquad (4)$$

$$f_{ij} \leq M y_{ij} \quad \forall (i,j) \in E \qquad (5)$$

$$x_i, z_i \in \{0,1\}, \; ds_i \geq 0 \quad \forall i \in V \qquad (6)$$

$$y_{ij} \in \{0,1\}, \; f_{ij} \geq 0 \quad \forall (i,j) \in E. \qquad (7)$$

The objective function 1 includes the revenue $r_i d_i$ from connecting node i to the grid, the transportation costs $t_{ij} f_{ij}$ and the link construction costs l_{ij} for every built link e_{ij}, and the facility construction costs c_i for every potential location of the power plant. This objective function has to be maximized under the constraint 3, which is the flow conservation constraint. Constraint 4 ensures, that demand can only be served from nodes, where a facility has been constructed, and constraint 5 states that supply flow can only be transported over constructed links. 6 and 7 are binary and non-negativity constraints.

In the next subsection, this general model will be adapted to fit the general framework of a bioenergy village with its specific parameters and constraints.

2.3 Adaption for modeling a bioenergy village

To fit the set-up of a bioenergy village, the input parameters of the model mentioned in section 2.2 are interpreted as specifications of this heating network design problem. The single nodes in the network represent the potential heat customers in the village, and the links represent the potential network segments of the local heating grid. The demand for every node is the heat demand of the customers, and directly implies the total network demand of the whole village. The link construction costs represent the economic value of the link. In this application, the NPV is used to economically evaluate all parts of the problem. This way, the economic value of grid segments and heat customers equals the sum of all discounted cash flows over the planning horizon of 20 years. The transportation costs are neglected in this scenario, since inducting heat into the grid is cost-free, apart from regular operation costs (which the NPV includes).

The facility construction costs have to be considered separately, since the structure of cash flow in this problem is different from the standard transportation or flow problem. Normally, it is costly to establish a facility

Table 1: Allowances for substrates used in a biogas plant, which started to operate in 2012, according to (BMU, 2011)

equivalent power [kW$_{el}$]	basic allowance [€ ct/kWh]	substrate class I	substrate class II	liquid manure
≤ 150	0.143	0.06	0.08	0.08
≤ 500	0.123	0.06	0.08	0.08
≤ 750	0.11	0.05	0.08	0.06
≤ 5,000	0.11	0.04	0.08	0.06

supplying the customers with the appropriate goods. In the case of a bioenergy village, the installation of a biogas plant connected to a CHP plant already generates incoming cash flow through the sale of electricity. The supply of villagers with heat is merely a secondary income. The revenue generated by these plants depends on their capacity. To represent these specifications, capacity-dependent NPVs for the biogas facilities are used. Furthermore, the biogas plants cannot be built at every node in the network. A separate set of potential locations $S \subset V$ is used to describe all nodes that meet the legal and technical requirements as a location for the biogas plant.

Various governmental grants and allowances are also included into the model. Subsidies for the heat distribution system include 1,800 € for every connected heat customer (KfW, 2011) and around 80 € for every meter of installed heat pipeline, depending on the diameter and the overall investments (KWKG, 2002). The price per kWh$_{el}$ inducted into the national grid is also granted by the Renewable Energy Act (BMU, 2011). These allowances (displayed in table 1) depend both on the installed capacity of the biogas plant and on the type of substrate used in the fermentation process, and without these governmental allowances, most biogas plants would not be profitable at all. However, to be eligible for these subsidies, the biogas plants must meet certain requirements. Most importantly, the plants must be operated with at least 60% liquid manure as a substrate, or 60% of the generated heat must be used through the local heating network with an overall heat loss of 25% at most. These constraints are included in the linear program, preventing the building of power-generating facilities on all possible construction sites, since a certain number of heat consumers or a high availability of liquid manure is necessary for every plant in order to be profitable.

Heat loss in the network is another important factor, which must be considered during the planning of a local heat distribution system. To include the heat loss in the mixed integer linear program, the incidence matrix A, used in the flow conservation constraint $A \cdot f + ds = d \cdot x$, is

altered. Being a customer-to-server system, the linear program displays the flow of heat demand from the heat customers to the CHP plants. The conservation of this demand flow is ensured by the constraint 3, which is included in the model. Every column A_i of the incidence matrix A represents the coefficients of the demand flow on the given edge $e_i = (v_j, v_k)$ of the underlying graph. Examining an exemplary edge $e_1 = (v_1, v_2)$, the matrix entries $a_{11} = 1$ and $a_{21} = -1$ ensure that the amount of demand flow entering e_1 at node v_1 leaves this edge at node v_2. Increasing the absolute value of the entry a_{21} therefore changes the behaviour of the demand flow on edge e_1. The amount of demand flow entering the edge e_1 at node v_1 is multiplied with the factor $|a_{21}|$ before leaving the edge at node v_2. Thus, the heat demand rises by merely flowing over the edge e_1, thereby simulating a heat loss on this edge. In this way, an individual heat loss can be modeled for every edge in the graph.

In the next section, a case study is presented to analyze the planning situation in a rural area. The data for the input parameters are calculated on the basis of Uhlemair et al. (2012b) and adapted to this specific situation.

3 Application to a bioenergy village problem

In this section the design of a local heating network in a fictional bioenergy village with 45 potential heat customers is analyzed in a case study. Several farmers are planning to install a biogas plant with a CHP station in their village, to establish a local heating system. There are four potential construction sites for the plants, located on the farmers' own estates. The farmers cultivate enough energy crops on their arable land to neglect the restrictions of biomass availability, but no liquid manure is available. The overall heat demand of the 45 households (including private single-, and multi-family houses) amounts to 956 MWh per year. The biogas facility is expected to run at a full load for 8,000 hours per year, have an electrical efficiency of 35%, and a thermal efficiency of 45%. Further, we expect 25% of the residual heat to be needed for internal consumption during the fermentation process.

Figure 1 shows the optimal heating network for this modeled village. In this solution, 37 households are connected to the grid with an overall heat demand of 855,000 kWh_{th} per year. The optimal capacity of the biogas plant is 300 kW_{el} supplying 1,085,000 kWh_{th} per year. This corresponds to an overall heat loss of 21.2%, meeting both the requirements of the Renewable Energy Act. The value of the objective function is 623,000 €. Three nodes are connected in this scenario, which are not profitable by themselves. The cost of connecting these nodes is higher than the revenue they generate through the demand of heat. This is due to the fact that
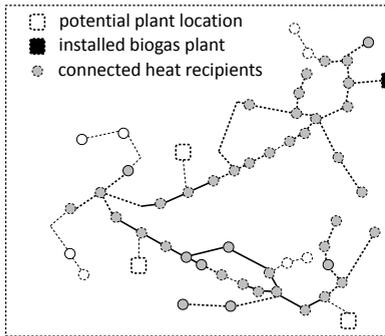
Figure 1: Optimal heating netwo[rk] with 37 connected households (3[00] kW$_{el}$ installed, NPV: 623,000 €)
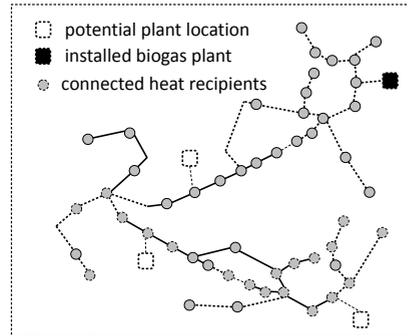
Figure 2: Heating network including all villagers (300 kW$_{el}$ installed, NPV: 566,000 €)

liquid manure is unavailable in this scenario, and the installation of electric capacity of the biogas plant is limited to the point where 60% of the generated heat is actually used in the heating network. Unprofitable households (that generate insufficient revenue to make up for their connection costs) are therefore connected to the grid, allowing for the installation of a larger biogas plant. The increased revenue from the added electricity production overcompensates the connection of the unprofitable households.

People's willingness to participate in bioenergy projects and receive locally generated heat also calls for consideration: Some people may prefer to use other heat sources for different reasons, whereas others may want to receive locally generated heat, even if their connection to the grid is economically unprofitable. Nevertheless, a bioenergy project could be beneficial even if some unprofitable heat customers are included – excluding villagers who would like to receive local bioenergy could endanger the entire spirit of local bioenergy projects and might thus lead to a cessation of the project (Ruppert, 2008). The effects of incorporating all villagers in the project are shown in Figure 2, which displays the optimal solution of the problem with the additional constraint that all households must be connected to the grid. Since here, all households are included with an overall heat demand of 956,000 kWh$_{th}$, the biogas plant has to supply 1,172,000 MWh per year with an overall heat loss of 18.4%. The optimal biogas plant capacity is still 300 kW$_{el}$, since the increased heat demand does not allow for the installation of a larger plant capacity, while still meeting the requirements of the Renewable Energy Act. The overall NPV is only 566,000 €, and thus lower than before, due to the connection of some unprofitable households.

The planning situation changes if liquid manure from livestock is available. This permits using liquid manure as a substrate for meeting the
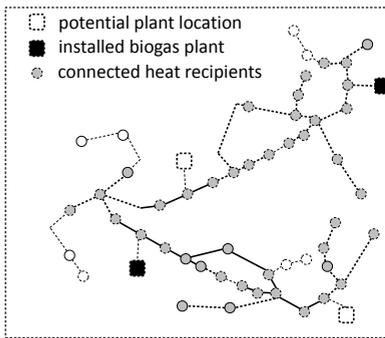
Figure 3: Optimal heating network with 6000 tons of liquid manure available (200 kW_{el} and 300 kW_{el} installed, NPV: 1,219,000 €)
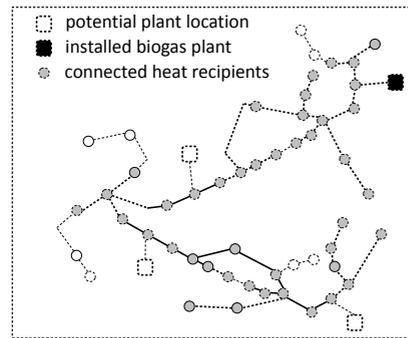
Figure 4: Heating network with liquid manure and one single plant with accumulated capacity of 500 kW_{el} (NPV: 1,451,000 €)

requirements of the Renewable Energy Act. Figure 3 shows the optimal course of the heating network and the location of two biogas plants with a capacity of 200 kW_{el} and 300 kW_{el}, in the case that 6,000 tons of liquid manure are available free of charge each year. The same 37 customers as in Figure 1 (with a total heat demand of 855 MWh per year) are connected to the heating network, and a total NPV of 1,219,000 € could be realized. This figure clearly demonstrates the economically optimal use of liquid manure as a substrate under the given legal restrictions. The heating network and the capacity of the heat-producing plant remain unaltered, compared to the scenario without liquid manure, and the manure is completely used in a second biogas plant, that does not supply any villager with heat. This effect is due to the fact that the additional use of liquid manure (in case 60% of the heat are used externally) does not allow for an increase in capacity. However, since an extended capacity and the corresponding additional electricity production is highly lucrative, a second power plant should be installed that uses liquid manure for 60% of its substrate.

Yet, the efficiency of a second biogas plant is lower than that of a single plant with an augmented capacity. The single plant can realise higher economies of scale, lower construction costs per kW of installed capacity, and a greater reduction of greenhouse gas emissions in comparison to two separate plants with the same accumulated capacity (Sievers, 2011). Figure 4 shows the optimal solution under the assumption that the additional use of liquid manure allows for the capacity expansion of the heat supplying biogas plant. In fact, the installed capacity is 500 kW_{el} in a single plant and the connected households remain unaltered. However, the overall NPV is significantly increased to 1,451,000 €, emphasizing the economic advantages and increased efficiency of a single plant.

The model presented here allows to analyse the economic effect of including all households of a village in a local bioenergy project. Furthermore, they can be used to investigate some effects of legal restrictions on the economically optimal solutions. Although the model excludes social or ecological aspects, it depicts most economically relevant facets of the present planning situation. Furthermore, the flexibility of the model offers the implementation of further parameters through the inclusion of suitable constraints. Thus, the optimized solutions provided by this model should be used as economic "benchmarks" and first indicators for feasibility, to support negotiations and decision-making during the planning phase of such a project.

4   Conclusion

Renewable resources are one major aspect, that must be considered on our way towards sustainable and decentralized energy supplies. Biomass, as one of such renewable resources, is a central aspect with special relevance for local heating systems, but also for demand-driven electricity supplies. The presented model offers decision support for the planning of a decentralized energy supply in bioenergy villages.

The planning of such a system is challenging, and requires the consideration of many different factors. Implementing an efficient, decentralized biogas facility already raises the difficulties of location planning and estimating the required capacity. When an additional CHP is installed, that supplies electricity and heat, problems of how to design the heating network and which households to connect to this network arise. Additional political and social issues are involved, e.g. legal restrictions or the acceptance of the affected population. All these concerns of decentralized combined heat and power supply complicate the planning and development of a bioenergy village. Therefore, appropriate models for operations research are needed.

The linear program presented here models this planning situation of a bioenergy village as a network with weighted links and nodes. The model allows for the simultaneous optimization of the connected heat recipients, the heating network, the number of CHPs, their capacity, and their locations. This optimization offers the possibility to assess and compare various different set-ups of a bioenergy village, thereby supporting the complex process of decision making. The results from the optimization can be further used to calculate break-even prices for the heat or estimate the dependency on governmental grants or allowances. Additional constraints can be included in the model to analyze various other aspects – such as biomass availability or participation of villagers. Even the representation of varying geographic conditions is possible by adapting the

economic assessment of the links as input parameters.

Further research should analyze the use of peak load boilers for the plants and take the load curve of heat customers into consideration. The uncertainty of the heat demand is another aspect that has to be investigated. However, the flexibility of the model already allows for the modeling and economic assessment of a wide variety of scenarios, and is thus suitable for covering a broad range of investment questions. We propose to use the systematic analysis of such planning situations to support the decision-making and the strategic planning of these investments and thereby contribute to the realization of efficient, decentralized energy supplies.

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Policy Options for the Harmonisation of Renewable Energy Support Schemes in the EU after 2020

A Multi-Criteria Decision Analysis

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Abstract

This paper applies the outranking method PROMETHEE to a policy decision problem regarding support schemes for renewable electricity after 2020. Three decision maker prototypes with different weighting vectors based on qualitative interview data are developed. The group decision analysis results indicate that a combination of bottom-up and top-down processes is the most likely compromise solution. It seems both acceptable to many stakeholders as well as politically feasible. A likely policy outcome could be a mixture of EU-prescribed minimum design standards (top-down) and stronger voluntary cooperation and coordination between groups of Member States (bottom-up).

1 Introduction

Directive 2009/28/EC (RES Directive) sets a target of 20% renewable energy as share of gross final energy consumption in the EU in 2020, specifying individual targets for each Member State. As a result, a variety of support regimes for renewable energy sources (RES) have been developed in EU Member States, ranging from feed-in laws to tradable certificate schemes, and from investment grants to tax deductions.

This paper presents an analytical framework developed in order to identify and assess policy pathways concerning harmonised renewable electricity (RES-E) support schemes after 2020. The paper further uses interim modelling and qualitative analysis results to assess a selection of policy pathways in more detail, applying the multi-criteria decision support method PROMETHEE.

2 Analytical Framework for the Assessment of Harmonisation Options

The analytical framework described in the following sections was developed in the *Beyond2020* project, financed by the European Commission under the *Intelligent Energy Europe* Programme. It details possible policy pathways (alternatives) and assessment criteria.

2.1 Policy Pathways

The current status quo for RES support, including RES-E is a common target framework with non-harmonised support schemes in each EU Member State. The current target framework remains in force until 2020. Table 1 shows how policy pathways for RES-E support after 2020 can be structured along two dimensions, i) the support instrument applied, and ii) the degree of harmonisation.

Four pathways in particular shall be subject of preliminary analysis in this paper (Resch et al., 2013):

- **Pathway 3a,** a quota scheme under full harmonisation: A binding European 2030 RES target exists. A technology-neutral quota scheme with tradable green certificates is applied in all Member States.

- **Pathway 5,** no dedicated RES support: No binding 2030 RES target exists, only a binding greenhouse gas emissions target is assumed. The main incentive for the deployment of RES is provided by the European emissions trading system (ETS). No voluntary national RES support is allowed.

- **Pathways 7a and 7b:** Extension of the current RES directive, with a binding 2030 RES target, broken down into Member State targets. Either moderate cooperation (7b) or strong coordination (7a) between Member States.

Table 1: Policy Options for the harmonisation of RES-E support schemes in the EU after 2020. Pathways 3a, 5, 7a, and 7b are subject of more detailed analysis. Source: adapted from Del Río et al. (2012a).

	Support instrument	FIT (feed-in tariff)	FIP (feed-in premium)	QUO (quota system with uniform TGC)	QUO banding (quota system with banded TGC)	ETS (no dedicated RES support)	TEN (Tendering for large scale RES)
Degree of harmonisation							
Full	•EU target •One instrument	1a	2a	3a	4a	5	6
Medium	•EU target •One instrument •Additional (limited) support allowed	1b	2b	3b	4b		Sensitivity to 7 (national support, but harmonisation for selected technologies)
Soft	•EU & National targets •One instrument •MS can decide on various design elements incl. support levels	1c	2c	3c	4c		
Minimum	•With minimum design standards for support instruments	•EU & National targets •Cooperation mechanism (with or without increased cooperation)	**7a Ref**erence :national RES support with strong coordination - *with minimum design standards*				
None	•No minimum design standards for support instruments		**7b Ref**erence: national RES support with moderate cooperation - *without minimum design standards*				

2.2 Evaluation Criteria

National RES support schemes have been evaluated against a number of criteria in the literature. Effectiveness, efficiency, and equity are frequently mentioned (Junginger et al., 2010; Lauber and Mez, 2004; Markard et al., 2004; Mitchell and Connor, 2004; Palmer and Burtraw, 2005; Reiche and Bechberger, 2004; Verbruggen, 2009; Yatchew and Baziliauskas, 2011). Del Rio et al. (2012b), after thorough literature research, define the following criteria for this analysis:

- *Effectiveness* refers to the extent to which a promotion strategy is capable of triggering RES deployment, measured against a reference quantity, for instance a RES target, or nationally available RES potentials (Del Río et al., 2012b). In this analysis, a target share of 30% renewable energy in gross final energy demand was assumed (except for the ETS pathway). Modelling results were used to quantify target fulfilment.
- *Static efficiency* (or cost-effectiveness) refers to the achievement of a given RES-E target at the lowest cost to society. Maximum efficiency, in accordance with the equimarginality prin-

ciple commonly applied in environmental economics, is reached when those firms with the lowest RES deployment costs are encouraged to deploy more RES, while those with higher costs deploy less (Del Río et al., 2012b; Verbruggen, 2009). Two alternative indicators are used in this analysis: Support costs and generation costs. Modelling results were used to obtain data.

- *Dynamic efficiency* refers to the extent to which a promotion strategy incentivizes continuous technical improvements and cost reductions in RES. Modelling data is used to assess two sub-indicators: i) the diversity of the renewables portfolio, based on the Hirschman-Herfindahl-Index for different RES technologies' 2030 share in renewable energy production; ii) a learning index is calculated from different RES technologies' reduction in investment costs (€/MW) between 2020-2030, weighted by the energy production from these new installations.

- *Equity* refers to a support strategy's distributive impacts on consumers, citizens, sectors, or firms (Del Río et al., 2012b). It is assumed that the most desirable situation is one in which consumers in each Member State carry the same financial burden, in relation to GDP. The standard deviation of support expenditures in 2030 (in % of GDP) in the 27 Member States is thus calculated for each pathway.

- *Environmental and economic effects* in this analysis will be represented by two indicators: The average annual greenhouse gas emissions avoided due to RES installed between 2021-2030 (expressed in bn €); and the average annual fossil fuel imports avoided due to RES installed between 2021-2030.

- *Socio-political acceptability* is based on semi-structured interviews with national decision makers (DMs) from seven Member States, centred on a questionnaire in which DMs had to assess the political attractiveness of each policy pathway in their country on a scale from 1-5 (1= "very unlikely to be politically feasible in my country"; 5= "very likely to be politically feasible in my country").

- *Legal feasibility* is based on estimate by legal experts on the complexity of the adoption procedure which would be necessary to introduce each pathway, on a scale from 0-10 (0= "difficult/impossible to adopt"; 10= "easy adoption procedure").

3 Multi-Criteria Decision Analysis for Selected Policy Pathways

3.1 Methodology

3.1.1 Selection of method

PROMETHEE (Brans et al., 1986; Figueira et al., 2005), a multi-attribute decision making method from the European school (outranking method), is applied to this decision problem, as it offers several benefits: It is suitable to structure a complex decision problem and to deal with contradictory information and incomparabilities between alternatives. It requires relatively little information from decision makers and is thus easy to apply in practice. Through the use of generalised criteria, PROMETHEE offers the possibility to avoid complete compensation between criteria, by setting different rules for how differences between alternatives are to be treated under each criterion. PROMETHEE further offers the possibility to analyse group decisions. In this analysis, the group algorithm by Macharis et al. (1998) is applied.

The analysis is carried out using a software tool developed by Hirzel (2013) at Fraunhofer ISI.

3.1.2 Specification of Input data

Table 2 summarises all input data. A specific rule was defined for the *socio-political acceptability* criterion, which strongly interacts with the *legal* criterion: Some pathways received a score of zero under the *legal* criterion, meaning that unanimity in the Council of the European Union would be required. If one or more Member State respondents indicated that this same pathway would be "highly unlikely to be politically acceptable in my country" (score: 1), then unanimity cannot be achieved and the pathway cannot be implemented. In the PROMETHEE calculation, this circumstance is taken into account by penalising all such pathways with an overall score of zero for the *socio-political acceptability* criterion.

To elicit weighting vectors, a survey and detailed stakeholder interviews were carried out. Based on the results, two stakeholder prototypes with strongly accentuated weighting vectors were developed. Real stakeholders move between these extremes, but often with a clear tendency towards one or the other:

- The Environmentalist: This type puts most emphasis on the short- and long-term development of RES, with a strong focus on environmental effects (GHG emissions).
- The Cost-concerned: In the recent European Commission's public consultation on the "Green Paper on a 2030 framework for climate and energy policies", a number of stakeholders argued against a 2030 RES target and thus an "ETS only" pathway for RES, mainly with cost-efficiency in mind. Among them were Member States such as the UK, Romania, the Czech Republic and Poland, and other stakeholders, often related to the conventional energy sector, such as Eurelectric, Eurogas, and FORATOM.

Thirdly, in order to balance the strong viewpoints of the above two prototypes, a third is introduced.

- The Pragmatic: This type puts strong emphasis on which policies are actually feasible, given socio-political and legal circumstances.

Finally, regarding PROMETHEE generalised criteria, the type 1 indifference function (usual criterion) was chosen for effectiveness. This simple preference function only distinguishes between strict preference and indifference. This seems a suitable choice for the *effectiveness* criterion, as the 2030 RES target either is or is not achieved. All other assessment criteria are treated with the type 6 indifference function (Gaussian criterion) for this analysis. Type 6 enables a continuous move from indifference to weak, then strong, and finally, strict preference. It is suitable for continuous data as available for the assessment criteria here. S-values were defined according to the methodology specified in Queiruga et al. (2008).

Table 2: Criteria fulfilment and PROMETHEE specifications for four selected pathways

Criterion	Desired direction	Fully harmonised quota (pathway 3a)	ETS (pathway 5)	Reference with strong coordination (pathway 7a)	Reference with moderate cooperation (pathway 7b)	Generalised criterion	s-value	Environmentalist	Cost-concerned	Pragmatic
Effectiveness (share of targeted 2030 RES volumes in %)	maximise	100	57.5	100	100	usual	-	20%	80%	20%
Static efficiency (support expenditures in bn €)	minimise	46.87	1.12	30.78	30.85	Gaussian	15.29	-	10%	10%
Dynamic efficiency										
Decrease in investment cost (%)	maximise	10.7	5.8	11.7	12.2	Gaussian	0.02	20%	10%	10%
Portfolio Diversity (Hirschman-Herfindahl-Index)	minimise	0.143	0.296	0.128	0.127	Gaussian	0.06	20%	-	-
Equity (standard deviation)	minimise	0.00396	0.00117	0.00205	0.00211	Gaussian	0.0097	-	-	-
Environmental and economic effects										
Avoided GHG emissions (bn €)	maximise	16.62	8.77	16.91	17.05	Gaussian	2.86	30%	-	-
Avoided fossil fuel imports (bn €)	maximise	66.42	31.03	57.59	68.92	Gaussian	14.30	10%	-	-
Socio-political acceptability										
Preference of national DMs *(mean score of 7 respondents, scale 1-5)*	maximise	2.12	2.67	3.46	3.04	Gaussian	1.15	-	-	30%
(number of respondents who gave a "1")		3	2	1	0					
Legal feasibility (rated 0-10)	maximise	0	0	8	10	Gaussian	3.33	-	-	30%

3.2 Results

Table 3 summarises the results for all three decision makers and the group, assuming that the decision makers have equal weight. The two reference pathways 7a (strong coordination) and 7b (moderate cooperation) perform in a similar way, no matter for which decision maker. REF-7b, closely followed by 7a, is the top-ranking pathway for both the Environmentalist and the Pragmatic, while pathway 5 (ETS only) ranks last. In contrast, for the Cost-Concerned, ETS-5 is most preferred, followed by REF-7b. Figure 2 visualises the PROMETHEE I result for the whole group. Pathway 7b (Reference with moderate cooperation) is the top-ranking pathway, followed by 7a (strong coordination). Pathways 3a (harmonised quota) and 5 (ETS only) are incomparable, but rank lower than the previous two.

A detailed decomposition of flows according to criteria is provided in Figure 1, which illustrates that only the *static efficiency* criterion results in positive flow for the ETS-5 pathway.

Table 3: Positive, negative, and overall outranking flows for decision maker prototypes and the group

Pathway	Environmentalist			Cost Conscious			Pragmatic			Group		
	$\Phi+$	$\Phi-$	Φ	$\Phi+$	$\Phi-$	Φ	$\Phi+$	$\Phi-$	Φ	$\Phi+$	$\Phi-$	Φ
ETS-5	0	0.9762	-0.9762	0.71606	0.19513	0.52093	0.17902	0.58433	-0.40531	0.29836	0.58522	-0.28686
QUO-3a	0.32935	0.0307	0.29865	0.06372	0.50393	-0.44022	0.06372	0.52589	-0.46217	0.15226	0.35351	-0.20125
REF-7a	0.33387	0.01695	0.31692	0.1839	0.22707	-0.04317	0.49199	0.07404	0.41795	0.33659	0.10602	0.23057
REF-7b	0.36062	0	0.36062	0.18884	0.2264	-0.03755	0.51259	0.06305	0.44954	0.35402	0.09648	0.25754
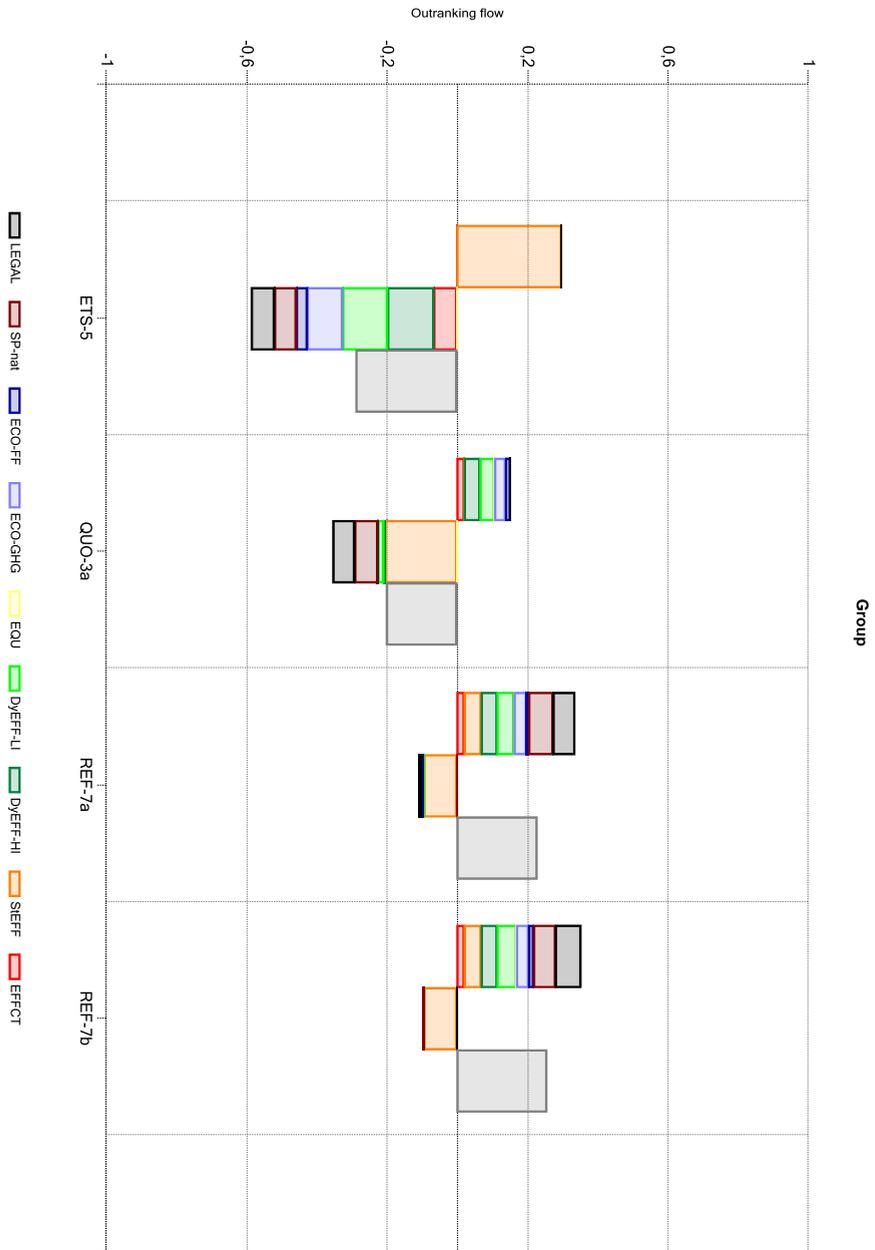
Figure 1: Decomposition of positive, negative, and net outranking flows according to criteria
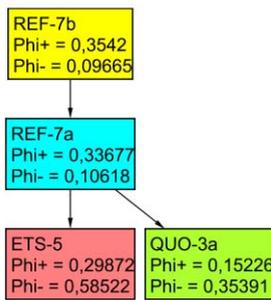
Figure 2: PROMETHEE I ranking for the group decision

Figure 3 shows a decomposition of flows according to decision makers. It illustrates how the Environmentalist's position has the strongest effect on the negative outranking flow of pathway 5 (ETS-only). The Pragmatic's strong contribution to positive flows for reference pathways 7a and 7b is due to the fact that he puts a strong emphasis on *political* and *legal feasibility*. Both pathways perform well under these criteria. The Environmentalist's preferred choices, though due to other criteria weightings, coincide with these politically and legally feasible options.
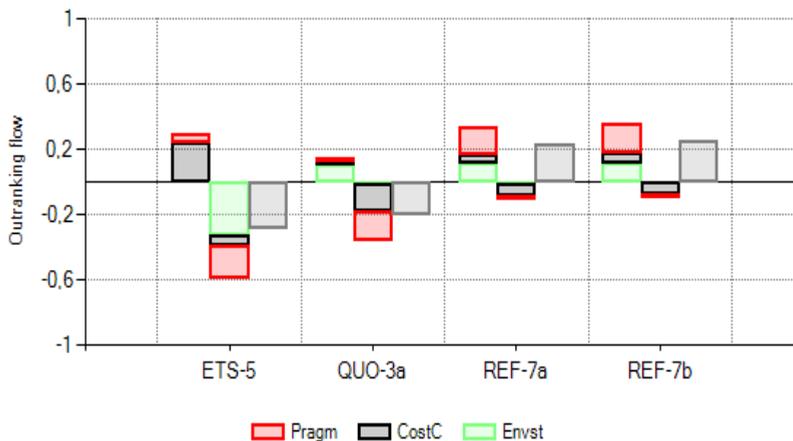
Figure 3: Decomposition of positive, negative, and net outranking flows according to decision makers

4 Conclusions

Preliminary modelling data, legal analysis results, and interview results for four pathways indicate that voluntary cooperation, or at most a pathway with minimum harmonisation, are a more likely compromise solution than those pathways where Member States would lose competence to implement their own support schemes. Only stakeholders who put very strong emphasis on the *static efficiency* criterion will favour the ETS-only pathway.

Taking the qualitative data from the interviews into account, a combination of bottom-up and top-down processes as assumed in pathways 7a and 7b seems both acceptable to many stakeholders as well as politically feasible. A likely policy outcome could be a mixture of EU-prescribed minimum design standards (top-down) and stronger voluntary cooperation and coordination between groups of Member States (bottom-up). Interviewees stress the importance of a reliable and transparent support system, which in some cases they viewed as even more important than the question on which instrument or harmonisation degree was chosen. Approaches similar to the fully harmonised technology-neutral quota system discussed in 2007-2008 and also favoured by some market-liberal stakeholders today, are unlikely to be feasible in practice for legal and political reasons.

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Techno-economic analysis and evaluation of recycling measures for iron and steel slags

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Abstract

The consumption of primary resources can be reduced by using secondary resources obtained by recycling industrial by-products. An essential group of by-products of the iron and steel industry are iron and steel slags. Iron and steel slags can be converted into secondary resources, e.g. road construction material, cements and fertilizers. To obtain intended secondary resources, different slags can be processed using multiple recycling measures. The recycling measures differ in a multitude of technical, economic and ecological variables. The concurrence of these variables does not allow a general statement concerning the advantage of specific recycling measures. An approach offering decision support taking all relevant variables into account is not known. This contribution introduces an approach providing decision support for slag recycling. The approach aims at short term recycling planning for iron and steel slags by means of a techno-economic analysis and evaluation.

Keywords

Techno-economic analysis, recycling, iron and steel slags, operative planning, process industries

1 Introduction

Primary resources are limited and scarcities lead to an irreversible price increase. Furthermore, the depletion of primary resources and its impact on the ecological system are scrutinized critically in sustainability debates (Huthmacher, 2012). The consumption of primary resources can be reduced by using secondary resources obtained by recycling industrial

by-products (Knappe et al., 2012). An industry characterized by versatile by-products is the iron and steel industry (Fröhling, 2006).

An essential group of by-products of the iron and steel industry are iron and steel slags. In Germany, the production of 42.7 million tons of crude steel led to the generation of 13.4 million tons of iron and steel slags in 2012 (Merkel, 2013). Thus, on average, the production of one ton of crude steel generates 314 kg of slags. Slags perform important metallurgical tasks and are inevitable for iron and steel making processes.

Nevertheless, slags are not considered waste and can be converted into secondary resources, e.g. road construction material, cements and fertilizers (Das et al., 2007). Depending on the slag and the intended secondary resource there are multiple recycling measures, depending on a multitude of technical, economic and ecological variables (Das et al., 2007; Endemann, 2012). From the perspective of an iron and steel producer this poses the question how slags are to be recycled since he is legally obliged to deal with accruing by-products (Endemann, 2012). Due to produce and location dependent constraints, a general statement concerning the advantage of specific recycling measures cannot be given. Besides, an approach offering decision support taking all relevant variables into account is not known.

This contribution introduces an approach providing decision support for slag recycling. The approach aims at short term recycling planning for iron and steel slags from an iron and steel manufacturer's point of view. To achieve this aim, in Section 2 the planning of slag recycling is addressed. Here the planning task and the relevant technical, economic and ecological requirements are described. Regarding these requirements, existing recycling planning approaches are discussed critically. In Section 3, a conceptual approach meeting the requirements is introduced. The approach is based on a techno-economic analysis and evaluation of recycling measures for iron and steel slags. The techno-economic analysis and evaluation features a quantity and a value structure. The quantity structure comprises an activity analysis and the value structure is based on management accounting. Subsequently, the quantity and value structure are incorporated into a formal mathematical model. In Section 4, the approach is discussed based on an illustrative example. The contribution closes with a conclusion and an outlook in Section 5.

2   Planning of slag recycling

2.1   Planning task and requirements

Planning slag recycling needs to comprise three dimensions. These are slag production, the application of slag recycling measures and the usage of recycled slags as secondary resources. Slags are produced in different sources and vary in composition and amount depending on the origin, e.g. blast furnace slag or steelmaking slag. According to composition and amount slags can be recycled in different ways. Depending on how slags are recycled different sinks, e.g. road construction or cement production can be supplied.

The three dimensions can be regarded as elements of a network structure consisting of sources, recycling measures and sinks. For this network the aim of operative recycling planning is to determine the relevant material and energy flows from sources to recycling measures to sinks with regard to quantities and values. In order to determine the material and energy flows three categories of requirements have to be considered. These are technical, economic and ecological requirements.

From a technical perspective, slag recycling is based on mechanical and chemical process engineering (Schicht & Guldan, 2011; Das et al., 2007). Therefore, the allocation of material and energy flows requires a sufficiently detailed representation of mechanical and chemical processes. In order to illustrate this, an example of a common recycling measure is given in Figure 1.

Figure 1: Common recycling measure for iron and steel slags

The starting point of the recycling measure is the generation of liquid slag. The liquid slag is led into a slag pit where it continually solidifies. After solidification the slag is processed through a configuration of crushers and screens in order obtain raw material similar to natural stone. Depending on the production units and actual operating points, the quality of the raw material can be influenced. An important quality attribute of the raw material is its particle size distribution (Rychel, 2001; Schicht & Guldan, 2011). The particle size distribution describes how many particles of a specific diameter are included in the raw material. An exemplary particle size distribution is given in Figure 2.

The curve shape of the particle size distribution is determined by the crushing aggregates processing the solid slag. In addition, the screening aggregates are used to separate different fractions of the raw material. For example the middle fraction of the raw material obtained by screening

ranges from 16 to 32 mm in particle diameter. Varying with the particle size distribution and the fraction range, there are different applications for the raw material as secondary resources, e.g. road construction material or coarse aggregates in concrete (Das et al., 2007).
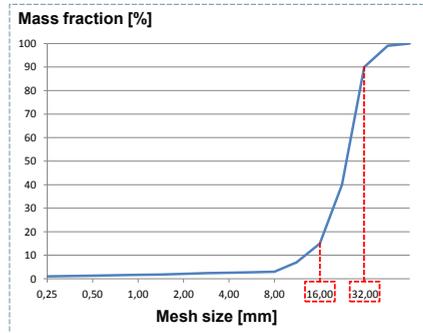
Figure 2: Particle size distribution

From an economic perspective slag recycling is characterized by recycling costs and revenues from sales of secondary resources. Determining recycling costs requires information on the relevant cost categories and their manifestation in a management accounting system. Determining revenues requires information on the target market for the secondary resources produced. Due to generally low revenues for raw material, the target market is characterized by regional sales depending on the local supply of secondary resources and seasonality (Knappe et al., 2012). Therefore, the attainable price for secondary resources depends on the quantities to be sold and the current season.

From an ecological perspective, slag recycling must comply with versatile regulations, e.g. legislation and standardization (Endemann, 2012). Among others, these regulations specify the chemical composition of recycled slags. Since iron and steel slags contain variable amounts of heavy metals for example, a slag exceeding the respecting limit values cannot be used as secondary resource in any sink.

2.2 Existing approaches for recycling planning

With regards to the three categories of requirements and the overall aim to determine the material and energy flows within the recycling network, potential planning approaches have to feature an appropriate quantity and value structure. Planning approaches incorporating these characteristics are techno-economic operations research models (Spengler, 1998; Schultmann, 2003). Promising approaches for planning the recycling of iron are steel slags are those addressing operative recycling planning in process industries especially focusing on iron and steel or building material

production (Spengler, 1994; Fröhling, 2006).

Process industries such as iron and steel or building material production are characterized by mechanical and chemical process engineering principles. Modelling processes based on these principles often results in high demands for the quantity structure of approaches focusing operative recycling planning (Spengler, 1998; Fröhling, 2006). In operative recycling planning, chemical processes have been addressed by thorough and versatile modelling (Fröhling et al., 2010). This applies to the fulfillment of technical as well as ecological requirements. On the contrary, mechanical processes such as the example illustrated in Figures 1 and 2 have only been partially considered. Although existing approaches, e.g. centering on recycling construction waste in (Spengler, 1994; Nicolai, 1994) or electric arc furnace dusts in (Fröhling et al., 2010) show similarities, the specifics of recycling iron and steel slags have not yet been incorporated into a planning approach.

Provided a sufficiently detailed quantity structure, the considered quantities are evaluated within a value structure. The value structure incorporates the relevant costs and revenues based on management accounting. In operative recycling planning, there are versatile approaches comprising cost modelling fulfilling the economic requirements (Spengler, 1998). On the contrary, revenues depending on local supply of secondary resources and seasonality have only been partially considered. Existing approaches, e.g. centering on recycling construction waste in (Spengler, 1994; Valdivia Mercado, 1995) show similarities, but require adaptation to the specifics of recycling iron and steel slags.

As described above, existing approaches show congruencies with the mentioned requirements, e.g. concerning the representation of revenues for secondary resources or their chemical composition. Nevertheless, there is no approach fulfilling all necessary requirements in technical, economic and ecological regard. In particular, this applies to the incorporation of technical specifics of slag recycling into a planning approach. Therefore, an approach is introduced in the next section.

3 Approach concept and model formulation

3.1 Approach concept

The approach is based on a techno-economic analysis and evaluation of recycling measures. The techno-economic analysis and evaluation features a quantity and a value structure. The quantity structure comprises an activity analysis and the value structure is based on management accounting.

The quantity structure is based on activity analysis, which has already been incorporated successfully in planning approaches for operative

recycling planning (Spengler, 1994). In the concept of activity analysis relevant recycling processes are represented through activities. Activities are described by activity vectors containing information on a defined number of input and output object types. Object types can represent material as well as energy flows, e.g. solidified slag, different mass fractions obtained by screening or electrical energy used in a process. These object types are represented in an activity vector which is given in (1) in its generalized form.

$$
\vec{z_i} = \begin{pmatrix} z_{i,1} \\ \vdots \\ z_{i,m} \\ z_{i,m+1} \\ \vdots \\ z_{i,m+n} \end{pmatrix} = \begin{pmatrix} 0 \\ \vdots \\ 0 \\ y_{i,m+1} \\ \vdots \\ y_{i,m+n} \end{pmatrix} - \begin{pmatrix} x_{i,1} \\ \vdots \\ x_{i,m} \\ 0 \\ \vdots \\ 0 \end{pmatrix} = \begin{pmatrix} -x_{i,1} \\ \vdots \\ -x_{i,m} \\ z_{i,m+1} \\ \vdots \\ z_{i,m+n} \end{pmatrix} \in \mathbb{R}^{m+n} \tag{1}
$$

The activity vector $\vec{z_i}$ consists of components $1, ..., m+n$ describing the transformation of object quantities. The transformation refers to a one-time application of activity i. Thereby negative quantities $x_{i,1}, ..., x_{i,m}$ refer to inputs whereas positive quantities $y_{i,m+1}, ..., y_{i,m+n}$ characterize output objects.

In order to represent a process an activity is combined with an activity level λ_i stating how often activity i is used. Formally, the combination of the activity and its activity level is achieved by defining technologies. A technology $\bar{T}$ allows to regard and combine multiple activities $i = 1, ..., I$ in a resultant vector $\vec{z}$ as shown in (2).

$$
\bar{T} = \{\vec{z} \in \mathbb{R}^{m+n} | \vec{z} = \lambda_1 \cdot \vec{z_1} + \cdots + \lambda_i \cdot \vec{z_i} + \cdots + \lambda_I \cdot \vec{z_I}, \lambda_1, \ldots, \lambda_i, \ldots, \lambda_I \geq 0\} \tag{2}
$$

$\bar{T}$ describes a linear technology. This type of technology implies a linear dependency between the object quantities transformed by an activity and its level. Since recycling measures for slags are primarily based on mechanical and chemical process engineering the application of a linear technology constitutes a potential oversimplification of the relevant processes (Rychel, 2001; Schicht & Guldan, 2011). In order to prevent inaccuracies multiple operating points are assigned to each process to incorporate possible non-linearities. Thereby an operating point describes a snapshot of a process to be modeled. By considering these snapshots, it is possible to utilize that activity analysis unlike production functions does not require functional relations (Spengler, 1998). Therefore, it is sufficient to model processes on the basis of representative snapshots. The necessary snapshots can either be obtained through empirical data or by means of simulation. By this means it is possible to incorporate a sufficiently detailed process description into the operative recycling planning for iron and steel slags.

For determining the material and energy flows within the recycling network regarding quantities and values, the quantity structure is supplemented with a value structure based on management accounting. This value structure comprises recycling costs and revenues for secondary resources.

In order to determine the recycling costs the activities in the quantity structure are evaluated on the basis of cost rates. The cost rates are obtained by assigning values to the quantities of the object types consumed or produced by an activity. Since the consumed or produced quantities are standardized to a onetime application of an activity, the absolute recycling costs are obtained by multiplying the respective activity level with the cost rate.

In addition to the recycling costs, the value structure needs to comprise revenues for secondary resources. To determine the revenues for a secondary resource its quantity and price are combined in a sales activity similar to the determination of the recycling costs. Other than the recycling costs the price depends on the sold quantity as well as the point in time when the quantity is sold due to the regional market. As a result, price functions are incorporated into the value structure (Spengler, 1994). In Figure 3, a general affine price function is given exemplarily.
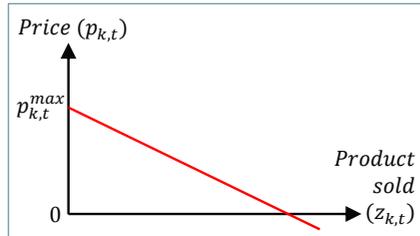
Figure 3: Affine price function

The affine price function implies that starting from a theoretical maximum price $p_{k,t}^{max}$ the attainable price $p_{k,t}$ continually declines with increasing sales $z_{k,t}$ to sink k in period t. The price might even be negative to represent the possible disposal of product amounts if the maximum capacity of a sink is exceeded. To describe seasonally varying demand the parameters of the price function are time dependent. Relevant parameters such as $p_{k,t}^{max}$ of the price function are obtained by using empirical data or market studies.

The quantity and value structure described above provide a flexible foundation for further adjustments such as incorporating the ecological requirements. For example integrating limit values for the chemical composition of secondary resources can be achieved by limiting the activity level of the respective sales activity.

To enable operative recycling planning based on the quantity and

value structure, the overall aim to determine the material and energy flows within a recycling network needs to be formalized. The aim is formalized by maximizing the contribution margin (Spengler, 1994; Fröhling, 2006). The contribution margin results from the difference of the obtained revenues reduced by the necessary operational costs. The operational costs feature the recycling costs and possible inventory costs for secondary resources. To render the approach applicable, the next subsection centers on a mathematical model formulation.

3.2 Model formulation

In this subsection, a mathematical model formulation for the conceptual approach is introduced. In the model the aim of maximizing the contribution margin is formalized on the basis of the developed quantity and value structure. The notation of the model is as follows.

The material flows in the recycling network are represented as quantities of objects j, determined for a considered period t. Object j can refer to input as well as output objects. The transformation of input objects to output objects is represented by recycling activities i. These recycling activities provide different operating points m. The objects representing secondary resources are allocated to compatible sinks k. On this basis the following model is derived.

$$Max \; CM \tag{3}$$

$$= \sum_{t=1}^{T} \sum_{k=1}^{K} p_{k,t}\left(z_{k,t}\right) \cdot z_{k,t} - \sum_{t=1}^{T} \sum_{j=1}^{J} c_j^s \cdot s_{j,t} - \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{m=1}^{M} c_{i,m}^r \cdot \lambda_{i,m,t}$$

subject to

$$z_{k,t} = \sum_{j=1}^{J} z_{j,k,t} \;\; \forall k,t \tag{4}$$

$$z_{j,k,t} \leq a_{j,k} \cdot \left(s_{j,t-1} - s_{j,t} + y_{j,t}\right) \;\; \forall j,k,t \tag{5}$$

$$s_{j,t} = s_{j,t-1} + y_{j,t} - \sum_{k=1}^{K} z_{j,k,t} \;\; \forall j,t \tag{6}$$

$$s_{j,t} \leq S_j^{max} \;\; \forall j,t \tag{7}$$

$$y_{j,t} = x_{j,t} + \sum_{i=1}^{I} \sum_{m=1}^{M} v_{i,j,m} \cdot \lambda_{i,m,t} \;\; \forall j,t \tag{8}$$

$$\sum_{m=1}^{M} u_{i,m} \cdot \lambda_{i,m,t} \leq U_i^{max} \quad \forall i,t \tag{9}$$

$$z_{j,k,t}, s_{j,t}, \lambda_{i,m,t} \geq 0 \quad \forall i,j,k,m,t \tag{10}$$

$$s_{j,0} = 0 \quad \forall j \tag{11}$$

The objective function (3) aims at maximizing the contribution margin being the difference between revenues for secondary resources and cumulated inventory and recycling costs. The revenues are obtained by multiplying the price $p_{k,t}(z_{k,t})$ with product quantity $z_{k,t}$ allocated to sink k in period t. Due to the market characteristics the revenue gained for a product depends on the product quantity allocated to a sink. The inventory costs for products are obtained by multiplying specific inventory costs c_j^s with the inventory quantity $s_{j,t}$ of object j in period t. The recycling costs are obtained by multiplying specific recycling costs $c_{i,m}^r$ with an activity level $\lambda_{i,m,t}$ for activity i in operating point m and period t. In addition to the objective function (3), the model incorporates constraints (4) to (11) which are explained below.

Constraint (4) describes the total product amount $z_{k,t}$ allocated to sink k in period t as sum of product amounts $z_{j,k,t}$, whereby $z_{j,k,t}$ represents the specific amount of object j allocated to sink k in period t. Hence, the overall demand $z_{k,t}$ of one sink k can be satisfied by multiple product amounts $z_{j,k,t}$.

Constraint (5) ensures that only compatible products are allocated to respective sinks. Here, the allocation of product amounts $z_{j,k,t}$ to a sink k is limited due to technical and ecological reasons using a binary parameter $a_{j,k}$. The parameter is multiplied with a large number $(s_{j,t-1} - s_{j,t} + y_{j,t})$ which is composed of possible inventory changes $s_{j,t-1} - s_{j,t}$ and the object quantity $y_{j,t}$ produced or consumed in the recycling network. Because of j representing input as well as output objects, $y_{j,t}$ represents quantities of input as well as output objects in period t.

Constraint (6) is the inventory equation. Thus, inventory quantities $s_{j,t}$ of object j in period t are equal to the inventory quantity in the previous period plus the production or consumption of object quantities $y_{j,t}$ minus the object quantities allocated to the entirety of sinks. Constraint (7) ensures that the maximum inventory capacity is not exceeded.

Constraint (8) connects the produced or consumed object quantities with an input parameter $x_{j,t}$ and the recycling activities. Therefore, a recycling coefficient $v_{i,j,m}$ is multiplied with the activity level $\lambda_{i,m,t}$ thereby determining the total object quantity produced or consumed.

Constraint (9) ensures that the execution of an activity does not exceed a given capacity. Therefore, the activity level $\lambda_{i,m,t}$ is multiplied with a utilization factor $u_{i,m}$.

Constraint (10) ensures that $z_{j,k,t}, s_{j,t}$ and $\lambda_{i,m,t}$ are nonnegative and Constraint (11) initializes the inventory quantities to be zero.

Apart from $p_{k,t}(z_{k,t})$ not specified in the general form of the model, the model formulation is linear and allows a simple representation of the underlying recycling planning problem. Depending on the actual choice of function for $p_{k,t}(z_{k,t})$, the model can become nonlinear. The following section centers on an illustrative example using linear price functions.

4 Illustrative example

In order to give an impression of the scope and the functionality of the model, an illustrative example is considered. The model was implemented in LINGO 14 and solved using a standard PC with 2.67 GHz and 4 GB RAM. The example network consists of one source, two recycling measures and three sinks, whereby two consecutive months are considered. The data used is oriented towards real quantities and values.

The source is given through a quantity of 90.000 t/month of blast furnace slag ($j = 1$) to be completely recycled. For recycling two activities can be used. Recycling activity 1 ($i = 1$) produces granulated blast furnace slag ($j = 2$) whereas recycling activity 2 ($i = 2$) produces air-cooled blast furnace slag in a coarse ($j = 3$) and a fine fraction ($j = 4$). Therefore, activity 2 features two operating points. Using the first (second) operating point 60 % (40 %) coarse and 40 % (60 %) fine fraction are produced. According to the activity and the operating point used specific recycling costs $c_{i,m}^r$ ranging from 2 to 3 EUR/t are considered. Each of the secondary resources produced is allocated exclusively to one of the three sinks ($j = 2$ to $k = 1$; $j = 3$ to $k = 2$; $j = 4$ to $k = 3$). In order to incorporate an attainable price $p_{k,t}$ depending on the total product amount $z_{k,t}$ and the selling period t affine functions as in (12) are considered.

$$p_{k,t} = p_{k,t}^{max} - b_{k,t} \cdot z_{k,t} \tag{12}$$

$b_{k,t}$ is determined by maximum prices $p_{k,t}^{max}$ ranging from 3 to 6 EUR/t and maximum product amounts $z_{k,t}$ of 80,000 t/month leading to $p_{k,t} = 0$. In order to include the possible disposal of superfluous product quantities negative prices are allowed. Furthermore, a slight increase in maximum prices is assumed for the second month on account of seasonality. Apart from allocation to a sink, product quantities can also be stored in the first period for specific inventory costs of 0.5 EUR/(t·month).

Due to the affine price function the described problem is quadratic and solved within less than one second by the LINGO solver. The solution of the numerical example leads to a contribution margin of 17,668 EUR. An excerpt of the results of the example is given in Figure 4.

Figure 4 shows the resulting material flows and product prices for

both periods. The specified 90,000 t/month of blast furnace slag are recycled using both activities in a relation of 21,648 (28,055) t granulated to 68,352 (61,945) t air-cooled blast furnace slag in the first (second) month. In both months air-cooled blast furnace slag is produced by using operating point 1 obtaining 60 % coarse and 40 % fine fraction.
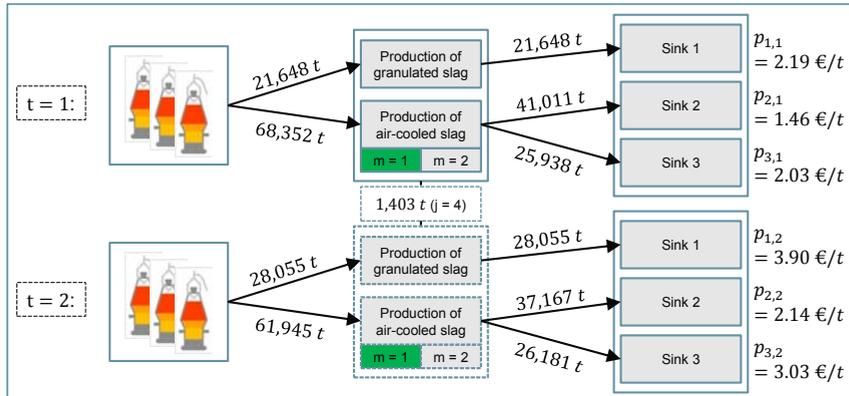
Figure 4: Optimal allocation of material flows in the recycling network

The secondary resources produced in the first month are almost completely allocated to the three sinks. Merely 1,403 t of fine air-cooled blast furnace slag are stored and allocated in the second month. This behavior can be explained by slightly higher prices for the products in the second month. The resulting product prices range from 1.46 to 3.90 EUR/t.

5   Conclusion and outlook

This contribution introduces a recycling planning approach for iron and steel slags. The planning task and the technical, economic and ecological requirements are described. Regarding these requirements, existing recycling planning approaches are discussed. Based on the planning task and the requirements, an approach and a model formulation are introduced. The approach and the model are illustrated using a numerical example.

Further research is necessary concerning two points. The first point is a sufficiently detailed representation of the mechanical and chemical recycling measures for iron and steel slags. The recycling measures depend on specific circumstances such as the actual technology, process configuration or operating point. Therefore, comparable empirical data is scarce. To allow a reliable representation of recycling measures by means of activity analysis simulation based approaches such as flowsheet simulation are promising. The second point is the choice and formulation of the price function leading to the revenues for secondary resources. Depending on

the actual price function, the model formulation can become complex, especially considering practical problem sizes.

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An Approach for the Assessment of Sustainable Supply Chain of Biomass

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1 Introduction

The supply chain of biomass is normally regulated by farmers and their access to other farmers' biomass. Either plants like crops or corn are grown as feed into the biogas fermenter or alternative substrates and manure is the feedstock. Very few farmers are connecting to get the best available biomass into their plant and the competition is very high. We identify a high pressure on biomass availability in the Northern Region of Germany and a high availability of manure. Biogas fermenter is always one step in the whole supply chain of biomass since the output of the biogas plant is used as fertilizer to the fields.

At Oldenburg University we developed a tool for stakeholders, municipalities or biogas plant owners to assess their regional potential of operating biogas plants with sustainable biomass usage. The tool shall help to highlight potentials for raising the sustainability factors in their operation. New in this approach is the variable emphasis on the sustainability pillars as economy, ecology and social stability.

Given the fact that there are some plants that achieve the highest Methane yield we often notice monocultures in the area where corn and raps plants are dominant. Monocultures are not accepted by the public and the soil is suffering as well. That problem is commonly known as the food versa fuel debate. Culture diversity on farm fields is more and more implemented with sometimes the drawback that the methane yield may not be as high compared to the high energy plants. In contrast the soil contains higher nutrients for varying cultures and the long-term output might be increased. Therefore on the short term we identify less methane pro-

duction but in the long term we yield more output. In contrast the fertilizer needed on the fields might decrease with the "right" culture mixture. This improves directly the environmental and furthermore sustainability impact of the plants and related processes.

Main targets to consider include:

- reduction of distance of the biomass to the production plant
- optimization of the biomass transportation (mainly by lorry)
- usage of alternative biomass (like road sides flower stripes)
- energy conversion into electricity or fuel and the usage of excess heat

2   Supply Chain Manager

With the help of an assessment model we are able to determine the best sustainable solution for biogas production. The working group Business Information Systems / Very Large Business Applications VLBA has developed a "Sustainable Supply Chain Manager" (SSCM) for the assessment of biogas solutions. This software is implemented using web-based techniques and so allows using the functionalities in a normal web browser. No plug-ins or additional Software has to be installed on the user's computer. The Manager is based on the Multi Criteria Decision Analysis methodology Promethee and allows the assessment of bioenergy project scenarios based on indicators and related weightings.

Using the software thus requires the definition of an appropriate scope of the project and its scenarios that are being considered. Starting with the definition of sustainability in the context of the project by specifying targets and finding appropriate indicators to measure these targets, the values for the indicators have to be measured or specified otherwise. The software is based on a five stages model that group the different aspects of a bioenergy supply chain:

1) Biomass Supply
2) Biomass Logistics
3) Production of Bioenergy
4) Distribution of Bioenergy
5) Usage of Energy

This approach allows a segmentation of different aspects of the considered supply chain scenarios for easier handling and more specific investigation. In addition, the software allows the visualization of the indicators of the scenarios to provide easier ways of comparing the scenarios and offer further stakeholder oriented communication possibilities.

First results are shown in the presentation with a focus on the coastal region in Northern Germany with practical insights of a maritime and a terrestrial area.

3   Case studies in Northern Germany

It is necessary to know and to describe the case areas for the realistic assessment of sustainable supply chains of biomass. The availability of biomass input into the biogas fermenter has to be addressed since the sustainable impact of biomass is less if the competition with food is low. Land use and biomass harvesting is a key factor for low environmental impact in biomass treatment.

Ammerland case study
The case study in Ammerland is represented by one biogas plant in the west of Westerstede city. The area is identified as terrestric and rural area which is dominated by farming activities. According to the biomass supply of the biogas plant three areas are taken into account for the area description:

-        Apen region
-        Westerstede area
-        Uplengen area

All areas can be considered as rural areas with more than 80% of biomass relevant areas. Also nature reserve can be identified with the most percentage in Uplengen area with mostly marshland and heathland as representative nature environment. Nature reserves with no biomass harvesting are considerably low in Westersted and Apen.

Dornum case study
The project area of Dornum contains two biogas plants that are investigated in our research. Dornum region has a maritime location due to its vicinity to the North Sea. The area comprises the dike line and the flood plains; also those zones might be of interest for its biomass usage. Coastal protection makes it necessary to continuously cultivate the dike´s green spaces. Hence, this territories offer great potentials if not used for sheep feed. Dornum farmers have to cope with difficult soil behavior since the plant growth is shorter compare to region in a terrestric location in Germany. Also the soil is very muddy and the trucks are coping hard with getting through. Even with a short distance of about 70km between the Ammerland case region and the Dornum region there are big differences in plant growth and farming the field.

4 Summary

The presentation is going to present a new software tool to assess biomass supply chains. It is developed for stakeholders, municipalities or biogas plant owners to assess their regional potential of operating biogas plants with sustainable biomass usage. The tool shall help to highlight potentials for raising the sustainability factors in their operation. New in this approach is the variable emphasis on the sustainability pillars as economy, ecology and social stability. Some first results are shown in the presentation.

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Multi-Criteria Decision Support within Corporate Environmental Management Information Systems

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Abstract

The present article describes a multi-criteria decision support system and its integration into a corporate environmental management information system (CEMIS). The integration is necessary because current CEMIS do not use their valuable information to guide strategic decision making. Especially small and medium sized enterprises will benefit from the system. It is based on reference points, which makes it relatively easy to understand. The reference points may be adjusted by the decision maker to act as saturation levels to match his/her preferences more precisely. To increase user acceptance the final results will be investigated with sensitivity analyses and an explanation system. Therefore, the system is suited to be used for a first assessment of possible business actions.

Keywords

Decision support, small and medium sized enterprises, sustainability, information system, reference points

1 Introduction

While scientific research about Corporate Environmental Management Information Systems (CEMIS) has begun nearly 30 years ago, they have become an increasingly important part of daily business routine in recent years (Fisher-Vanden & Thorburn, 2011). Firms which claim corporate social responsibility and/or start voluntary corporate initiatives to enhance their reputation, preempt legal sanctions, and want to manage their risks,

are dependent on such systems (Cruz, 2009). Additionally, more and more customers already include environmental aspects of products and services such as water consumption and carbon dioxide emissions into their buying decisions (Johnstone & Labonne, 2009). Companies which cannot offer such information might lose customers and will face decreasing market shares (Gonzáles-Benito et al., 2011). This challenge is especially decisive for small and medium sized enterprises (SME), as their economic future is strongly dependent on successful customer relations. CEMIS can provide companies with the required environmental related information and forward them to various stakeholders on the basis of material and energy flows (Gasbarro et al., 2013). However, currently available CEMIS usually offer only an operational perspective on the business processes. They focus solely on the current enquiry period and lack a strategic point of view (Teuteberg & Gómez, 2010). Newly developed CEMIS have to address this need for a strategic forecast which means they are also required to offer decision support.

In this paper a decision support approach is presented as part of an advanced CEMIS. It has been designed to be used by decision makers in SMEs to guide them in their strategic decision processes. Available information should be automatically preprocessed and integrated into the decision process in order to reduce the complexity for the decision maker while offering comprehensive decision support.

The paper is organized as follows: Section 2 gives a brief overview on CEMIS including their general purposes and current limits. In section 3 the interactive decision support tool is explained in detail, before section 4 gives a short conclusion.

2 Corporate Environmental Management Information Systems

Environmental Management Systems such as ISO 14000 series and the Eco-Management and Audit Scheme (EMAS) play an important role in either improving environmental performance and compliance or comparing environmental impacts of various enterprises with each other (Potoski & Prakash, 2005). These tasks are supported by CEMIS and "while there is more to environmental management than information, there is virtually no aspect which does not depend heavily upon the availability and accessibility of correct and current information" (Frysinger, 2001). Hence, the term subsumes computer programs which support executives in collecting, documenting and evaluating environmental relevant data (Page & Wohlgemuth, 2010). However, in the past, many companies which dealt

with environmental information solely did so, because they were obliged to fulfill governmental regulations. They were supported by traditional CE-MIS that assessed material and energy flows and reported environmental impacts to the appropriate institutions. Nowadays, more and more stakeholders, e.g. clients and investors, are also interested in this information. Additionally, executives recognized that, when used right, such information can lead to various improvements, for instance financial ones (Chan et al., 2012). However, only few companies used designated CEMIS to develop life cycle assessments and if they did most of them used Microsoft Office products (Lang-Koetz & Heubach, 2004).

This shows that CEMIS are not used to their full potential and that they mainly serve as a data source accounting legal compliance (Teuteberg & Gómez, 2010). The reasons are manifold. Firstly, the circumstance that some companies use tools like MS Office to work with environmental data may indicate that current CEMIS lack user-friendliness. Siegenthaler et al. (2005) estimate the period of introductory training for certain software products to be at least one day if the user is already familiar with the concept of LCAs. Furthermore, current solutions are not capable of being integrated into preexisting software architectures, especially ERP-systems (Teuteberg & Straßenburg, 2009). Additionally, current CEMIS lay a strong focus on the day-to-day business and gather environmental data concerning the past, which is appropriate for accounting legal compliance but does not support the management to incorporate environmental information into decisions regarding the future.

CEMIS should not be used solely as a documentary end-of-pipe solution but may deliver and store decision relevant information by appropriate interfaces and services. Therefore, CEMIS need to be further developed and integrated into corporations' IT infrastructure in order to handle services and processes which are necessary in current information flows (Heubach & Lang-Koetz, 2006; Joschko et al., 2009).

Once the systems are integrated into the current infrastructure and have access to decision relevant data they may also guide strategic decision making. However, this requires a system that is easy to understand, which takes the decision makers preferences into account and which provides an insight into the decision problem while providing the ability to integrate different (economic, environmental, and social) goals.

3 Multi-Criteria Decision Support

Multi-criteria decision aiding (MCDA) methods provide an appropriate way to analyze possible business actions (Behzadian et al., 2010). MADM

methods as PROMETHEE, ELECTRE, AHP and MAUT/ MAVT are well established among researchers, but can be intimidating to decision makers in companies. While larger companies could afford to spend money for a human analyst who will provide moderation during the decision making process, SMEs due to financial and personal restrictions, most certainly cannot.

The absence of a human analyst raises certain requirements that need to be addressed when offering decision support to SMEs. First of all, the method should be easy to understand. It is essential that the decision maker trusts the guidance given by the software. Without a human analyst who can describe the underlying concept of a method in detail, the decision maker is likely to refuse to accept the results if he does not know how the method works. This leads to another important requirement which shows that well-known approaches like PROMETHEE and MAUT may not be suitable in the present situation. They require inputs either via thresholds or preference information which are equally hard to conciliate to people who are not familiar with these concepts. Therefore, it is important to elicit preference information, so that the decision maker understands their explanatory power. Finally, time is a crucial factor. Decision makers and managers mainly expect reliable results with the least amount of time spent.

The proposed approach tries to address the aforementioned requirements with the help of an interactive decision support system. An interactive system is a system which is able to react to user interaction at any time and may be seen as a replacement for the missing human analyst. The system is able to react to user input, gives feedback accordingly and may point out conflicts which need further assessment by the decision maker. Additionally, it offers the possibility to mediate the underlying decision support methodology in an ostensive way which is based on reference points. Reference points are automatically made up of the best (Ideal) and worst (Nadir) values among alternatives (see Figure 1) and allow preference elicitation in conformity with the perceptions of the decision maker (Laux, 2005; Zeleny, 2011).
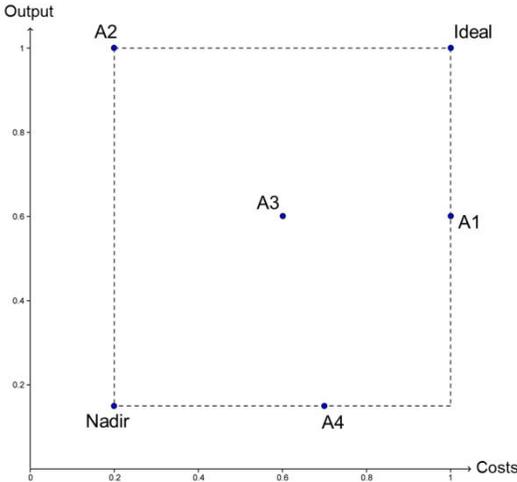
Figure 1: Reference points of a two-dimensional decision space

Figure 2 shows the individual steps which guide the decision maker. All in all there are nine steps of which the first three serve the preparation of the decision problem and are commonly found in MCDA methods. The last six steps enfold the aggregation and presentation of the results.
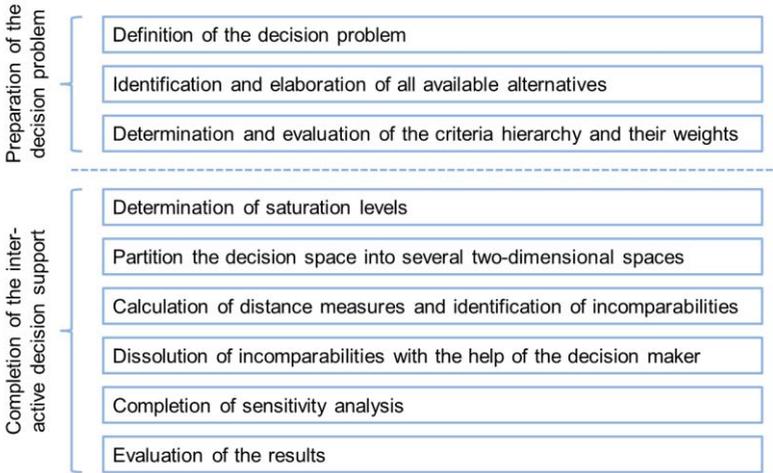
Figure 2: Overview of the decision process (following Oberschmidt, 2010)

3.1 Preparation of the Decision Problem

The decision support system starts with the definition of the decision problem. In a subsequent step the alternatives which need to be assessed have to be collected along with a first set of criteria. The decision maker is

advised to first arrange the criteria in a hierarchy and then allocate weights to each criterion. Besides a more structured weighting process which will avoid cognitive biases (Hämäläinen & Alaja, 2008) the separation of criteria will allow for a more detailed explanation of the final results in the end which will ultimately help the decision maker to get a better insight into the decision problem.

3.2 Solving the Decision Problem

After all criteria and alternatives are gathered, the decision support system determines the initial set of reference points based on the best and worst values for each criterion. The combination of the worst values generates a fictive alternative called 'Nadir' while the combination of the best values is called 'Ideal'. The decision maker can adjust these reference points based on his conceptions. A so called saturation level is able to constrain a criterion to a specific value. All alternatives which perform better will be treated only as well as the saturation level in the final assessment. This approach is advantageous if the decision maker is only interested in reaching a certain level of a criterion and does not want to treat it as a traditional "the more the better" criterion. For example if a machine has a high output which cannot be fully utilized because subsequent steps have a lower throughput, then the decision maker can set a saturation level equal to that lower throughput. Figure 3 shows the influence of a saturation level and how to constrain certain alternatives.
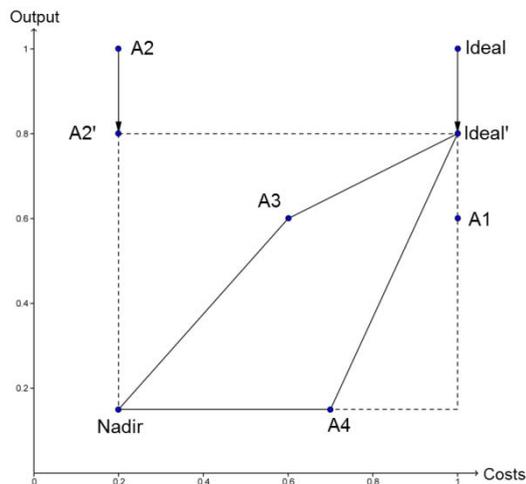
Figure 3: Setting a saturation level to constrain a criterion

Once the decision maker agrees with the reference points the next step is to divide the original multi-dimensional decision space into $((n-1) \cdot n) / 2$ two-dimensional spaces, where n is the number of criteria (see Figure 4).
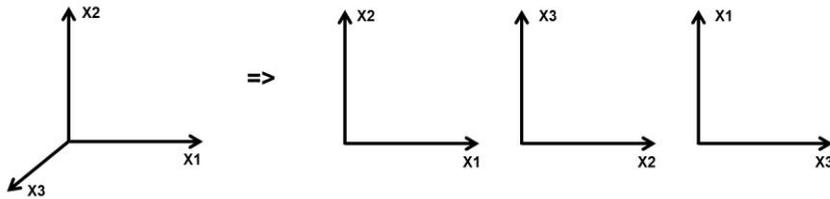
Figure 4: Splitting a multi-dimensional decision space into several two-dimensional spaces

This preparation is required because when dissolving incomparabilities between two alternatives at a later stage the decision maker can solely focus on two alternatives at a time. After that each two-dimensional decision space can be evaluated on its own.

The assessment is based on Euclidean distances as they were used in the TOPSIS approach by Hwang and Yoon (1981). The ad-vantage of this approach is that it is easy to understand. Basically, the assessment of alternatives follows an intuitive rule: An alternative is pre-ferred over another if it is closer to the Ideal and further away from the Nadir and two alternatives are indifferent to each other if both distances are the same. Yet, in traditional TOPSIS an alternative which is further away from the Ideal could perform better than an alternative closer to the Ideal. Opricovic and Tzeng (2004) argue that this is a disadvantage of the approach, because it seems non-intuitive to the decision maker. They proposed to weight both distances in order to solve the problem. While this approach solves the initial problem it raises another, namely that the decision maker is now forced to express weights for the distances and may not feel comfortable in doing so. Therefore, the present decision support system introduces the term "incomparable alternatives" whenever an assessment of alternatives is not distinct. An alternative is incomparable to another one if it is either closer to the Ideal and at the same time closer to the Nadir or if it is further away from the Ideal as well as from the Nadir. Figure 5 shows the different situations. A comparison of alternative 3 and 1 will favor alternative 1 because it is closer to the Ideal and further away from the Nadir than alternative 3. At the same time alternative 4 is evaluated worse than alternative 3 because it is closer to the Nadir and further away from the Ideal. However, the situation is not so clear when comparing alternative 3 and 2. Since alternative 2 is both, further away from the Ideal and from the Nadir the comparison is treated as incomparable.
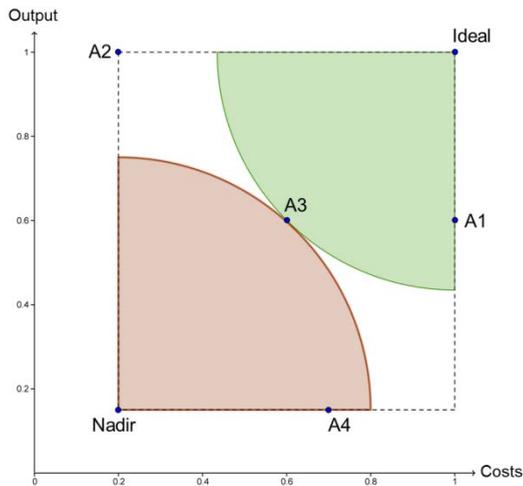
Figure 5: Incomparability between A3 and A2

In case of incomparabilities, the decision support system cannot decide on its own which alternative is better, it has to require feedback from the decision maker. He has to consider both alternatives and decide if he prefers one alternative over the other or if both alternatives are equal. But even with only two alternatives the assessment might be too complex for the decision maker due to the number of criteria. Hence, the decision space was reduced to two dimensions beforehand. The decision maker can give his feedback based on the assumption that all criteria are equal except the two under investigation. The complexity of the problem is reduced for the benefit of an easier assessment. Larichev and Moskovich (1990) used this procedure successfully in their ZAPROS-LM method. After the decision maker dealt with all incomparabilities, the assessments of all two-dimensional spaces will be recombined to retrieve a final result which is a rank order of all alternatives. Due to the interactivity of the system, the decision maker can adjust the reference points at any time and therefore influence the final result.

Once the decision maker does not wish to change the reference points anymore he can use different sensitivity analyses. The analyses will help the decision maker to strengthen his confidence in the final results. If he was not sure about certain criterion weights he can retrieve stability intervals for those weights and see until which value the result does not change. The same analyses can be performed on the reference points. A potential approach would be to calculate a value range for each reference point that indicates up to which values the final results will not change.

To further increase the understanding of the decision maker the decision support software contains an explanation system. Its primary task is to translate the assessments of alternatives and the findings of the sensitivi-

ty analyses in grammatically correct sentences that explain the facts rather than just providing plain numbers (Papamichail & French, 2005; Geldermann, 2010). Additionally, it provides reasoning explanations which elucidate the relations between criteria and alternatives. The decision maker is able to find out which criteria ensure that a certain alternative performs either well or badly.

4 Conclusions

Advanced CEMIS need to integrate a way to guide strategic decision making processes. Many decision problems will focus on the identification of suitable business processes, taking a multi criteria perspective. A simple comparison to best practices might not be a successful approach because either these processes are too unspecific or are not suitable for the current SME. Therefore, a multi-criteria decision approach needs to be used, however facing the dilemma between sophisticated methods requiring much time and input from the software users versus automated data analysis without much interaction. In the present paper, a method is being proposed which first uses as much information as possible automatically and only in a second step requires input from the decision maker. It aims to fulfill that task in a user-friendly and time saving manner, which is especially important for users from SME. The complexity of the decision problem is reduced by identifying target conflicts among alternatives and specifically asking the decision maker for his/her assessment. Though, the reduction which can be achieved is dependent upon the available alternatives and at worst can be close to zero if all targets are in conflict with each other. This way, the proposed method supports an understanding of the multi criteria character of decision problems. If only few criteria conflicts occur, a suitable solution for the decision problem can be found easily. In more difficult cases, a more detailed decision support and analysis should be sought for.

Acknowledgements

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Material consumption in the construction sector: resource efficiency from an inter-organizational perspective

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Abstract

Though construction activities and buildings represent a significant share of total material use and consumption, energy efficiency dominates the current discussion. This contribution provides an overview about starting points for improving material resource efficiency in the construction value chain and the life cycle of buildings. Peculiarities of the construction sector and buildings as its products are highlighted in comparison with other industrial sectors. One challenge is the variety of actors with changing roles and unclear responsibilities. Another is the long service lifetime of buildings with the possibility for refurbishments and adaptations. Furthermore, suitable indicators for measuring resource consumption and resource efficiency in the construction sector need to be developed.

Keywords

Built environment, material efficiency, reuse, recycling, value chain, actors, construction and demolition (C&D) waste, labeling.

1   Introduction

Construction covers both structural and civil engineering. The United Nations define construction as "economic activity directed to the creation, renovation, repair or extension of fixed assets in the form of buildings, land improvements of an engineering nature, and other such engineering constructions as roads, bridges, dams and so forth." (United Nations 1997). The construction sector is not only of high economic relevance, e.g. in the EU it accounted for 10.7% of the GDP, 51.5% of Gross Fixed Capital formation and 30% of the industrial employment in 2007 (Stawińska,

2010), it is also responsible for a significant share of environmental impacts, e.g. in the EU 42% of the total final energy and 50 wt. % of extracted materials (EC, 2007; ECTP, 2005). Furthermore, 35% of greenhouse emissions are connected to buildings and 22 wt. % of waste generation. Also material stocks in buildings are immense. Steger et al. (2011) estimate an amount of 8.6 billion tons of material in German traffic infrastructure of which 99% are mineral raw materials and the stock increase of the town of Vienna alone was estimated at 1.8 Mio. tons in 2001 (Merl, 2006). Accordingly, construction activities and buildings represent a significant share of material consumption for bulk materials such as sand, gravel, steel and wood and for other materials such as glass, PVC, copper etc. but also for fossil fuels and water. Whereas current discussions on resource efficiency in the built environment mainly focus on energy here the material side is addressed.

Resource efficiency has gained in importance in recent years and was addressed among others by the German Advisory Council on the Environment (SRU), the Study Commission on Growth, Wellbeing and Quality of Life of the German Bundestag and within the resource efficiency program of the German Government ProGress (BMU, 2011). In its strategy for sustainability the German Government set the target to double the raw material productivity from 1994 to 2020 (Bundesregierung, 2002). Having achieved a value of 147.5% in 2010 (Statistisches Bundesamt, 2012) with half of the set target left for the remaining 10 years puts a strain on the construction sector as one of the main raw material consuming sectors in Germany to realize further improvements.

This contribution provides an overview about starting points for improving material resource efficiency in the construction value chain and the life cycle of buildings. The focus lies on interfaces between different actors during the different life cycle stages of a building.

The remainder of this article is structured as follows. In section 2 an overview about measuring material use/consumption and material efficiency is provided. Section 3 addresses challenges for material efficiency in construction. After discussing several starting points for improving resource efficiency from an inter-organizational perspective in section 4, main findings are summarized in the conclusions.

2   Measuring Material Resource Efficiency

Resource efficiency is generally defined as the ratio between resource use and a desired output for which the resource is used ("doing more with less"). Operationalizing this simple definition introduces a number of problems discussed in the following.

2.1   Indicators for Material Use

Material use touches a variety of aspects including duration of use, exclusion of other uses at the same time, decrease in quality, dissipation or loss of the material after its use. When different materials are used they need to be aggregated into one (or several) efficiency figure. This requires a weighting of the different materials against each other. Straightforward but also very limited in its informative value is to use mass for weighting, sometimes used in combination with a differentiation into renewable and non-renewable resources. Other common weightings are based on their energy content (for fossil fuels), the mass flows associated with their supply or related to the scarcity of the material and consequences thereof (cf. Stewart & Weidema, 2005). In the following two approaches are briefly presented.

2.1.1   Material Input per Service Unit (MIPS)

The MIPS concept developed by Schmidt-Bleek in the 1990s measures the cumulative material input on a life cycle basis (Bringezu et al., 2009). MIPS differentiates between abiotic raw materials, biotic raw materials, earth movements, water and air of which the first three can be aggregated to total material requirement (TMR). Outputs such as emissions are neglected as covered in the inputs. The goal of the MIPS concept is to highlight the (hidden) rucksack associated with the use of materials.

2.1.2   Abiotic Resource Depletion Potential (ADP)

The Abiotic Resource Depletion Potential (ADP) developed at the Institute of Environmental Sciences (CML), University of Leiden, (cf. van Oers et al., 2002) is an LCA indicator to address resource depletion (cf. Klinglmair et al., 2013, for a recent review of impact indicators for resource depletion used in LCA). ADP uses the ratio between extraction from nature and the available resources in nature for weighting and offers three different resource bases to use: resources in the earth crust, reserve base and current reserves (van Oers et al., 2002). ADP is therefore similar to the

static lifetime concept in mining geology and has the same drawbacks. ADP is of high interest for the construction industry as it is the method which must be used in environmental product declarations (EPDs) for construction products (DIN EN 15804). The meaningfulness of the ADP concept for EPDs is highly questionable for various reasons. First, for many construction materials the market is rather regional or even local such that the global ADP characterization factors are not meaningful and developing regional ones is challenging. Second, the concept rather ignores the build-up of anthropogenic stocks and recycling. Third, dynamic aspects affecting either the resource base or the extraction rate are not accounted for.

2.2   Indicators for Material Resource Efficiency

Different options exist for setting material use in relation to an output and thus to define a material resource efficiency. The United Nations propose as indicators of sustainable development *domestic material consumption (DMC)*, i.e. domestic extraction plus imports, minus exports, and *material intensity of the economy* defined as DMC divided by Gross Domestic Product (GDP) at constant prices (United Nations, 2007). The German Government uses the reciprocal as indicator for raw materials productivity. Such indicators ignore hidden flows and are valuable for monitoring on the national or sector level only. For product level, other bases than GDP are needed, e.g. in case of buildings this could be floor area or building volume which introduces new challenges when the aim is to compare different buildings.

2.3   Recycling and Stocks

Indicators based on DMC account for recycling insofar as the DMC excludes recycled materials that enter production again. The use of DMC would be therefore useful in case of closed-loop recycling, i.e. the recycled materials enter the same product system again. Difficulties arise in case of open-loop recycling, i.e. recycling in which the recycled product enters a different product system. Then, first, DMC ignores downcycling and second, different options (Ekvall & Tillman, 1997, discuss eight options) exist how to allocate additional efforts for recycling and waste management as well as credits for avoided primary products between the product systems, each with its own advantages and problems.

Though recycling of construction and demolition (C&D) waste is practice in many countries, recycling rates and recycling quality levels differ strongly (Hiete, 2013). Furthermore, in general downcycling of C&D waste

such as the use of recycled aggregates in road construction and thus open-loop recycling prevails. As the built environment is far from equilibrium the shares of recycled material entering and leaving a product system (cf. UNEP, 2011, for clear definitions about recycling within and between product systems) might strongly differ and should be therefore clearly distinguished. In a closed-loop system with a build-up of stocks, waste recycling rates can be high even if input rates of recycling material are low.

In a case study for SW Germany, Hiete et al. (2011) showed that the expected demographic changes for Germany with reduced new construction and increased deconstruction, i.e. a decreased or even negative built-up of the built material stock, could lead to severe reductions in the C&D waste recycling rates if input rates of recycling material are not increased considerably. In other words: a system approaching equilibrium requires high-quality recycling whereas in a growing system C&D waste recycling rates can be high even if input recycling rates are low.

3 Challenges for Resource Efficient Construction

To increase material resource efficiency in the construction sector several challenges have to be addressed. These refer to buildings as the main product of the construction sector and to the structure of the construction sector.

3.1 Buildings

Buildings differ with respect to several aspects from other industrial products. These include the long lifetime of more than several decades, a structure of partly independent layers with different lifetimes such as windows and walls and the possibility to adapt the building to changing needs, e.g. by changing walls or adding a floor. From the material efficiency perspective these aspects are partly ambivalent. The long lifetime reduces turnover of materials and thus material losses always associated with recycling (cf. Hiete et al., 2011). However, 'building for eternity' may be also more resource consuming. In case the building's service lifetime ends prior to its physical life time, e.g. for economic or aesthetical reasons (cf. Bradley & Kohler, 2007), the additional material investment does not pay back. A long lifetime may also inhibit innovation which can be most easily realized in new construction. This may result in an inefficient building stock as is the case in Germany where the energy refurbishment rate is in the order of

1% instead of 2% as required to significantly improve the energy efficiency of the building stock (BMWi/BMU 2010). This is problematic as not only construction and end-of-life cycle stages are resource intensive but also the long use stage. The layer concept offers on the other hand the possibility to fundamentally refurbish and adapt the building to new needs while reusing a large part of the materials stored in those layers with a long lifetime.

The long time span of several decades between incorporation of materials in a building and their recycling poses additional challenges for recycling. Future recycling needs to be anticipated. This could be higher than today, e.g. due to better and/or more economic recycling techniques or scarce virgin materials. But it could be also lower, e.g. in case there will be new construction materials such as ultra-high performance (UHP) concrete reducing the demand for recycling (RC) material from today's concrete, or even obsolete, e.g. in case that recycling of a particular material becomes uneconomic or its quality too low for further use. Accordingly, Vieira & Horvath (2008) propose to use the term recyclability (an alternative would be recycling potential) instead of recycling and current technologies in the assessment.

3.2 Construction Sector

The construction sector is characterized by a large share of small and medium-sized enterprises (SMEs) acting on a local to regional market and by a large variety of actors (Kühlen et al., 2011, cf. Table 1). The construction supply chain differs from other sectors in several ways. In their review Segerstedt & Olofsson (2010) mention among others one-of-a-kind products, temporary organization and on-site production and in particular the different contractors and designers involved and the changes in the position within the supply chain from one project to another.

From the perspective of material resource efficiency, these peculiarities have several disadvantages. The strongly varying framework from one project to another makes stepwise resource efficiency improvements difficult and the dominating role of SMEs hinders the diffusion of innovations. On-site construction as such is also in general associated with a higher share of material getting broken and being spoiled. Maybe even more important are the different actors with varying roles leading to a situation with unclear responsibilities for the construction product, not to mention the following lifecycle stages with the possibility of refurbishments and adaptations. This makes developing a producer responsibility very difficult.

Table 1: Actors in the construction sector (modified after Kühlen et al., 2011)

Stage	Involved actors (examples)	Major activities
Design	– Project developers – Urban planners – Architects – Engineers/structural designers – Consultants of real estate owners	– Building/structure location – Building/structure design – Statics
Construction process	– Construction companies – Craftsmen	– Building/structure construction (envelope, interior, electricity)
Usage, maintenance	– Facility management companies – Real estate owners – Users – Construction companies – Craftsmen	– Building/structure operation (heating, electricity, cleaning) – Maintenance – Refurbishment
Deconstruction	– (De-)construction companies – Recycling companies	– Building/structure deconstruction – Waste disposal / recycling

4 Resource Efficiency from an Inter-organizational Perspective

After mentioning the challenges for resource efficiency in construction, in the following starting points for improving material resource efficiency from an inter-organizational perspective are briefly discussed.

A key role for material efficiency plays the design of the building and thus the interaction between the building designer and the client. The latter is not necessarily the user of the building such as in an apartment building. Though it is the designer who decides about the materials and their incorporation in the building which influences their recyclability the designer is bound to the wishes of the client. To support the discussion between designer and client Hiete et al. (2008) proposed to use multi-attribute value theory (MAVT) as this might help to better account for decision criteria other than price in the counseling interview between the

designer and the architect. A problem here remains, however, the lack of adequate material resource efficiency indicators as explained above. The designer might use Environmental Product Declarations, a type III eco-label (DIN EN ISO 14025) designed for business-to-business communication, as information base regarding the environmental criteria including abiotic non-fossil and fossil resources (DIN EN 15942). Life cycle stages other than the production of the construction product such as use stage or end-of-life stage are provided as scenarios in EPDs. A drawback here lies in the fact that EPDs provide only information about the abiotic depletion potential (ADP) but not the material intensity (see above) and thus ignore the input of materials such as gravel, stones etc. As there is partly a trade-off between material use during construction, e.g. for insulation material, and material consumption during the use stage in form of fossil fuels and related material flows, an integrated view is necessary. The MIPS concept might be useful to show such trade-offs but does not account for recyclability. Comparing today's with future material consumption might be also problematic and poses the question of discounting.

In contrast to EDPs building rating systems are designed for business-to-consumer communication. The German BNB and DGNB systems therefore provide not only a matrix with detailed results in the up to 50 criteria but also highly aggregated information in the form of a bronze, silver and gold certificates (BMVBS, 2013, DGNB, 2009), this, however, at the expense of information which criteria contributed most to the positive evaluation. For new office buildings the BNB systems considers under 'technical quality of the construction work' the easiness of deconstruction, the purity of the waste fractions and their recyclability with together 5.625% of the total score. Material consumption or the use of recycled materials is only indirectly accounted for in other environmental aspects such as greenhouse warming or acidification potential (cf. BMVBS, 2013). A MIPS based indicator could account for this.

Another starting point is the communication about the material content of the building allowing a better planning of maintenance, refurbishment and deconstruction. So far even in relatively new buildings such information is scarce and inventorying in the built building is complex (cf. Raess et al., 2005). The estimation of the materials content prior to deconstruction is often rather inaccurate. Woidasky et al. (2013) report typical uncertainties in the order of 30 to 50% for metal content. A material pass accompanying the building over its service life might improve this situation. It might be also helpful for detecting materials identified as hazardous after construction such as asbestos. With increasing prices of raw materials such a pass could also be useful for the estimation of the actual or residual value of the building. The pass could be developed by the designer based

on the EPDs and be part of the documents of the construction permit to ensure that it will not get lost over the long time span.

5   Conclusions

The construction sector and buildings differ in many respects to other industrial sectors and their products. Examples include the dominance of SMEs and manual work, make-to-order production on site involving a large number and heterogeneity of actors, an undefined often unique end-product with several layers subject to adaptations and refurbishments and the long service lifetime. Therefore, instruments from industrial production to foster resource efficiency are rather unsuitable, e.g. producer responsibility in view of the unclear roles and limited control possibilities over the service lifetime or stepwise improvements in a constantly changing framework. Consequently there is a need for supporting communication between the different actors such as EPDs for business-to-business and building rating systems for business-to-consumer communication and assistance in the design stage such that other criteria than price can be better communicated.

A problem is the lack of adequate resource efficiency indicators. The resource depletion indicator ADP used in EPDs is not meaningful for locally traded materials such as gravel or stones. MIPS could overcome this and account for hidden flows as well as trade-offs such as between increased material demand for insulation material and reduced consumption of fossil fuels and related material flows but does not account for recyclability of the materials. Thus an approach combining several indicators seems necessary. The BNB system accounting for easiness of deconstruction, purity of the materials and their recyclability goes into this direction. Anyway, due to the long service lifetime, many uncertainties regarding the best strategy for material efficiency will persist.

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A Material Flow-based Approach for the Economic Assessment of Alternative Landfill Mining Concepts

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Abstract

An entire landfill mining with waste processing and recycling can be seen as an alternative to landfill aftercare as well as an option to avoid pollution and to recover huge areas by land recycling. To realise an entire landfill mining, economic profitable landfill mining and waste processing concepts have to be identified. Therefore, we develop an approach for assessing alternative landfill mining and waste processing concepts in comparison to landfill aftercare. Our approach consists of four steps. First, mapping type and quantity of material flows by activity analysis. Second, calculating total costs of landfill mining and waste processing concepts according to "the material flow based environmental cost accounting" introduced by Spengler (1998). Third, comparing the total concept costs with aftercare costs and finally, considering uncertainties by scenario and sensitivity analysis. On that basis, it is possible to develop a decision support model, which facilitates decision making in terms of the selection of profitable landfill mining and waste processing concepts and the identification of the most profitable alternative, either landfill mining or landfill aftercare.

Keywords

Landfill mining, waste processing, economic assessment, material flow modelling, activity analysis.

1 Introduction

Exploitation of secondary raw materials by recycling is an opportunity for industrial nations like Germany to secure raw material access and reduce

import dependency by their own anthropogenic deposits. Therefore, the German federal government pursues resource orientation and sustainability. Hence, Germany wants to double its raw material productivity until 2020 (BMBF, 2012). Moreover, the revision of "Closed Substance Cycle and Waste Management Act" (KrWG) 2012 emphasises waste recycling, which promotes the consciousness of waste as a resource (BMU, 2012).

One option to recover secondary raw materials is landfill mining in combination with processing and recycling of the landfilled waste. The economic potential of secondary raw materials in landfills is high. German waste that has been landfilled since 1975, contains iron, copper and aluminium, approximately amounting to € 9 billion and high calorific fractions amounting to € 60 billion in oil equivalents (Fricke et al., 2012).

An entire landfill mining avoids possible pollution and shortens long-term landfill maintenance, also called landfill aftercare. Landfill aftercare includes landfill leachate or gas collection and clarification as well as plant and infrastructure maintenance (Stegmann et al., 2006). In case, pollution occurs, e.g. leachate reaches ground water, immediate actions, like an extensive ground water treatment, have to be executed. These actions also belong to landfill aftercare. The required maintenance duration is hardly predictable and varies from 30 to 200 years which leads to extensive costs over time. Furthermore, landfills need a lot of space and are partly located close to residential areas. An entire landfill mining facilitates land recycling, which can result in high revenues depending on the landfill position (Fricke et al., 2012).

Landfill mining with waste processing and resource recycling as an alternative to landfill aftercare, has not been conducted so far. Therefore, the development of sound landfill mining and waste processing concepts is needed. In order to develop these concepts, sound processes and process combinations for treating all the different material flows of landfilled solid waste are to be chosen. For each material flow a plurality of specific treatment processes is possible. Hence, the concept development depends on the specific waste constitution. The treatment process combination decides on the quality and quantity of the generated material flows which influence the achievable product revenues. In addition, treatment process combination determines mining and processing costs. As shown above, to identify profitable landfill mining and waste processing concepts, several, partly correlated factors have to be considered. This impedes the assessment of the alternative concepts.

Against this background, the aim of this contribution is to develop an approach for assessing alternative landfill mining and waste processing concepts in comparison to landfill aftercare. The approach bases on concept specific material flow models to describe kind and quantity of varying material flows. Therefore, landfill mining technologies, waste treatment

processes as well as technical and economic challenges of concept configurations are explained in chapter 2. Based on that, in chapter 3, requirements are derived and the material flow-based approach for assessing the alternative concepts is introduced. Finally, the results are discussed and options for further research are shown.

2 Landfill mining and waste processing

2.1 A general landfill mining process

In general, a landfill mining process comprises six steps: exploration, aerobe stabilization, mining and transport, conditioning treatment, material specific treatment and resources recycling respectively residues disposal (s. Figure 1).
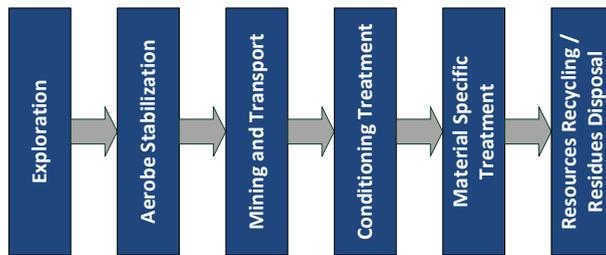
Figure 1: A general landfill mining process

Step 1, landfill exploration investigates the waste composition and constitution in different landfill storage areas based on historical data and material analyses by test drillings. In case of high landfill gas emission step 2, aerobe stabilization, is required for employment and climate protection by converting landfill environment with low oxygen content into one with high oxygen content. The first two steps serve mainly for landfill mining preparation. The actual landfill mining itself starts with step 3, mining and transport. Waste is excavated and transported to the subsequent processing plant by dredgers, wheel loaders and trucks. During this step, first disturbing materials are sorted out, like car tires or carpets. In step 4, the excavated waste is conditioned by screening and sorting which separates the waste into few heterogeneous material flows. These material flows are specifically treated by further separation or processing in step 5. The combination of step 3 to 5 leads to high variety of processing alternatives. Depending on the extent of processing, the recycled fractions can either be sold on the market or used as substitutes for fuel or building material without causing any costs. Residues that cannot be recycled have to be

landfilled again. However, the aim of an entire landfill mining is to mini-mize the amount of material that needs to be landfilled again (Fricke et al., 2012; Dörrie et al., 2000).

Material specific treatment processes for landfilled waste are missing so far. Therefore, modifications of existing treatment processes for cur-rently accumulated solid waste as well as development of new treatment processes are needed (Fricke et al., 2012). Most of the previous landfill mining projects were pursuing other objectives like gaining storage space, groundwater protection or landfill reconstruction (Budde et al., 2002). Hence, only a landfill rearrangement was necessary. Material specific treatment processes for landfilled waste will be introduced in the following section.

2.2   Material specific treatment processes

There is a wide range of conventional treatment processes that can be adapted or used as a basis for the material specific processing of landfilled waste. Which treatment processes suite best, depends on the specific properties of the input material and the required output quality. Conven-tional treatment processes are divided in three classes: mechanical, thermal and biological treatment. Each class can be further differentiated into sev-eral subclasses, whereby each subclass contains a plurality of treatment processes.

Mechanical treatment includes milling, screening and sorting. For milling, different machines like shredders, ball or hammer mills are used, depending on physical material properties (e.g. brittle or elastic). Screening separates material by its particle size, e.g. with a trommel screen. Sorting uses physical properties like density, magnetic properties, weight or electri-cal conductivity for separating materials with appropriate machines, e.g. ballistic separator, magnet or air classifier (Kranert et al., 2010).

Relevant thermal treatment processes are drying, pyrolysis, gasifica-tion or incineration. An established process for disposal is incineration in a waste incinerating plant (Kranert et al., 2010).

Aerobic or anaerobic biological treatments are suitable for materials with higher organic percentage. Aerobic composting is used to stabilise the waste by decomposing the organic fraction. Anaerobic digestion converts organic materials into stabilised residues and biogas (Kranert et al., 2010).

2.3 Configuration of landfill mining and waste processing concepts

Out of the just introduced treatment classes, technically suitable processes can be chosen and combined to landfill mining and waste processing concepts. So, several concepts with concept specific process combinations are generated. A certain process combination has dedicated material flows. Hence, material flow directions vary with the chosen concepts. The more processes are integrated in a concept, the deeper is depth of processing which leads to more differentiated material flows or products with higher quality. Configurations of the concepts can be made according to the landfill mining process (s. section 2.1), step 3 to 6. When choosing material flow specific treatment processes (step 5) landfill specific waste compositions and required product properties have to be considered. The latter determine the profitability of a product sale (step 6). Variation of waste composition and purchasers' requirements on products will be explained further in the following two paragraphs.

In order to choose suitable treatment processes to configure a concept for a certain landfill, the properties of landfilled waste as process input are to be taken into consideration. These properties, like waste composition and constitution, are landfill specific and depend on the point in time of waste storage, on the landfill location and the landfill operation. The point in time of waste storage serves as an indicator for the legal situation and along with the landfill location, for respectively established regional waste-management concepts. This allows for conclusions to be drawn on the level of separate waste collection and, due to this, on the kind and constitution of the landfilled waste. Waste composition is also influenced by further location-specific factors like regional consumer behaviour, rural or urban areas, commerce and industry close to the landfill. Landfill operation includes the landfill construction, ventilation and surface impoundment, which influences biological and chemical reactions of the waste over time. These reactions lead to leachate and landfill gas production. Landfill constitution can be described by parameters, like water content, organic ratio, also called TOC (total organic carbon), breathability after four days, glowing residue, biological and chemical oxygen demand (Kranert et al., 2012).

In addition to waste properties, a treatment process combination of a concept also has to comply with the required product properties. To recycle as many material flows as possible they have to fulfil consumer specific requirements. The more requirements are fulfilled, the higher are the prices for material flows, which influence material flow costs or revenues. Expected products of a landfill mining are metal fractions, inert materials, plastics and high calorific fractions which can either be sold or re-

used without causing costs. Steel works require a minimum of 85% iron in iron fractions from waste incineration to reuse them (BDSV, 2010). Inert or mineral material as stones, sand or soil are separated in a mechanical sorting process as well as remain in the output of thermal or biological treatment. Depending on pollutant load, composition and particle size distribution, this material flow can be used as construction material. Critical values that define material application areas are recorded in the "messages no. 20" by "the working group on Waste of the States of the Federal Republic of Germany" (LAGA M20) (LAGA, 2003). If materials fulfil the LAGA M20 Z2 standard, they can be used for road construction. Otherwise materials can only be used for construction work on a landfill. For landfilled plastics, like yogurt cups or plastic bottles, processing to plastic granulate is theoretically possible. Therefore, a sensor based separation in different kinds of plastic is required. However, plastics are to be rather clean which is contradictory to their landfill origin. So, the technical feasibility of landfilled plastic sorting is not proven yet. High calorific fractions consist of textiles, paper, plastic sheets and wood and can be used as "refuse derived fuels" (RDF) in power plants or for cement production. Depending on the application area specific requirements for calorific value, water content and heavy metal contamination are to be met. If no material recycling is possible, residues have to be landfilled again. Therefore, pollutant load of residues determines the landfill class, which is defined in the German landfill regulation (DepV §2 No. 6-10).
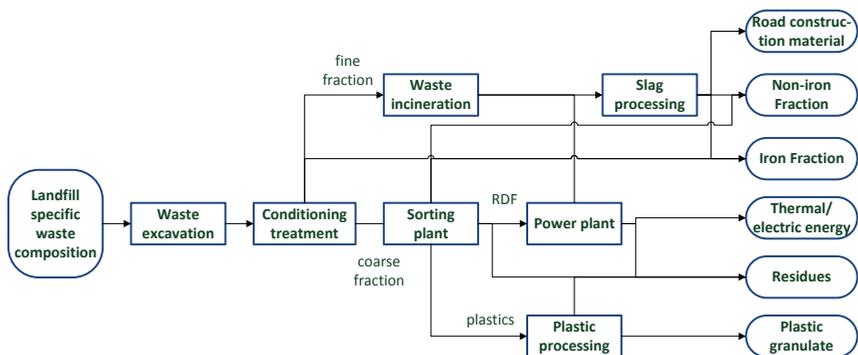
Figure 2: Exemplary landfill mining and waste processing concept

As an example, Figure 2 shows a complex concept with a high depth of processing. After waste excavation, the conditioning treatment can take place either directly on the landfill or in the mechanical treatment processes of a mechanical biological treatment (MBT) plant. There, input material is screened and sorted. This process leads to a fraction with increased iron concentration, a coarse fraction due to material particles with big a diameter and a fine fraction with small diameter particles. Next, the generated

material flows are specifically treated. In a sorting plant, the coarse fraction is separated in several material flows, into a fraction with low density, one with high density, iron and non-iron fractions. The low density fraction usually has a high calorific value, thus, it is used as RDF in a power plant, which produces electric and thermal energy. From the low density fraction, a separation of 3D-plastics could be possible for processing plastic pallets or granulates. The high density fraction consists of stones, construction waste and other inert materials that can be processed to road construction material. The fine fraction can be removed by a classic waste incineration, to reduce volume, TOC and to reach eluate stabilization due to decreased pollutant load. By incineration process generated ashes and slags are processed in a specific slag treatment. Again, metals and construction material can be separated. If required, the described processes can be extended in any direction, e.g. quality of metal fractions could be increased by pyrolysis before they are sold to metal working industry. The most profitable number of processing steps of a certain material flow is to be identified by an economic assessment of the alternative concepts.

2.4   Challenges by identification of profitable concepts

To decide, whether an entire landfill mining with waste processing is preferable to long-term landfill aftercare, at first, profitable landfill mining and waste processing concepts have to be identified. As already mentioned, the concept selection decides on the depth of processing and on the treatment process combination. This influences quality of the generated material flows which determines the achievable product revenues. However, extensive material flow treatment processes result in higher process costs. When making the decision on the depth of processing, it is necessary to investigate whether higher processing costs are compensated by increased revenues for high quality products. Furthermore, waste composition and the current development of prices for secondary raw materials have to be considered. Reflecting what has been written so far, the identification of profitable landfill mining and waste processing concepts is a challenging task.

As concepts for landfill mining and waste processing do not exist so far, a cost estimate for each concept is needed to assess the alternatives. When comparing alternative concepts, investment-related costs have to be included, in case new equipment is needed. In case, existing processes equipment, machines or plants can be used, a rent has to be paid. Furthermore, revenues from land recycling have to be considered. They increase with the space, which is gained by landfill mining as well as with the land price that depends on the landfill location. There is a correlation between the land recycling revenues and the residue disposal costs. If resi-

dues are disposed again on the same landfill, the recyclable area decreases, but disposal costs decrease as well.

In consideration of the explained challenges, assessment requirements are derived and described in the following section.

3 Economic assessment of landfill mining and waste processing concepts

3.1 Requirements on an assessment approach

Landfill mining and waste processing concepts can be characterized as multilevel divergent joint production processes. Each concept has its own treatment process combination that leads to different material flow directions. Hence, to assess alternative concepts, **modelling of landfill mining and processing activities** is required to identify the resulting material flows and their masses.

Due to the variety of possible landfill mining and waste processing concepts and the interrelations of input materials, treatment combination, product quality and achievable prices, the identification of the most profitable concepts in comparison to landfill aftercare is not trivial. In order to support decision-makers, the intended approach has to consider all **crucial economic parameters** and allow for concept assessment by **appropriate economic key figures**.

As explained in section 2.3, waste composition is landfill specific. Therefore, the intended approach has to facilitate concept modelling and assessment with **varying waste compositions** as inputs. However, waste composition can only be identified approximately (s. chapter 2.3). Furthermore, **the price development of primary and secondary raw materials** has to be considered, as it defines the revenues for the processed material flows. Price development forecasts are uncertain, as well. Hence, **uncertainties** that occur due to variable waste composition, price development and further assumptions have to be included in the intended approach.

3.2 Approach on material flow-based economic assessment of landfill mining and waste processing concepts

In the following, we present an assessment approach that allows not only for the identification of profitable landfill mining and waste processing concepts but also for a financial comparison of profitable concepts with landfill aftercare (s. Figure 3). This facilitates decision making in terms of concept configuration and the required investments.

First, material flows for all concepts are modelled to map the quantity structure as basis for the assessment. For material flow modelling, activity analysis is used. This method is based on research work of Koopmans (1951) and Debreu (1959) and has proven appropriate to model joint production processes (Fandel, 1990; Spengler, 1994; Ploog, 2004; Walther, 2005).

Secondly, a cost based comparison of landfill mining and waste processing concepts is carried out for an exemplary operating period. Since an entire landfill mining avoids potential pollution, it can be considered as an environment protection action. Hence, the total concept costs are to be estimated according to "the material flow based environmental cost accounting", which was introduced by Spengler (1998) and is based on VDI (2001) (Walther, 2005). Thus, a concept's profit or loss is calculated from the sum of investment-related costs, material flow revenues or costs, process costs and crucial miscellaneous overhead costs. Investment-related costs include depreciations and imputed interests caused by investments in equipment and machines, and if necessary costs for maintenance, insurance, taxes, etc. that are caused by the investment. Material flow costs and revenues include all kinds of costs, which are caused by material flows that cross the concept's system boundary. Those costs are procurement costs for input materials like process water or auxiliary chemicals, revenues for recycled material flows and disposal costs for residues. Process costs are directly related to the intensity of landfill mining and waste processing activities, including energy costs, costs for operating supplies, rents of machines and equipment and personnel costs, in case the latter are variable. Miscellaneous overhead costs pool all costs that are not directly connected to processes or material flows but in some way relevant for landfill mining and waste processing. These are for example administration costs, logistic costs and concept specific revenues for land recycling.

Thirdly, identified profitable landfill mining and waste processing concepts are compared with landfill aftercare. Therefore, beforehand calculated total concept costs plus one-time landfill mining preparation and planning costs are compared with landfill aftercare costs. In this context, landfill mining and processing capacities and the time span until the landfill

is completely removed, could become relevant. In that case, to compare landfill mining and aftercare, an investment based approach could be required. Further research is to be done on this issue. Finally, uncertainties in terms of waste composition, price development and other assumptions are to be considered by sensitivity or scenario analyses.
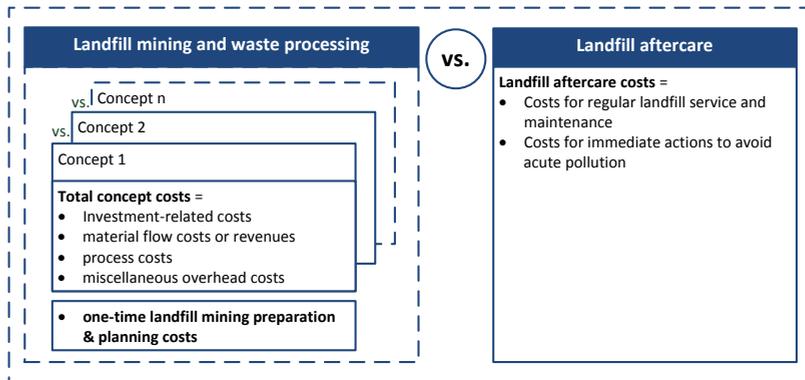
Figure 3: Assessement approach

4 Conclusions and Outlook

An entire landfill mining with waste processing and recycling can be seen as an alternative to landfill aftercare as well as an option to avoid pollution and to recover huge areas by land recycling. Therefore, a variety of waste treatment processes exist that can be combined to obtain technically suitable landfill mining and waste processing concepts. The choice of profitable concepts is a challenging task since several parameters that are partly correlated have to be considered.

The introduced approach supports decision making in terms of the selection of profitable landfill mining and waste processing concepts. Moreover, it allows for a comparison of profitable concepts with landfill aftercare. Once, a concept has been chosen, decisions on the technology to use for the treatment of certain material flows and on the materials to process further for generating high quality products can be made. To do so, material flows and their quantities of each concept are modelled and relevant costs are determined. Total concept costs are compared with landfill aftercare costs. For the identification of concepts that are to be preferred given expectations regarding varying waste compositions or future developments of resource prices, scenario and sensitivity analysis have to be conducted.

As this research work is part of a research project on landfill mining which is undertaken by several project partners, technical appropriate concepts will be configured by waste-management and waste-processing engineers, whereas the economic assessment of these concepts will be our task. Hence, our future research will concentrate on the identification of crucial material flows, quantities and process parameters for material flow modelling, in close cooperation with the engineers. Furthermore, we will implement the introduced approach into a decision support model, which will either be a simulation or an optimisation model, depending on the number of alternatives.

5   Acknowledgment

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Decision Support for Logistic Networks of Renewable Resources based on Tracking and Tracing System

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Abstract

Tracking and tracing systems (TTS) can improve logistics networks and the utilization rate of renewable resources. For wood supply chains, a substantial savings potential through reduced wood loss and improved wood transportation are being reported in the scientific literature. In this study, a logistics network model of two companies producing engineered wood products in Lower Saxony has been implemented using the LCA-software Umberto 7.0 in order to analyze several economic, technical and environmental parameters and their possible improvements due to TTS.

Keywords

Renewable resources, logistics, tracking and racing system, Umberto, wood flow.

1   Introduction

Wood is considered one of the most versatile renewable resource for material, chemical and energy use worldwide (Sathre & Gustavsson, 2006). Due to the growing demand of wood especially for energy use, there is a trend in recent years to improve wood utilization along its supply chain. Several actors, including harvesting and sawmill industries are involved in the processes of wood supply chain networks (Figure 1). All actors intend to improve their economic performance by minimizing their costs. How-

ever, it is also important to consider the environmental impacts (e.g. CO_2-emission) of individual activities through wood flows. A precondition for effective supply chain management is the implementation of a suitable information technology (IT) that is able to provide precise and timely data throughout the wood supply chain. The concept of tracking and tracing systems (TTS) in particular, has drawn much attention in logistics planning. As such, TTS provides necessary data that should be considered beforere sources arrive throughout its supply chains in order to identify the status and location of an object (e.g. logs and boards) and reconstruct the object's history (Fritz & Schifer, 2009). The usage of TTS includes applications of finding the source of recalls and proof of product quality and its origin which leads to improvement of logistics and production processes. The role of TTS in wood supply chains has already been investigated (Uusijärvi, 2010; Timpe 2006, Zabarenko 2012, Kasturi, 2005.) in order to reduce costs and improve quality, flexibility and competition (Figure 1).

Forestry		Saw mill			
Harvesting	Forwarding and storage	Wood Transport	Log Sorting	Debarking	Sawing	Drying

| Development of new customer services (information about quality and quantity)

Generation of certifications of origin

Reduction of risk illegally harvested wood (15 Billion $ per year worldwide)

Improvement and support of internal processes:
• Improvement of bucking and sorting
• Improvement of commissioning | Reduction of lost logs (current 10-15 % of total volume)

Improvement and support of internal processes:
• Optimizing of the transport route
• Optimizing the utilization of the transport capacity | Development of new customer services (information on the results of quality tests)

Improvement of the rough planning and prediction processes as well as timely reaction to deviations

Increasing the yield (amounting up to 20%)

Improvement of the stock management (Cost Reduction amounting up to 60%)

Improvement and support of internal processes:
• Improvement of sorting
• Improvement of commissioning
• Improvement of drying |

Figure 1: Wood supply chain using tracking and tracing system

In this paper, the possible changes by TTS on wood supply chains are analyzed for individual companies producing engineered wood products such as MDF (medium-density fiberboards) and OSB (oriented strand boards) in the German State of Lower Saxony. The logistic network model is implemented by using Umberto software and allows for the identification of the economic performance of each actor and of the environmental parameters of each industrial activity from cradle to grave (with mass and energy flows from forestry source to client).

2 Effects of TTS on wood logistics network

TTS is designed to capture, archive and communicate information e.g. about wood properties, log and chips supply and submit it along the supply chain using extensive IT infrastructure. Data from TTS can be used as a basis to achieve a higher quality of decision making within the supply chain management. TTS data can be extended to customer requirements, European norms, optimization of production and logistics processes and cascade utilization rules. To plan the logistics and production processes for renewable resources like wood and lignocelluloses material, potential deviations in the quality and quantity of the input streams must be taken into account (Friedemann, 2013). Quality and quantity are influenced by weather conditions, transportation and storage (Geldermann, 2012). Rolling planning allows an update of production and logistics planning and adjustments to changing external factors and environmental conditions (Alicke, 2005).

TTS can therefore provide the necessary data for such an updated planning process when information on variations in the supply chain is available. The presence of new data is an essential condition for a supply chain (event). These events are then recorded, monitored and evaluated in supply chain event management (SCEM) systems (Nissen, 2002). For example, in the wood supply chain, data about quality (e.g. density and moisture content) and quantity of each kind of wood is captured during harvesting. There are two ways to capture the data: automatically with modules on the harvester, or manually with a mobile data collection unit. The data can be transmitted without delay to a TTS database through mobile network connections. TTS periodically notifies the SCEM-system via the internet if new data is available. The SCEM-system can carry out comparative analyses with target values and perform rule-based processing of events when deviations are present. The results can be made available to the decision makers along the affected supply chains.

Several studies indicate that the use of TTS data leads to improved wood supply chain processes, cost reduction and/or reduction of environmental pollution. This is due to the fact that the right information is being provided to the right persons at the right time, such that decisions within production and logistics planning can be supported (Uusijärvi, 2010; Timpe 2006, Dykstra, et al., 2002).

The main sources of information are from forest enterprises. Even before harvesting, information on the spatial distribution of timber volume and forest structures is available. Such forest inventories can be supported by modern information technologies such as automatic evaluation of terrestrial as well as airborne laser scanning data. This information can sup-

port the planning of demand-oriented supply of wood. At harvesting, information is captured for each type of wood such as its diameter, length, moisture content, density and strength. In the best case, each piece of wood receives an identification marker such as RFID tags for thick wood or ink-print for industrial wood (Dykstra et al., 2002). For residual wood, it is possible to equip the collection container with identification markers to establish the history for the entire container (Erhard et al., 2010). The quality of information helps the forest company sort and decide the future use of the wood. There is a strong competition for wood consumption (particularly for industrial wood) between material and energy sectors (HDH 2010). Data on strength, density and moisture allow for the classification of wood pieces for material use. New data such as weight and volume for each log and pile can also be derived from product histories. If harvesters and forwarders are equipped with a Global Positioning System (GPS), information about the position of a pile on the wood road can be stored in the product history. Such information can assist in locating the wood and optimizing the transport route reducing both transportation costs and CO_2 emission (Gronalt et al., 2006). Precise information about the amount of wood in piles also helps in the selection process of the type of vehicle and its capacity. TTS in combination with GPS supports transport tracking starting from the felling of wood until its arrival at its end destination, the business of the wood industry. During this process, all participants in the wood supply chain can access the present status of the logistic unit using an internet-based shipment information system. Logistic unit monitoring can help reduce high wood losses within the transport between forestry and sawmill operation (Kasturi 2005). Information on moisture content can support the choice of an appropriate drying process downstream the wood supply chain in order to reduce drying defects such as cracks and unwanted changes of color as well as energy consumption. In the sawmill, TTS data on wood quality supports the selection of the most suitable sawing machine and patterns can be selected so that the yield can be increased (Uusijärvi, 2010). Such information can support the precise calculation of the yield and thus, for example, a timely reaction with changes to the order quantity in the wood materials industry.

In summary, TTS together with SCEM is a basis for realizing and supporting the rolling planning because it allows for improving existing plans (based on historical data) using current information. Table 1 compiles some of the potentials of TTS within the wood supply chain in regards to the different types of decisions within the production and logistic systems. From an economic perspective, the trade-off between savings potential by implementing TTS and its necessary investments need to be taken into consideration.

Table 1: Potentials from the use of TTS data in the decision making process

Information	Wood supply chain (WSC) Step	Decision	Potential
Information on the spatial distribution of wood volume and forest structure	Forestry	Harvesting plan and harvester type; selection of route	Support of demand-oriented supply of round wood: reduction of transport costs and environmental impact through better route planning
	All participants in WSC	Annual planning	More accurate planning
Position of a pile on the wood road (GPS data)	Wood transport	Selection of transport routes	Reduction of transportation costs and environmental impact through better route planning
Information on amount of wood in piles (weight or volume)	Wood transport	Selection of a vehicle type	Reduction of transportation cost and environmental impact through better transport capacity utilization
Quality Information (diameter, moisture content, density, length, strength)	Forestry	Sorting of wood	Elimination of manual labor, higher process speed, automatic documentation of the results, precise information on wood availability to customers, support of demand-oriented wood supply
	All participants in WSC	Selection of drying technology	Decrease energy consumption and drying defects such as cracks and unwanted changed of color
	Saw mill (sawing)	Selection of sawing patters and technology	Increase yield of wood, reduction of waste heat
	Wood materials industry	Production planning	Reaction to deviations (e. g. by changing the order size)
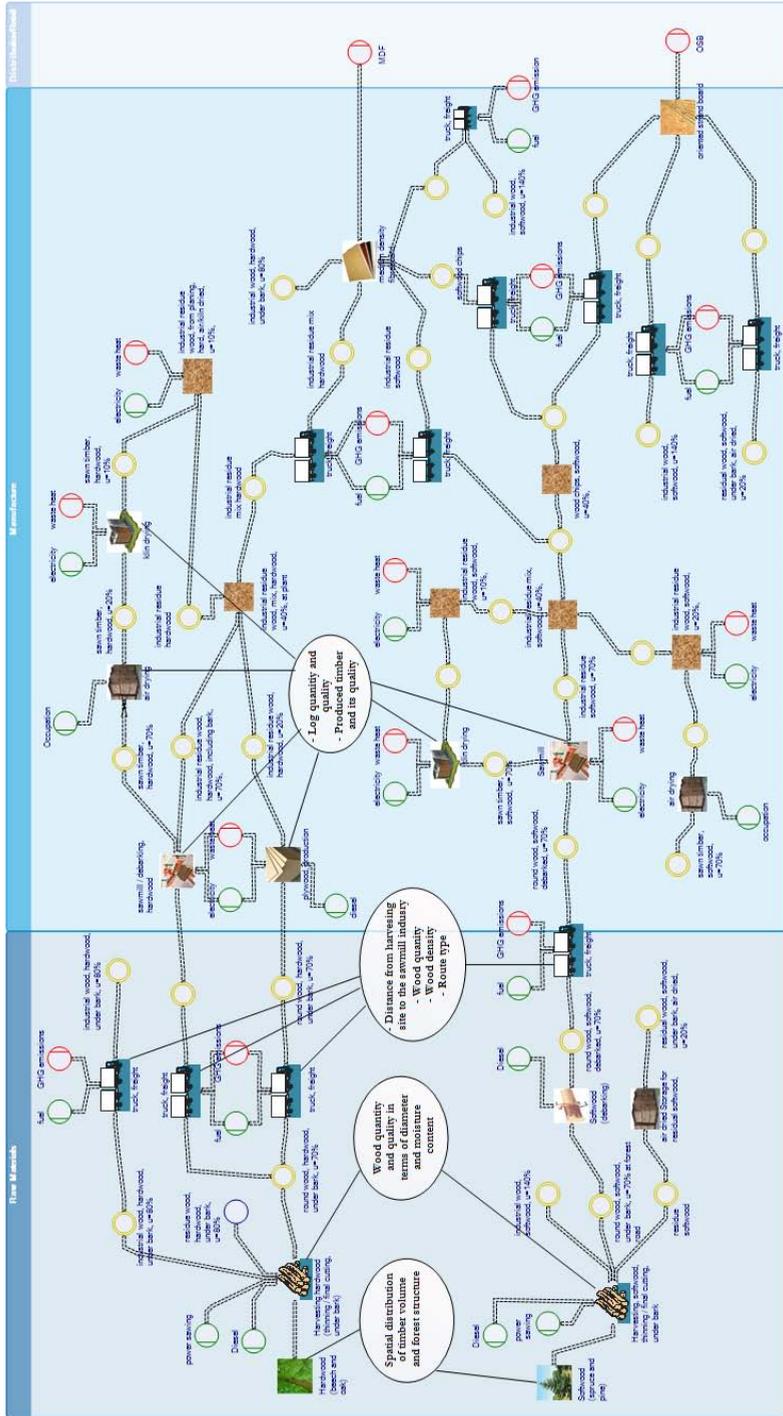
Figure 3: The supply chain processes for MDF and OSB production modeled by Umberto and the impact of TTS

3 Umberto model for wood logistics network

Several studies in business informatics outline the advantages of TTS in the processes of wood supply in general. The aim of this paper is to analyze to which extent existing information on quality and quantity as well as position of logs in the forest affects the costs and environmental effects in the wood supply chain. In this case study, we study the logistics network for the production of MDF (medium-density fiberboards) and OSB (oriented strand boards) in Lower Saxony. MDF and OSB are engineered wood products, based on hardwood or softwood residuals in combination with wax and resin binders. Döring and Mantau (2012) report data for one company in Bevern, which produces 455,000 m³/year of OSB, and for another company in Nettgau, which produces 105,000 m³/year of MDF. Wood availability and quality allow for supply from forestry sources in Germany, where on total, 11.1 million hectar forests yield more than 66 million m³/year of logs (Polley & Kroiher, 2006). Based on this data and information about demand for softwood and hardwood by products as well as its density, as summarized in Table 2, the wood logistics network can be modeled.

The commercial LCA (life-cycle assessment) software Umberto v7.0 (www.umberto.de) uses Petri networks, a special type of network from theoretical informatics whose strict systematics not only allows the set-up of complex systems but also a combined material and inventory calculation. Petri networks can model material flow networks with closed loops. Umberto especially allows for a graphical representation by Sankey diagrams which are traditionally used to display mass and energy flows. Such models help to identify where the flows origin and where the maximum is directed at, and where the place for changes with maximum impact in the investigated processes could be, and to perform a life cycle assessment (LCA) or calculate a so-called "carbon footprint" (Schmehl et al., 2012; Geldermann & Rentz, 2004).

Figure 3 shows the supply chain processes modeled by Umberto with their mass and energy flows connected with wood byproducts which are produced during harvesting and sawing processes. Four different wood types (beech and oak as hardwood, and spruce and pine as softwood) are considered as input from forestry sources in Lower Saxony (Polley & Kroiher, 2006). Three types of wood products could be produced through harvesting:

- Two kinds of round wood with diameters of more than 40 cm, and the other with between 20 to 40 cm which is suitable for timber production in sawmills. Some of these logs with high moisture content require drying processes (kiln and ambient).

- Industrial wood is comprised of logs that are not supplied to the sawmill industry due to a lack of quality in terms of diameter since its diameter is less than 20 cm. These kinds of logs are supplied directly to the companies.
- Wood residues or woodchips that are produced during the wood harvesting process as byproducts are being supplied directly to the company for OSB production.

Figure 3 also shows where data from TTS could be collected and used within the wood logistics network. In order to investigate the influence of TTS on the designed logistics network, two scenarios are analyzed for the selected case study:

Scenario 1: Logistics network for wood flow of two companies in Lower Saxony without TTS

In this scenario, the logistics network based on the data summarized in Table 2 is modeled by using Umberto software. This mass and energy flow model helps identify feasible solutions to meet the demand for wood for the two companies in our case study. Two databases (ecoinvent 2.2 and 3.0; see http://www.ecoinvent.org/database) in Umberto software are used to calculate CO_2 emission as well as waste heat generation connected with business activities in the modeled wood supply chain. In this scenario, total transportation costs are computed based on the average diesel price that is estimated from online sources (http://www.benzinpreis-aktuell.de/). To decrease computation complexity, it is assumed that the average distance is 100 km.

Table 2: Basic data and technical factor

Parameters	Value	Reference
Harvestedlog,softwood, in Lower Saxony	2,286,000 m³/year	Polley & Kroiher, 2006
Harvested log, hardwood, in Lower Saxony	1,608,000 m³/year	Polley & Kroiher, 2006
Demand for softwood by-products(in the two selected companies)	1,262,587 m³/year	Döring & Mantau, 2012
Demand for hardwood by-products (in the two selected companies)	48,300 m³/year	Döring & Mantau, 2012
Averagedistance (between each process)	100 km	Assumption
Averagedensity of the wood	800 kg/m³	Estimated based on ecoinvent 2.2[**]

Vehicle type[1]	TR3[*]	ecoinvent 3.0[**]
Average diesel price	1.38 Euro/l	http://www.benzinpreis-aktuell.de/
Sawing yield	55%	ecoinvent 2.2

[*]TR 1: Truck with capacity of less than 7.5 tons; TR 2: Truck with capacity between 7.5 to 12 tons; TR 3: Truck with capacity between 12 to 24 tons; TR 4: Truck with capacity between 24 to 36 tons

Scenario 2: TTS-based logistics network

In this scenario, we consider the expected influence of TTS on the logistics network, for the two modeled companies in our case study in comparison to the previous scenario. Some studies have discussed the advantages of using TTS in the processes of wood supply (Uusijärvi et al., 2010). Kasturi (2005) mentions that 10-15% of the volume of wood logs is lost during wood transportation, which could be reduced to 5% by using TTS. In another study, Hug (2004) finds that the advantage of TTS on route optimization is 10%. Accordingly, Scenario 2 assumes that an improvement of the efficiency of wood transportation by an increase of wood supply and a decrease of distance between forestry and sawing industries. Therefore, we increase the coefficient of wood flow in the transportation process in the Umberto model by 10% and we decrease the average distance to 90 km. We keep the values for other input parameters unchanged.

Figure 4 illustrates the results of the two scenarios. Although the case study has many limitations, such as the average values and historical data taken from literature, a general tendency can be observed. Firstly, the consequences of TTS on the logistics processes throughout the wood supply chain can be pinpointed. Secondly, several parameters in the logistics network improved due implementing TTS in the transportation processes. However, other parameters including electricity and waste heat remained unchanged since these parameters are derived from the impacts of sawmill and drying processes. Their optimization, based on TTS, is still subject for further research. Finally, the presented Umberto model of the wood supply chain can be used as a starting point for decision making by individual companies or supply chains in the wood industry. Company specific data can be fed into the model, and if there is the choice between various logistics and production processes or between different supply modes, various optimization methods from Operations Research can be applied in combination with Umberto.
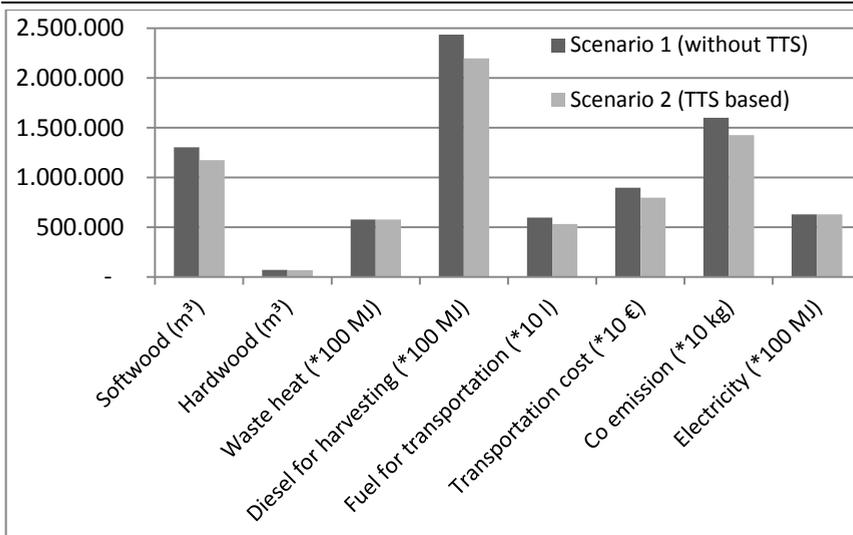
Figure 4: Results of both scenarios for the illustrative case study with and without TTS.

4   Conclusions

In this paper, the possibilities and potentials of Tracking and Tracing Systems (TTS) on the logistics processes in wood supply chains are being investigated. Various positive effects of TTS on wood logistics networks have been mentioned in the scientific literature. In order to investigate the influence of TTS on logistics and production processes in individual companies, a wood supply chain model has been implemented using the commercial LCA-software Umberto. Changes in wood and log quantities as well as transportation costs, fuel consumption, CO_2-Emissions or LCA impact assessment factors can be calculated, as the illustrative case study on two companies producing MDF and OSB shows.

The graphical representation of the wood supply chain and the comparison of various scenarios with different assumptions alone offer some a degree of decision support. Although the case study is currently focused on wood transport, further research is warranted to investigate the effect of TTS on the yield of the different actors in the wood supply chain, taking their interaction along the entire wood supply chain into account. For example, the increase of the yield in sawmills reduces the volume of sawmill byproducts, which in turn can lead to a shortage of input resources for MDF and OSB manufacturers. They must be prepared to switch input materials such as fiber plants and to deepen cooperation with forestry

operations. For MDF manufacturers, it is possible to use the waste wood. Rolling planning is intended to enable the timely adaptation to new situations. Further research is necessary to refine the presented model and allow for simple customization for other companies in other regions or with other supply sources.

The combination of Umberto and TTS opens new strands for decision support, as up-to-date information can be integrated for rolling planning. TTS can provide the necessary data on the raw materials quality, quantity and delivery date. Suitable optimization models need to be implemented for the characteristics of the wood supply chain in order to improve both logistics and production processes, taking various criteria in account; such as cost, CO_2-emssions and various constraints such as raw material availability or product demand.

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Track C:
Governance, Coordination
and Sale

Consumer Behavior towards Eco-Friendly Products

Consumer-relevant Information about Bioplastics

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Keywords

Durable consumer products, biobased products, attitudes towards biogenic resources, consumer behavior

Abstract

Bioplastics from biogenic resources constitute a renewable alternative to crude-oil-based plastics. Yet, the majority of consumers in Germany are not familiar with durable bioplastic products. Few studies show that once informed about bioplastics, consumers generally support their introduction and use, but these studies focus on non-durable packaging products. In this paper, we concentrate on durable bioplastic products. We conducted a pilot study to assess consumers' understanding of bioplastics and types of information that they find relevant about bioplastics. We found that consumers' understanding is limited to the fact that bioplastics are degradable and made from biogenic resources. Consumers seek information about the particular type of raw material and about effects of bioplastics on environment and climate. These findings from the pilot study entail implications for our forthcoming economic experiment.

1   Introduction

A limited number of durable bioplastic consumer products are currently available on the German retail market (IfBB, 2013). As consumers rarely encounter this plant-based, renewable material on the market, they lack general information about bioplastics (European Bioplastics, 2013; Kurka, 2012; Kurka & Menrad, 2009). This lack of information might also be due to the fact that bioplastics neither look nor feel other than conven-

tional crude-oil-based plastics. Thus, bioplastics are a credence good: Consumers have to trust the information on the product that reads something like "made from renewable resources" or "biobased product". Some studies found that consumers attach importance to credence attributes such as ecological effects of a product or a plant-based raw material source (Barnes et al., 2011; Blindingmaier et al., 2003). In a study by Kurka and Menrad (2009), consumers rated environmental protection and the frugal use of resources as more important than a low price when buying products in bio-based packaging. But overall, scientific literature reports little about consumers' perceptions of bioplastics and their interest in them. Therefore, we conducted a pilot study to determine consumers' understanding of bioplastics and existing information gaps. In addition, we assessed the types of information consumers find relevant for bioplastics. The effects of the resulting relevant types of information are to be tested in our forthcoming economic experiment. Finally, we inquired consumers' attitudes towards bioplastics and biogenic resources as well as their behavior towards ecological and regional products.

2 Methodology

We conducted an online survey with the open source questionnaire tool LimeSurvey (www.limesurvey.org). Participants were recruited in Germany via mailing lists, social networks and a call in a local newspaper. The survey remained online for one month in May/June 2013.

We designed a questionnaire with five parts: (1) consumers' understanding of bioplastics, (2) consumer-relevant information about bioplastics, (3) attitudes towards regional and ecological products, (4) attitudes towards biogenic resources and bioplastics, and (5) socio-demographic characteristics. In part 1 the respondents listed their understanding of bioplastics and their characteristics. Hence, we received an overview of the existing understandings and misunderstandings of bioplastics. Part 2 consisted of an open-ended question in which respondents specified general information about bioplastics that is relevant to them. Thus, we could determine what information consumers really wish for and compare them to the understandings listed in part 1. In part 3 respondents stated their attitudes towards biogenic resources and bioplastics (ABR) by rating statements on a 5-point scale from 5=strongly agree to 1=strongly disagree. We developed the statements by ourselves as according to our knowledge there is no standard scale that measures attitudes towards biogenic resources. We defined statements that focus on the environmental and climate effects of biogenic resources and bioplastics. Furthermore, we

included the ongoing food or fuel discussion as well as purchase behavior regarding products from biogenic resources (see appendix for item details). Part 4 assessed the respondents' attitudes towards characteristics of ecological products such as price or quality, and the respondents' reasons for buying regional products. Agreement or disagreement to the six statements was measured on the same 5-point Likert scale as in part 3 (see appendix for item details). We derived the statements from different studies about consumer behavior towards ecological and regional products (Schoeberl, 2012; Kurka, 2012; Brown & Wahlers, 1998). In addition, we measured how consumers perceive the environmental effects of their buying behavior with the GREEN Consumer Value (GCV) scale by Haws and colleagues (Bearden et al., 2011). "Green Consumers are defined as those who have a tendency to consider the environmental impact of their purchase and consumption behavior" (Bearden et al., 2011: 172). Thus, the stronger the agreements with the GCV-items, the more likely consumers make purchase decisions that are in line with the environment. We reduced the original 7-point scale to five points (5=strongly agree, 1=strongly disagree) to make it easier for respondents to answer. Besides, we added the items "Instead of wasting more and more resources we should recycle and reuse as much material as possible" and "When I buy products I think about the environmental impacts of their use" to the original GCV-items. The additional items put a particular focus on the environmental effects of product use and disposal and focus on future product purchase.

3   Results

70 questionnaires were fully completed and an additional 11 respondents completed the first half. 50 % of the respondents are female. The sample is highly educated with 70 % university graduates and has an above average income as 59.1 % stated a monthly net income exceeding 2,599 Euros. The average age is 34.6 years with almost half of the respondents between ages 18 and 29. 27 % of the respondents had already bought one or more bioplastic products in the previous 12 months.

About 60 % of the sample knew that bioplastics contain "renewable, biogenic or natural resources" and about 45 % mentioned the "biodegradability" of bioplastics. One quarter of the sample characterized bioplastics as environmentally friendly and sustainable. In addition, good recycling qualities and compostability were specified. Some respondents compared bioplastics to conventional crude-oil-based plastics and stated opinions ranging from "worse characteristics than conventional plastics" to "similar characteristics". It seemed to be clear to respondents that bio-

plastics are not made of crude oil. Some respondents admitted not to know bioplastics and some pointed to the oppositeness of the term.

70 respondents gave 146 answers to the open-ended question on relevant information about bioplastics. We aggregated the answers in a way that they were thematically related to each other. This reduction of qualitative data resulted in six information types represented in Figure 1. The frequencies show that "raw material and origin" and "effects on environment and climate" were mentioned most often, "price" is ranked in the middle and "product characteristics" were mentioned least (Figure 1).
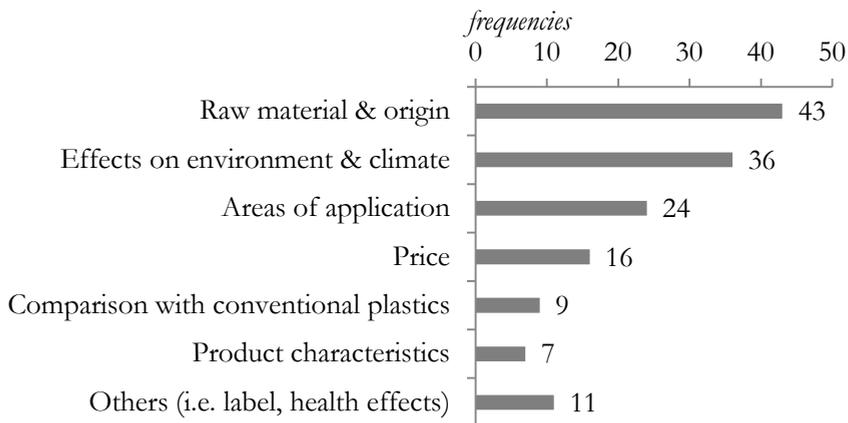
Figure 1: Relative frequencies of information types related to bioplastics (n=70, multiple answers).

The following results from questionnaire parts 3 and 4 depict consumers' attitudes towards biogenic resources, bioplastics and environmentally friendly products as well as their purchase behavior. We used Pearson's correlation coefficient to measure the strength and direction of correlations between items.

Table 1 shows the correlation between the respondents' attitudes towards biogenic resources and bioplastics (ABR) and the GREEN Consumer Values (GCV). The item "I purposefully buy products from biogenic resources" (ABR1) significantly correlates with all the GCV-items. Also, the item "I am willing to be inconvenienced in order to take actions that are more environmentally friendly" (GCV6) correlates significantly with five ABR-items. In addition, there is a highly significant correlation between "The use of biogenic resources reduces greenhouse gas emission" (ABR7) and all GCVs. Note that the willingness to be inconvenienced in order to act environmentally friendly (GCV6) significantly correlates with a number of ABRs and that the purchase of ecological products positively (ABR1) correlates with the GCVs.

Table 1: Pearson's correlations between the purchase of ecological products (ABR1) and the GREEN Consumer Values (GCV) are highly significant.

	ABR1	ABR2°	ABR3°	ABR4°	ABR5	ABR6°	ABR7	ABR8
GCV1	.485**	.205	.232	-.120	.224	.048	.433**	.133
GCV2	.332**	.289*	.259*	-.079	.258*	.181	.568**	.214
GCV3	.398**	.334**	.316**	-.012	.225	.110	.495**	.096
GCV4	.376**	.138	.317**	-.086	.200	.128	.465**	.124
GCV5	.264*	.181	.157	-.006	.372**	.075	.429**	.188
GCV6	.410**	.328**	.411**	-.119	.307**	.099	.459**	-.008
GCV7	.346**	.077	.134	.004	.301*	.236*	.411**	.238*
GCV8	.490**	.217	.093	-.091	.265*	.044	.405**	.161
n=71, **significant at α=.01, * sig. at α=.05, ° inverted items *see appendix for item details*								

Table 2 depicts the correlations of the questions about consumers' attitudes towards ecological and regional products (ERP). "I prefer to buy environmentally friendly products" (ERP1) and "I am willing to pay more for environmentally friendly products" (ERP2) strongly correlate (r=.771). Regional production positively correlates with the interest in ecological products (ERP5 & ERP6). Note that the preference to buy environmentally friendly products (ERP1) positively correlates with a general support of ecological and regional products (Table 2).

Table 2: The item "I prefer to buy environmentally friendly products" (ERP1) correlates significantly with ERP2 "I am willing to pay more for environmentally friendly products".

	ERP1	ERP2	ERP3°	ERP4°	ERP5	ERP6
ERP1	1					
ERP2	.771**	1				
ERP3°	-.299*	-.196	1			
ERP4°	-.301**	-.284*	.362**	1		
ERP5	.714**	.695**	-.276*	-.200	1	
ERP6	.555**	.472**	-.266*	-.393**	.658**	1
n=71, **significant at α=.01, * sig. at α=.05, ° inverted items *see appendix for item details*					

Table 3 shows the highly significant correlations between all GCVs and the ERP-statements "I prefer to buy environmentally friendly products" (ERP1) and "I am willing to pay more for environmentally friendly products" (ERP2). The correlation between "I am willing to be inconvenienced in order to take actions that are more environmentally friendly" (GCV6) and ERP2 is strong (r=.759). The correlation of r=.697 between ERP1 and GCV6 supports this result (Table 3). Note that the correlations

between GCVs and the willingness to pay more for environmentally friendly products (ERP2) are highly significant.

Table 3: GREEN Consumer Values significantly correlate with the preference to buy environmentally friendly products (ERP1) and the willingness to pay more for these products (ERP2).

	ERP1	ERP2	ERP3°	ERP4°	ERP5	ERP6
GCV1	.652**	.632**	-.219	-.268*	.591**	.307**
GCV2	.573**	.547**	-.304**	-.221	.444**	.233
GCV3	.656**	.642**	-.339**	-.291*	.587**	.288*
GCV4	.629**	.642**	-.259*	-.213	.530**	.290*
GCV5	.471**	.376**	-.298*	-.244*	.381**	.297*
GCV6	.697**	.759**	-.366**	-.322**	.641**	.464**
GCV7	.408**	.461**	-.156	-.012	.313**	.079
GCV8	.572**	.541**	-.275*	-.160	.474**	.327**
n=73, **sig. at α=.01, * sig. at α=.05, ° inverted items *see appendix for item details*						

4   Discussion

Respondents' understanding of bioplastics is one-sided and predominantly limited to general knowledge about the raw material source and some kind of degradability. The frequent reference to the biodegradability of bioplastics is surprising as we argue that the majority of consumers in Germany are not familiar with the particular meaning of the term. We think that consumers use biodegradability as a synonym for compostability, whereas the two terms are in fact subordinates: The superordinate term biodegradability means that material can be broken up into its inorganic chemical components through microorganisms or environmental influences (Endres & Siebert-Raths, 2011: 6). Compostability is a particular type of biodegradability as the material degrades into inorganic components and the organic component humus.

Overall, respondents have a general, predominantly positive idea about bioplastics, but lack detailed understanding of material type, environmental effects, areas of application and others. Kurka (2012: 63) reached a similar conclusion in a study about consumer behavior towards biobased products: He found that about 56 % of German respondents were informed about the availability of bioplastic bags and about 45 % correctly named plants that are used for the production of bioplastics. In our pilot study, consumers' limited understanding becomes apparent by the types of information that consumers find most relevant about bioplastics: "Raw material and origin" and "effects on environment and climate".

These two types comprise the ongoing discussions about climate change and food or fuel that are largely covered by the media. The requests about "areas of application" underline the limited supply of bioplastic products on the markets and thus consumers' limited confrontation with them. Kurka (2012) found that more than 65 % of respondents had never bought bioplastic products and about 20 % had not bought any in the last six months. This percentage is in line with our own findings: 73 % of respondents have not bought bioplastic products in the previous 12 months.

From our point of view, the low numbers of respondents who showed interest in "price" and "products characteristics" were surprising. We would have expected that these attributes play a bigger role for consumers. The lack of knowledge about applications of bioplastics might also have influenced the low number of responses for "product characteristics". In general, social desirability might have caused a bias in this pilot study as environmentally friendly behavior is generally accepted and expected in society. Bias might also be due to the high education level of the sample as positive attitudes towards the environment tend to be more pronounced in this population group (Kuckartz et al., 2007). However, the consistent response to inverted questions confirms that the questionnaire was understood and stringently answered.

GREEN Consumer Values (GCV) and attitudes towards ecological and regional products (ERP) measured intentions as well as self-reported actions and behaviors. The mostly significant correlations of GCVs and ERP and especially the highly significant correlations between GCVs and the preference to buy environmentally friendly products are in line with the definition of GCVs that the purchase behavior of GREEN consumers tends to be environmentally friendly. This disposition is supported by the highly significant correlations of the willingness to be inconvenienced in order to act environmentally friendly and positive attitudes towards biogenic resources (ABR) such as "I purposefully buy products from biogenic resources", "the use of biogenic resources reduces the use of fossil resources" and "the use of biogenic resources reduces greenhouse gas emissions". These insights are in line with the findings from other studies that consumers prefer sustainable, biogenic products (Barnes et al., 2011; Chan-Halbrendt et al., 2009; Blindingmaier et al., 2003).

It seems that consumers are willing to pay more for environmentally friendly products. Findings by Barnes et al. (2011) who assessed that consumers are willing to pay more for environmentally friendly food containers and Yue et al. (2010) who measured a higher willingness to pay for biodegradable plant containers support this notion. Whereas these studies concentrated on non-durable packaging products, we found a strong correlation (r=.771) of the preference to buy environmentally-friendly durable consumer products and the willingness to pay more for environmentally

friendly durable consumer products. Thus, we formulate the following hypothesis that will be tested in our forthcoming economic experiment: Consumers are willing to pay a surplus for durable bioplastic products.

5   Implications for forthcoming economic experiment

Our pilot study identified information types about bioplastics that are relevant to consumers and suggested that consumers are willing to pay more for environmentally friendly durable consumer products. In order to test this hypothesis we will conduct an experimental auction of durable, bioplastic products and their crude-oil-based equivalents. In addition, we will measure the effect of different types of information on consumers' willingness to pay (WTP) for both product alternatives.

An experiment enables the experimenter to control for parameters and conditions. The central characteristic of an experiment is the variation of only one parameter whereas all others are kept constant. Thus, causal relationships can be measured. We will use three types of information that we identified in the pilot study as varying parameter (Figure 1): "Raw material and origin", "effects on environment and climate" and "product characteristics". The first two types of information were mentioned most frequently by respondents and take into account consumers' limited understanding of bioplastics. The case of the latter type of information is different: "Product characteristics" were mentioned rarely in our pilot study, but product attributes such as durability, quality and specific functional properties allow consumers to estimate the value of a product (Kroeber-Riel & Weinberg, 2003) and should therefore influence WTP. When informed about these attributes, consumers claim in recent studies that they are willing to pay more for bioplastic waste bags and food containers compared to the equivalent crude-oil-based products (Barnes et al., 2011; Chan-Halbrendt et al., 2009). These findings show that information about bioplastics put consumers in a better position to evaluate a product and that credence attributes actually have an effect on WTP. Furthermore, recent economic experiments proved that different types of information and different sources of information have distinct effects on WTP (Disdier & Marette, 2013; Roosen et al., 2011; Depositario et al., 2009). These experiments also demonstrated that the effect of information on WTP is contingent on the importance consumers attach to the information in question. In our experiment, we will provide one type of information after the other and elicit WTP after each information round (Table 4). Thus, we can determine the different effect of each type of information on WTP.

An experiment may consist of different treatments in order to test the influence of distinct conditions on the outcome. We will conduct two treatments to take the pilot study respondents' wish for a comparison of bioplastics and conventional plastics into account (Table 4). In the "bioplastics only" treatment the participants exclusively receive information about the bioplastics product. In the "bioplastics and conventional" treatment the same types of information are provided but this time for both product alternatives. We use these two treatments because consumers usually do not receive a lot of information about a conventional product during the purchase process, however, product information is usually provided through labels on ecological products. Therefore, we mimic the purchase situation in the "bioplastics only" treatment. We assume that WTP will be even higher for bioplastic products if we clearly confront consumers with the differences between the two product alternatives.

Table 4: Preliminary design of the experimental auction to elicit consumers' WTP for durable bioplastic products and to test the effects of information on WTP.

Treatment		„bioplastics only"	„bioplastics & conventional"
Auction round	1	No information	
	2	Raw material & origin	
	3	Product characteristics	
	4	Effects on environment & climate	

An experimental auction is the appropriate method to elicit WTP because it is non-hypothetical and incentive compatible and thus reduces hypothetical bias as well as untruthful bidding (Lusk & Schroeder, 2004). Participants bid on real products with their own money and are directly confronted with the consequences of their bidding behavior.

Our forthcoming experimental auction consists of two treatments with four auction rounds each (Table 4). The treatments differ from each other in exactly one parameter and participants bid simultaneously on a bioplastic product version labeled "made from biogenic resources" and a conventional product version without label. The order of the auction rounds 2-4 remains the same throughout all treatments. We will auction products from two different categories: sunglasses, which are an upscale life-style product and a low priced convenience good such as a toothbrush.

Taking into account the results from our above described pilot study, we assume the following outcomes in our forthcoming experiment: WTP for bioplastic products will be higher than for the conventional products. The surplus people are willing to pay derives from the credence attribute that the product is made from biogenic resources in the first place. The additional information from the relevant types of information might cause a further increase of the surplus consumers are willing to pay.

The size of this second surplus depends on two aspects: (1) the way information is provided and (2) the importance consumers attach to the information type. In addition, information effects per se might play a role and thus must be controlled for. Finally, the experiment will provide a deeper insight into the role of information for the formation of WTP. To our knowledge, it will be the first scientific study that elicits WTP for durable bioplastic products with an experimental auction.

6   Conclusions

We conducted a pilot study to assess consumers' understanding of bioplastics and to find out what type of information related to bioplastics is relevant to consumers. We found that their understanding of bioplastics is limited to a general knowledge about the source of raw material and degradability and that consumers lack information about aspects such as effects of bioplastics on environment and climate, raw material, origin and product characteristics. Overall, our sample has a positive attitude towards the use of biogenic resources and is interested in ecological and regional products. Respondents also show a tendency to consider the environmental effects of their purchase behavior. From our point of view, the pilot study constitutes a solid basis for our forthcoming experiment. The relevant types of information that resulted from the pilot study have been incorporated in an experimental auction design. An experimental auction will be conducted to elicit consumers' WTP for durable, bioplastic products. WTP will be elicited for a life-style and a low involvement good.

Our findings aim to contribute to an important research field that seeks to understand consumer behavior in the contexts of climate change and a growing awareness for the environment. Our goal is to derive recommendations for new and adapted marketing strategies that account for consumers' growing interest in environmentally friendly consumption.

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Appendix

Attitudes towards ecological and regional products (ERP)
ERP1   I prefer to buy environmentally friendly products.
ERP2   I am willing to pay more for environmentally friendly products.
ERP3   Environmentally friendly product alternatives do not work as well.
ERP4   Environmentally friendly products are too expensive.
ERP5   I buy regional products because of shorter transportation routes.
ERP6   I buy products, made from regional resources.

Attitudes towards biogenic resources and bioplastics (ABR)
ABR1   I purposefully buy products from biogenic resources.
ABR2   The production of bioplastics induces an increase in monocultures.
ABR3   The cultivation of resources for bioplastics production reduces the area of food production.
ABR4   Bioplastics should be produced from biogenic resources that are explicitly grown for this purpose (sugar beet, corn, sunflowers).
ABR5   The use of biogenic resources reduces the use of fossil resources.
ABR6   The cultivation of sugar beet, corn and sunflowers for the production of bioplastics has a negative effect on the landscape.
ABR7   The use of biogenic resources reduces greenhouse gas emissions.
ABR8   Bioplastics should mainly be produced from agricultural by-products (beet leaves, bagasse).

Labelling for bio-based plastics

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Abstract

Plastics from renewable raw materials are gaining importance in the conservation efforts of fossil fuels. But consumers do not easily recognize these products because no specific label exists to distinguish them from fossil-fuel based plastics in Germany. We conducted a pilot study to detect what visual details and information with regard to content are important for consumers when assessing a label for plastics made from renewable resources. We found that consumers' visual evaluation of such a label depends mainly on content and type of information provision. Regarding the information content consumers evaluate three different underlying factors when including the label in their decision process. These are the attributes of bio-based plastics which concern participants directly, altruistic motives like environmental protection and resource conservation as well as the origin of the renewable raw materials. The results from the pilot study will be used for our forthcoming online consumer survey.

Keywords

Bio-based plastics, renewable resources, labelling

1   Introduction

With the increasing importance of climate and environmental protection and conservation of fossil fuels agricultural raw materials become more and more interesting for the production of plastics (Beucker et al., 2007). Various products - especially for food packaging - based on renewable resources are already available in the food and retail markets. But consumers do not easily recognize these products due to lack of knowledge

(Decker et al., 2009). Besides, no specific label exists in Germany to distinguish them from crude-oil-based plastics (Verbraucherinitiative e.V., 2013). Thus, it is impossible for consumers to determine the raw material of the different plastics. Plastics made from renewable raw materials are a credence good (Nelson, 1970): As it is impossible for consumers to validate product quality before or after purchasing they have to trust the information on the product such as "bio-based" or "from renewable resources".

To inform consumers about the existence and advantages of bio-based plastics the objective of this project is to create a label which is informative and easily understandable.

Although there are 400 existing labels for food and fast-moving consumer goods (FMCG) in Germany (Verbraucherkommission Baden-Württemberg, 2011), from a consumer point of view labels play nevertheless an important role: They reduce uncertainty about product and process quality at the point of sale and help consumers make better buying decisions (Annunziata et al., 2011; Tsakiridou et al., 2011).

To get the necessary information for creating such a label, we conducted a preliminary study to answer the following questions:

- What visual aspects are relevant for consumers when choosing a label for plastics made from renewable resources?
- Which concept is easier to understand for consumers, "bio-based" or "renewable resources"?
- How do consumers visually evaluate a label for plastics made from renewable resources?
- Which criteria regarding content must be fulfilled that a label for bio-based plastics plays a role in purchasing decision?

2 Methodology

We designed a questionnaire with four parts: (1) label decision, (2) visual label evaluation, (3) evaluation of label content and (4) socio-demographic characteristics of respondents.

In part 1 the respondents decided on six visually completely different label designs. These label drafts were partially derived from existing labels from other countries, some were newly developed. The labels differed in color, shape and information content. First, participants were shown a screen including six different label drafts containing the concept "bio-based". From these drafts they had to choose one label which described plastics from renewable resources best in their view. Second, par-

ticipants were shown the same six label designs but with the concept "renewable resources". Again, they had to choose the label they found most appropriate to identify bio-based plastics. In the next step, the two label designs from the first ("bio-based") and the second ("renewable resources") choice appeared again, so consumer had to choose one more time between these two label drafts. Thus, we could determine which concept ("bio-based" or "renewable resources") and which visual draft is preferred. Further, we added an open-ended question in which respondents specified what visual aspects were crucial for their decision.

Part 2 contained the visual evaluation of the chosen label draft. For that reason we conducted a semantic differential with opposed adjectives (Mudgal et al., 2012) on a 5-point Likert scale. For evaluation the mean values are shown in a polarity profile (Fantapié Altobelli, 2011). Thus, we could learn how participants perceive the visual impact of the chosen draft.

In part 3 respondents had to evaluate criteria which must be fulfilled if the label is to play a role in their purchasing decision. This question was answered on a 5-point scale from "completely true" (1) to "completely untrue" (5). We sampled criteria which focus on the environmental and climate effects, but also on characteristics of bio-based plastics. On the basis of the results we conducted a factor analysis to extract independent criteria of consumers for a label for bio-based plastics. This is a procedure for the explanation of relationships between variables as well as when a large number of variables should be returned to a few key factors (Backhaus, 2008). Those variables that correlate strongly with each other are combined into one factor (Bühl, 2012). The Kaiser-Meyer-Olkin measure (KMO) indicates the extent to which the output variables belong together and whether a factor analysis seems to make sense. A KMO measure above 0.8 is desirable (Backhaus, 2008). Only variables with a factor loading higher than 0.4 enter into the factor (Worthington & Whittaker, 2006). As a measure of significance for the whole population, the explained total variance is used (Backhaus, 2008). The reliability of factors is checked with Cronbach's alpha (CRA), its value should be above 0.6 (Eckstein, 2000).

In part 4 the socio-demographic characteristics of respondents were detected.

For that we conducted an online survey with the open source questionnaire tool LimeSurvey (www.limesurvey.org). Participants were personally recruited in Straubing, a town in Lower Bavaria with about 45.000 inhabitants.

3   Results

70 questionnaires were fully completed. 67.1 % of the respondents are female. 28.6 % are younger than 30 years, 42.9 % are between 30 and 49 years old and 28.6 % are 50 years or older. Household size is 2.46 on average. The sample is highly educated with 51.4 % university graduates. Employees and officials are over-represented with 67.1%. Almost half of the participants live in cities between 20,000 and 99,999 inhabitants, 40.0 % in villages smaller than 5,000 inhabitants. 80.0 % of the respondents said that they pay attention to labels when purchasing food. 60.0 % stated to consider labels when buying FMCG.

The results of questionnaire part 1 (label decision) are as follows: Participants prefer the concept "renewable resources" compared to the concept "bio-based", since 61.4 % of the respondents chose a label alternative with the first wording.

When asked which label would be the best to identify plastics from renewable resources two labels prevailed: 37.1 % of respondents preferred label no. 1 and 21.4% chose label no.2. The label designs are shown below (Figure 1, Figure 2).

Figure 1: Label no. 1 ("Aus nachwachsenden Rohstoffen" means "From renewable resources")

Figure 2: Label no. 2 ("Nachwachsende Rohstoffe" means "Renewable resources"; "Verpackung: 57 % Biobasiert" means "Packaging: 57 % bio-based")

The open-ended question concerning the crucial visual aspects for the decision for a specific design was non-mandatory. Only 16 respondents gave an answer. 14 replies touched label no.1, whereas 11 mentioned the colorfulness and three the presence of the (imaginary) internet address. Two respondents stated that the information on label no. 2 about the share of renewable resources ("Packaging: 57 % bio-based") was positive. The results from questionnaire part 2 contain the visual evaluation of the finally chosen label draft. The mean values are shown in Figure   3.
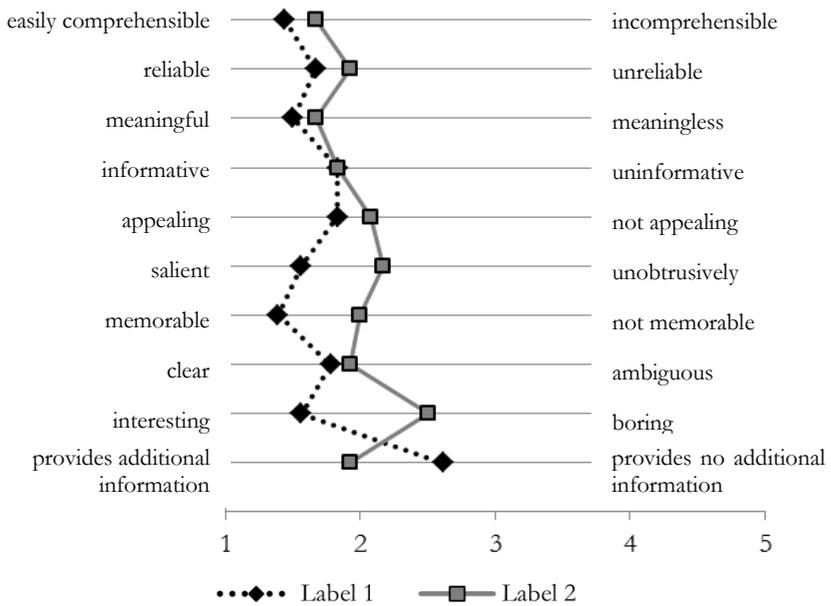
Figure 3: Semantic differential with adjectives containing labels no. 1 and 2
(n = 18; n = 12)

Figure 3 shows that both labels are rather "easily comprehensible", "reliable", "meaningful", "informative", "appealing" and "clear". Differences are seen concerning "salience", "memorability", "interest" and the "provision of additional information". Label no.1 is perceived as the more "salient" and "memorable" label. Label no.2 seems to be more "boring", but it provides more additional information than label no.1.

In part 3 respondents had to evaluate various criteria concerning a label for bio-based plastics. Variable, mean values ($\bar{x}$) and standard deviation (SD) are provided in Table 1.

Table 1: Variable for purchase decision, mean values (x̄) and standard deviation (SD) (n = 70)

Variable	x̄	SD
Sustainability	1.44	0.605
Independent certification	1.87	0.992
Independent control	1.54	0.774
Environmental protection	1.26	0.472
Resource conservation	1.33	0.607
Compostability	1.59	0.876
100 % Renewable resources	1.47	0.737
Health safety	1.47	0.756
Biological production of raw materials	1.94	1.141
Ethical acceptability	1.99	1.014
Regional origin of raw materials	2.21	1.307
Recyclability	1.69	0.894
No competition with food	2.39	1.067
Quality	1.71.	0.819

"Environmental protection" and "resource conservation" are most important, "regional origin of raw materials" and "no competition with food" are least important.

With all mentioned criteria we conducted a factor analysis which revealed four factors. These four factors are able to explain a cumulative total variance of 63.33 %. The KMO of 0.789 reaches nearly 0.8, thus the method appears to be useful.

CRA exceeds the value of 0.6 in the case of factors one and two, thus both factors can be considered reliable. Factor three reaches a CRA of 0.518 and is therefore difficult to interpret (George & Mallery, 2003). For factor four a CRA can not be calculated because only one variable loads on this factor.

The contents, shares of explained total variance, criteria, factor loadings and CRA of the four identified factors differ as follows (Table 2):

Table 2: Factors, share of explained total variance, variable, factor loadings and CRA (n = 70)

Factor (share of explained total variance)	Variable	Factor loading	CRA
1 Attributes of bio-based plastics (33.0 %)	Compostability	0.766	0.815
	Recyclability	0.723	
	Regional origin of raw materials	0.693	
	Health safety	0.671	
	Biological production of raw materials	0.648	
	Ethical acceptability	0.636	
	Quality	0.414	
2 Environment and examination (14.8 %)	Independent certification	0.868	0.731
	Independent control	0.665	
	Resource conservation	0.648	
	Environmental protection	0.560	
3 Renewable resources (7.9 %)	100 % Renewable resources	0.743	0.518
	No competition with food	0.713	
4 Sustainability (7.6 %)	Sustainability	0.864	-
KMO = 0.789; explained total variance = 63.33 %			

Factor one "Attributes of bio-based plastics" includes origin of raw materials, product characteristics and disposal. Factor two "Environment and examination" contains certification and control variables as well as environmental protection and resource conservation. Factor three "Renewable resources" is difficult to interpret due to the low CRA, but this factor seems to collect variables about raw materials. Factor four "Sustainability" depicts only one variable.

4   Discussion of results

Educational level of the sample is higher than the national average, females as well as employees and officials are over-represented (MDS online, 2012) and residents of big cities (> 100,000) and small towns (5,000 – 19,999) are almost completely absent. Because of this distortion, the limited sample size (n = 70) and the restriction to the town of Straubing this study is considered as non-representative and exploratory.

Although responsibility for the purchase in the household was not investigated the high proportion of women seems reasonable. Women are the main buyers in households and thus more familiar with purchasing decisions and labels.

Nearly two-thirds of participants prefer the concept "renewable resources". Due to two reasons this isn't surprising: on the one hand „bio-based" is an abstract concept and the consumer has probably little imagination about its meaning resp. consumers connect the word "bio" with food. On the other hand Straubing is called „Region of renewable resources". Thus a reference to the concept of renewable raw materials is already available in the population.

In the study two labels seem appropriate to describe plastics from renewable resources. Label no.1 has been chosen by most participants because of the presence of different colors and of the (imaginary) internet address. Label no.2 provides additional information regarding the share of renewable resources in the packaging ("Packaging: 57 % bio-based").

In the visual evaluation label no.1 is rated best. But regarding content label no.1 and 2 are perceived almost similarly. Particularly interesting is the evaluation of the items "informative" vs. "uninformative" and "provides additional information" vs. "provides no additional information": Both labels are rated equally informative (both $\bar{x} = 1.83$). But if we look at the provision of additional information label no.2 is rated best ($\bar{x} = 1.94$), followed by label no.1 ($\bar{x} = 2.61$). This means, although label no.1 and 2 are perceived as equally informative, label no. 2 provides more information with the term "Packaging: 57 % bio-based" than label no.1 which features an internet address. For respondents it seems to be more important to receive information directly on the label than to have the possibility to search for additional information in the internet.

The factor analysis which examined the criteria regarding the content of a label for bio-based plastics reveals four factors. Factor one reflects the attributes of bio-based plastics that are important to participants. Especially health, safety and quality play a role. Additionally, variables dealing with origin, production of raw materials and disposal load on this factor. Variables covering altruistic aspects like environmental protection and

resource conservation as well as aspects like certification and control load on factor two "Environment and examination". Factor three "Renewable resources" includes variables dealing with raw materials like "100 % renewable resources" and "no competition with food". Factor four "Sustainability" represents a special case because only one variable ("sustainability") loads on it. This variable doesn't match to any of the three other factors. Apparently participants evaluate sustainability in another way than resource conservation or environmental protection. Sustainability is perhaps too abstract and complex.

For this reason, the term of sustainability should be avoided. Furthermore, it is not only important to emphasize factors relating to the altruistic side of bio-based plastics such as renewable resources, environmental protection and resource conservation. But properties of plastics that personally affect the consumer should be particularly mentioned.

5 Implications for forthcoming survey

Our pilot study identified that the concept "renewable resources" and the perceived provision of information (internet address, share of renewable resources) on a label are relevant to participants. In addition, respondents evaluate three different underlying factors of a label for bio-based plastics when including the label in their decision process. These are the attributes of bio-based plastics concerning participants, altruistic motives and raw materials.

In a forthcoming step, we will conduct an online consumer survey to elicit the relevance of a label for bio-based plastics. This survey will consist of two parts:

In the first part we will apply an adaptive choice-based conjoint analysis (ACBC). Generally conjoint analysis is based on the assumption that a product is composed of different attributes (e.g. price, share of renewable resources, etc.) which contain different attribute levels (e.g. price 1.00 €, 5.00 €, 10.00 €) (Fantapié Altobelli, 2011). Consumers' perceived total utility is the sum of the utility of all particular attributes and attribute levels (ibid.). ACBC is an advancement of traditional conjoint analysis. More attributes and levels can be included (Fantapié Altobelli, 2011). In addition this method is interactive which means that consumers' answers are processed during the survey (ibid.) and the given answers provide the basis for the following questions (Herrmann et al., 2009). One attribute of our survey will be the presence of a label for plastics made from renewable raw materials. The two labels from the preliminary study represent the levels, whereas their information content differs: one contains an addition-

al internet address and one includes detailed information on the share of renewable raw materials in the packaging.

For this purpose we focus on packaging material, especially on shopping bags and catering-products like cutlery, single-use plates or cups. These products are simple, cheap and everyday consumer goods and users do not consciously reflect on their use.

In the second part we want to determine consumers' information processing. We will examine how consumers perceive, assess and process label information. The three determined factors "Attributes of bio-based plastics", "Environment and examination" and "Renewable resources" will be used in the context of the Heuristic-Systematic Model (Chaiken & Trope, 1999; Chaiken & Maheswaran, 1994; Eagly & Chaiken, 1993).

Our target group are persons who are responsible for household shopping. Sample size will be between 900 and 1,200 participants.

To our knowledge, our work will be the first scientific study that combines information processing with the heuristic-systematic model and labelling for bio-based plastic products with an adaptive choice-based conjoint analysis.

6   Conclusions

We conducted a pilot study to detect which visual and content information are important for consumers when assessing a label for plastics made from renewable resources.

We found that participants prefer the term "renewable resources" instead of "bio-based". Moreover, respondents show a tendency to favour a colourful design of the label providing and additional information in the form of an internet address or the share of renewable raw materials.

Consumers seem to evaluate three different contents of a label. These are the attributes of bio-based plastics, which concern participants directly, altruistic motives like environmental protection and resource conservation as well as the origin of renewable raw materials.

From our point of view, the pilot study constitutes a solid basis for our forthcoming survey. An online consumer survey will be conducted to elicit the relevance of a label for bio-based plastics. For that, we use an adaptive choice-based conjoint analysis in combination with a theory about a person's information processing, called the Heuristic-systematic model.

For this purpose we focus on packaging material, especially on shopping bags and catering-products like cutlery, single-use plates or cups.

Our findings aim to reach a further market penetration of bio-based plastics and in this way contribute to the conservation of fossil resources.

Therefore consumers must be informed about the existence and advantages of plastics from renewable raw materials.

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Products consisting of innovative Wood Polymer Composites:

Is there a market for ecologically aware consumers?

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Abstract

Innovative materials as WPC are a promising approach to realize efficient resource utilization. However, innovative materials will fail without achieving consumer acceptance. Since WPC is a conjunction of two as very contradictory perceived constituents (natural and synthetic), this study explores, whether common findings regarding traditional eco-friendly materials also hold up for this innovation. Three materials (wood, WPC, plastic) were compared within subject by means of an online survey ($N = 198$) concerning the purchase of a chair. The behavioral intention to purchase the products serves as the dependent variable. Environmental Concern (EC) and Awareness of Consequences (AC) are assessed, two scales which are commonly used to predict the acceptance of ecological materials. In the results, WPC positions itself in the perfect center between the solid wood and the plastic chair (intention ratings 3.18, 2.50, 1.95). As expected, AC and EC increase the preference for wood over plastics. However, AC and EC do not influence the WPC center position. Accordingly, WPC has a greater amount of potential customers than previous research have suggested.

Keywords

Composite materials, WPC, consumer acceptance, green marketing, environmental consciousness

1 Introduction

Efficient resource utilization becomes increasingly important due to resource scarcity and a wide range of environmental problems. In this context, innovative materials as Wood Polymer Composites (WPC) seem to be a promising approach to implement cascade utilization by facilitating a material usage of otherwise only energetically used by-products (e.g., chipped wood). However, these innovations will fail without achieving consumer acceptance. So far, there is a lack of information about the acceptance of WPC regarding prospective customers. Hence, a series of studies should address the knowledge gap, being part of a project about the acceptance of eco-friendly products mostly in the B2C context. Specifically, the accompanying B2C-project intent is to indicate target groups and benefits marketing should focus on.

It has to be taken into consideration that WPC possesses different characteristics than conventional materials. One of the most significant issues is that WPC relies on the conjunction of two as very contradictory perceived materials (i.e. wood and plastics), requiring a collaboration of two very different industries (Caufield et al., 2005). An interview study of Jonsson et al. (2008) compared the consumer acceptance of WPC with wood-based materials. According to the 15 Swedish participants, solid wood is highly favored over composite materials. However, this study compares WPC solely with one of its components (i.e. solid wood), based on a small number of respondents. The present study extends the empirical approach by also considering the second component of WPC (i.e. plastics).

Since WPC represents an eco-friendly material facilitating resource efficiency, environmental conscious consumers emerge as a target group of special interest. Usually wood is favored by ecologically aware consumers, whereas plastics and materials with a high amount of additives are attractive for those for whom environmental protection is negligible. In their study of WPC acceptance in the Austrian decking market, Weinfurter and Eder (2009) looked for the importance of environmental attributes. Across the 391 participants characterized as 'do-it-yourselfers', the importance of environmental attributes was low. However, the study did not include measures to identify ecologically aware consumers. To the best of our knowledge, no previous research has been conducted on the acceptance of

innovative composite materials including a measure to select the ecological aware segment of customers. Therefore, the first study in the B2C-project of the DFG Research Training Group 1703 'Resource Efficiency in Inter-organizational Networks' investigates whether especially ecologically aware consumers accept WPC products: Does the intermixture with plastics and additives place WPC more to the wood or to the plastic products pol? And can common findings regarding the characterization of consumers favoring traditional eco-friendly materials be applied on WPC?

2 Theoretical Background

Numerous studies showed that general attitudes determine pro-environmental behavior (e.g., Bamberg, 2003; Gärling et al., 2003; Groot & Steg, 2007, 2009). Therefore, the present research incorporates two prominent psychological constructs that focus on the individual's ecologically awareness: the Environmental Concern (EC; Schultz, 2000, 2001) and the Awareness of Consequences (AC; Stern, Dietz & Kalof, 1993).

Evidence suggests that EC as well as AC are rooted in human values (Stern & Dietz, 1994; Stern et al., 1999). In turn, both of these constructs determine actual behavior. *EC* is a general attitude focusing on the evaluation of different objects that have to be protected environmentally (Bamberg, 2003), e.g. the climate. Schulz (2000, 2001) distinguishes three targets of environmental concerns: the self, other people and the biosphere (Groot & Steg, 2007). *AC*, a disposition to be aware of consequences of environment consuming behavior (Schwartz, 1968), is a further general construct commonly used to predict pro-environmental behavior (e.g., Ryan & Spash, 2012; Stern et al., 1993). Similar to EC, AC distinguishes consequences for the self, other people and the biosphere (Stern et al., 1993). However, recent research questions the three-factorial structure of EC and AC (e.g., Ryan & Spash, 2012; Snelgar, 2006). Other factor structures or differentiations are not yet well established. Therefore we only consider the global measures of EC and AC, respectively, both also used by authors to whom the distinction of EC and AC can originally be ascribed to (Stern, Dietz & Guagnano, 1995).

Regarding the purchase of eco-friendly products consisting of innovative materials as WPC, a comparison has to be made with both materials WPC consists of, i.e. solid wood and plastics. Hence, product appearance arises as another influencing factor. As Table 1 shows, all materials could either have a wooden or a synthetic surface. This leads to the following hypothesis:

Hypothesis 1 (H_1). The behavioral intention to purchase a product varies with a main effect of the products' appearance. A wooden will be preferred over a synthetic surface.

Table 1: Materials and appearances of the investigated product

Material	Appearance	
	wood	synthetic
solid wood	wooden chair	PVC chair, veneered
WPC	WPC chair	WPC chair
plastics	wooden chair, laminated	PVC chair

However, wood is usually perceived as a higher quality material than plastics. Since WPC comprises both materials, we parsimoniously expect a central position:

Hypothesis 2 (H_2). The behavioral intention to purchase a product varies with a main effect of the products' material. Consumers prefer solid wood over plastics, while WPC positions itself in the center.

Especially, we focus on ecologically aware consumers. As the above-mentioned research indicates, consumers with higher environmental concerns and a high awareness of consequences typically behave more eco-friendly. Therefore, ecologically aware consumers will favor solid wood. Since WPC consists of two elements, one of which is plastics (and additives), typically avoided by eco-friendly consumers, this component might have a stronger influence on their decision. Specifically, a perception of WPC as cheap and baneful might appear as well as health concerns due to the synthetic component (Eyerer et al., 2010; Petrescu, Ispas & Mohora, 2010). Hence, we derive two hypotheses:

Hypothesis 3 (H_3). The higher the AC/EC of an individual consumer, the stronger her/his preference for solid wood over plastics (an interaction of the AC/EC trait with the material factor).

Hypothesis 4 (H_4). For those having a high AC/EC, WPC is assimilated to plastics (an interaction of the AC/EC trait with the material factor, too).

H_4 becomes crucial for the WPC prospect. If WPC suffers more from its plastic additives than it gains from its wood constituent, the sustainability intention will fail.

3 Methods

3.1 Procedures and Participants

We conducted a study to examine consumer's intention to buy products consisting of innovative eco-friendly materials. Therefore, an online survey was conducted with German respondents. The present study realizes a 3 (material: solid wood, WPC, plastics) x 2 (appearance: wooden, synthetic surface) within subjects design. Due to its innovativeness, respondents received information about WPC in the beginning of the survey. We exemplarily focused on furniture as product category. Specifically, we chose chairs, since they are available in all three considered materials and represent a product which everyone is acquainted with. Additionally, furniture is an important WPC market, also for outdoor applications. Therefore, participants were instructed to imagine going to purchase a chair with different options to choose from. Pictures were shown to familiarize respondents with the different appearances. A black chair with a plastic optic represented the synthetic appearance, while a middle brown chair with a wooden appearance displayed the wooden alternative. Apart from the surfaces, both chairs did not differ with respect to any other criterion.

Participants were recruited through mailed letters and announcements in online platforms. As motivation for participation, each respondent automatically entered a prize draw. Prizes included three vouchers worth 10 to 20 Euro that respondents could either use in an online shop or donate to charity. In total, 250 respondents participated, whereof 198 fully completed. Participants' ages ranged from 18 to 40 years ($M = 25.47$, $SD = 3.41$). 38 per cent of the respondents were male, and 69 per cent were university students. At the end of the questionnaire 50 per cent indicated that WPC was unknown to them prior to the survey, while only 8 per cent reported good knowledge about the innovative material.

3.2 Measures

The online survey consisted of several parts, whereupon the present paper only focuses on the measurement of AC, EC and the behavioral intention to purchase chairs in the experimental 3 x 2 design. In addition, we consider sociodemographic information.

AC and EC. The constructs were measured with established scales which were translated into German language. For AC, we used the scale from Ryan and Spash (2012), which incorporates the 14 most common used AC items, focusing on consequences for the self (5 items), other peo-

ple (5 items) and the biosphere (4 items). Responses were made on a 7-point scale ranging from 1 (totally disagree) to 7 (totally agree). EC was measured with the questionnaire of Schulz (2001), where respondents had to estimate the significance of environmental problems for themselves (4 items), other people (4 items) and the biosphere (4 items). Again, a 7-point scale was used ranging from 1 (not concerned) to 7 (extremely concerned). The items of each instrument were presented in random order. Mean scores were 5.64 ($SD = 0.84$) for AC and 4.74 ($SD = 1.04$) for EC. Internal consistencies (Cronbach's alpha) were .88 for AC and .89 for EC.

Behavioral intention. The dependent variable was measured with two items per chair 'If I wanted to buy chairs, I would take a closer look at this chair' and 'If I had to buy a chair today, I would buy this chair'. Thereby, every chair was characterized by a description of the material and a picture illustrating either a synthetic or a wooden surface. Respondents indicated to what extent they agree on a 5-point scale ranging from 1 (disagree) to 5 (agree). Internal reliability was high (Cronbach's alpha .86) and the two ratings were aggregated.

3.3   Data analyses

Both intention items per chair were aggregated and its mean analyzed by general linear models with material(3) and appearance(2) as repeated measure factors. Polynomial contrasts compared the three investigated materials (wood, WPC, plastics). The preference for wood over plastics is described by the linear contrast of the material source. A significant quadratic contrast indicates a deviation of WPC from the center position: While a positive quadratic term points to WPC being assimilated to plastics, a negative quadratic term refers to WPC being treated like solid wood.

4   Results

4.1   Effects of material and appearance

Table 2 presents means and standard deviations for the behavioral intention ratings in the experimental design. WPC positions itself in the perfect center between the solid wood and the plastic chair (mean intention ratings 3.18, 2.50, 1.95). While the linear contrast of the material main effect is significant ($F(1,197) = 197.83$, $p = .001$), the quadratic contrast of the material main effect remains non-significant ($F(1,197) = 1.32$, $p = .251$). The chairs' appearance has a main effect on behavioral intention ($F(1,197)$

= 81.56, p = .001), too. These findings support hypotheses H_1 and H_2. Additionally, appearance interacts with the materials linearly, strengthening the material slope for wooden appearances. The central position of WPC, indicated by the non-significant quadratic contrast of the interaction (Table 3), remains unaffected.

Table 2: Means and standard deviations for behavioral intention ratings ($N = 198$)

Material (Appearance)	wood (wood)	WPC (wood)	plastics (wood)	wood (syn.)	WPC (syn.)	plastics (syn.)
M	4.04	2.88	1.88	2.32	2.12	2.01
(SD)	(1.08)	(1.16)	(1.02)	(1.19)	(1.13)	(1.16)

Table 3: General Linear Model of the behavioral intention in the experimental design ($N = 198$)

Source		F(1, 197)	p
Appearance		81.56	.001
Material	linear	197.83	.001
	squared	1.32	.251
Appearance x Material	linear	205.11	.001
	squared	0.19	.662
Constant Term		4432	.001

4.2 Influence of the ecological awareness

Table 4 shows the effects of the inclusion of the psychological trait in a general linear model of the behavioral intention. The AC and EC scores were standardized before inclusion. According to the linear material contrasts, AC and EC increase the preference for wood over plastics (AC x linear material contrast: $F(1,196) = 19.11$, $p = .001$; EC x linear material contrast: $F(1,196) = 13.87$, $p = .001$). The higher AC or EC, the stronger is the preference for wood (see Figure 1 and 2). Thus, Hypothesis H_3 is supported. Effects of the chair's appearance are not affected by AC or EC (AC x appearance: $F(1,196) = 0.70$, $p = .405$; EC x appearance: $F(1,196) = 0.13$, $p = .909$). Contrary to the pessimistic H_4, the quadratic material contrasts remain non-significant: There is no particular influence of AC and EC on the WPC position (AC x squared material contrast: $F(1,196) = 1.77$, $p = .185$, EC x squared material contrast: $F(1,196) = 0.27$, $p = .604$). As illustrated in Figure 1 and Figure 2, WPC kept its center position regardless of the environmental orientation of the prospect customer. Therefore, hypothesis H_4 is not supported.

Table 4: General Linear Model of the behavioral intention including the psychological constructs (*N* = 198)

Source		Ψ: EC		Ψ: AC	
		F(1)	p	F(1)	p
Appearance		81.14	.001	81.51	.001
Appearance x Ψ		0.13	.909	0.70	.405
Material	linear	211.21	.001	216.67	.001
	squared	1.31	.253	1.31	.253
Material x Ψ	linear	13.87	.001	19.11	.001
	squared	0.27	.604	1.77	.185
Appearance x Material	linear	207.51	.001	205.28	.001
	squared	0.19	.662	0.20	.657
Appearance x Material x Ψ	linear	3.10	.080	1.03	.311
	squared	0.07	.796	1.60	.208
Ψ		0.60	.440	0.21	.650
Constant Term		4423	.001	4414	.001

Table heading spanning the four value columns: Psychological Construct

Table 4 further shows that neither the linear nor the quadratic appearance x material interaction contrasts are significantly affected by AC or EC. To sum up, the present study reveals that AC and EC, while strengthening the preference for wood over plastics, do not change the central position of WPC. Thereby, a high AC and EC did not lead to a rejection of WPC.
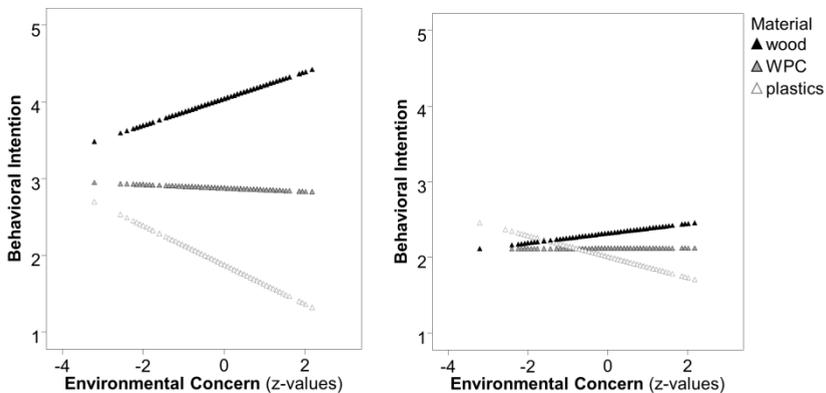

Figure 1: Behavioral intention as a function of Environmental Concern for wooden (left figure) and synthetic product appearance (right figure)
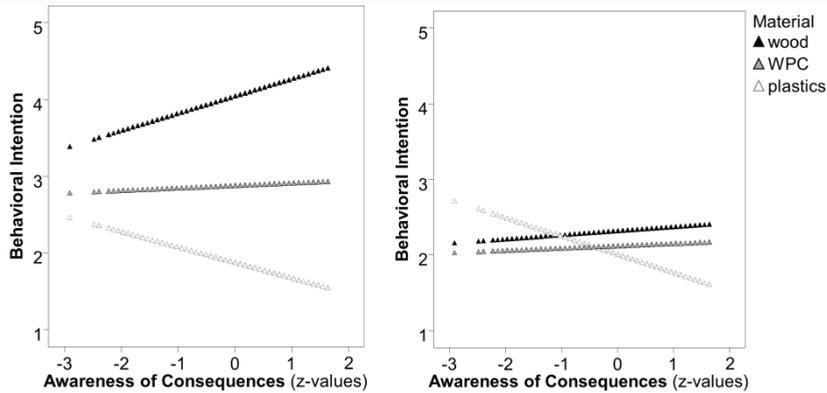
Figure 2: Behavioral intention as a function of Awareness of Consequences for wooden (left figure) and synthetic product appearance (right figure)

5 Discussion and Conclusions

WPC has capacities to implement cascade utilization of materials. The acceptance of the material is doubtful, since WPC is a conjunction of natural and synthetic constituents, the latter typically rejected by environmental concerned consumers. We present the first consumer study comparing WPC with wood and plastics. We expect and found that customers prefer eco-friendly materials (wood) over materials with greater environmental impact (plastics). This preference applied the stronger the more eco-friendly the consumer. This result is in line with previous research showing that ecologically aware consumers tend to behave eco-friendly (e.g., Bang et al., 2000; Schultz et al., 2005). The innovative part lies in the positioning of WPC in the continuum between solid wood and full plastics.

The present study shows that the behavioral intention to buy WPC products is just in the center between solid wood and plastic products. Therefore, the results are more optimistic compared to Jonsson et al. (2008), whose research indicated that solid wood is highly favored over composite materials. In contrast, the present study reveals that WPC is, although not preferred as solid wood, not rejected as plastics. Most notably, this holds also true for consumers with a high ecological awareness. Both of the obtained measures for ecological awareness (AC, Ryan & Spash, 2012 and EC, Schulz, 2000, 2001) reveal that WPC keeps its center position regardless of the environmental orientation. While AC and EC are different constructs that either refer to an affective evaluation or beliefs about harmful consequences, they lead to same conclusions, at least within

the context of wood-based products' acceptance. Accordingly, in future investigations the assessment of one construct appears to be sufficient.

The results reported in this paper have practical implications for the marketing of the material. First and in contrast to pessimistic forecasts, WPC is not assimilated to plastics for those having a high ecological awareness. Therefore, WPC should have a greater amount of potential customers as previously thought. This implies a wider range of different target groups marketing should concentrate on. Referring to ecologically aware consumers, a further market growth appears possible: This target group might be even more open towards WPC, if it becomes possible to replace fossil fuel-based plastics by bioplastics. Material sciences should address this issue and develop strategies to reduce the carbon footprint of WPC. Second, this study shows that customers do not reject the combination of two as very contradictory perceived constituents (wood and plastics), even if they are informed about the material composition. However, consumer information appears necessary, since the great majority of consumers participating in the study indicated no or only limited WPC knowledge. Finally, the present study reveals design recommendations, by indicating that consumers considerably favor WPC with a wooden instead of a synthetic appearance. This applies to customers regardless of their environmental orientation. Hence, producers should engage in adapting WPC appearance to consumer preferences.

Despite these promising results, the present study has some limitations. First, participants were younger adults aged 18 to 40 years and the majority was students. These individuals are usually more open to innovations. Therefore, further studies have to investigate consumers aged 41 years and older. Second, the investigated product, a chair, is not as expensive as a car or decking. Even if furniture is an important WPC market, consumer acceptance regarding other WPC products remains unexplored. WPC might lose its center position for product categories where aspects as hygiene and secureness (e.g., bathroom furniture, toys) got a special weight. Third, other factors influencing consumers purchase decisions should be included in future analyses in the B2C-project. Not only material and product appearance determine purchase decision. In this context, the willingness to pay for eco-friendly materials is an important issue, especially regarding the communication of WPC as a sustainability contribution. Finally, the present study measures behavioral intention, but not actual purchase behavior. Due to the intention-behavior-gap literature (Sheeran, 2002; Webb & Sheeran, 2006), future studies should consider methods that approach purchase situations further (e.g., choice-based conjoint analysis, experimental auctions).

To sum up, as the increasing global demand for resource efficiency requires the development of innovative materials, the present study indi-

cates that German consumers accept WPC. At a later stage, the ongoing B2C-project also aims at identifying ecologically concerned customer demands regarding WPC products being directly relevant for the material sciences.

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Resource Use Efficiency in the Information Society

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Abstract

In the last decades the emergence of the Information Society, based on the needs of individuals and enterprises, was strongly encouraged both on regional level and on a global level. The hope was that by developing the Information Society, the resource use will decrease or will become more efficient, this means that the sustainability of our society will be naturally assured.

However, the real developments in the last time did show that the emergence of the Information Society does not automatically assure its sustainability, because of several factors, which do play an important role in this context. The question regarding resources, their availability and their efficiency is a very important one. But also the resources usage manner is a very relevant issue and has a lot to do with the consumer behaviour.

Connected with this issue, it is interesting to analyze different phenomena raised up in the Information Society, especially the so-called "rebound effects". It has been demonstrated that, under certain conditions, such effects do become a real problem of our society. In order to succeed analyzing these effects, several models in the context of different research projects have been developed. The goal was actually to get and to evaluate different scenarios, representing different possible development paths of our societies. Such "integrative models" connect so-called "old" variables, like energy and paper consumption with "new" variables, related to IT-based applications. These so-called "new" variables are connected with the needed infrastructure for the use of different IT-based services, in this paper being especially emphasized the on-line-informing and e_working.

The results show that under certain conditions rebound effects could appear, especially because of changes in consumer behaviour and at the end in human lifestyles, which could influence the resource use efficiency and the sustainability of our society.

Keywords
Information society, integrative models, consumer behaviour, scenarios, rebound effects.

1   Introduction

The Information Society Technologies (IST) Programme of the European Commission was intended several years before to accelerate the emergence of an information society based on the needs of individuals and enterprises. The IST - Programme was at that time structured around four Key Actions (ftp://ftp.cordis.europa.eu/pub/ist/docs/b_wp_en_200201.pdf): Systems and Services for the Citizen, New Methods of Work and Electronic Commerce, Multimedia Content and Tools as well as Essential Technologies and Infrastructures.
Beside these actions, the Action Plan **eEurope** has been developed (http://europa.eu.int/comm/information_society/eeurope), which has been clustered around three main objectives:

- A cheaper, faster, secure Internet
- Investing in people and skills
- Stimulate the use of the Internet

By these programs the general use of ICT was strongly stimulated in the European region. The reality did however show that the effective use of these technologies is strongly depending on the personal skills to use these ones and that ICTs are critical to improve the competitiveness of European industry and to meet the demands of its society and economy.
Basing on a complex analysis of information society challenges, the European Commission proposes three priorities for Europe's information society, with the hope of achieving a sustainable European information society (European Commission, 2005):

1. the completion of a Single European Information Space which promotes an open and competitive internal market;
2. strengthening Innovation and Investment in ICT research in order to promote growth as well as more and better jobs;
3. achieving an Inclusive European Information Society that promotes growth and jobs in a manner that is consistent with sustainable development and that prioritises better public services and quality of life.

The European Commission recognised the multitude of possibilities given especially by IT-applications and tried to exemplarly apply these multitude

of possibilities in the context of the Seventh Framework Programme FP7 (http://cordis.europa.eu/fp7/home_en.html), having as broad objective to further promote the development of ICTs for achieving the best possible resource use efficiency in all human activity fields.

As mentioned in the Work Programme 2013 for the ICT theme of the FP7 Specific Programme ”Cooperation”), ICTs are critical to improve the competitiveness of European industry, not at least by achieving a higher resource use efficiency as well as to meet the demands of its society and economy (http://cordis.europa.eu/fp7/ict/docs/ict-wp2013-10-7-2013-with-cover-issn.pdf).

The Information Society Directorate General published during the last years several Status Reports about the existing situation in Europe and expectations regarding the field of eWorking. The overall objective was represented by succeeding in making Europe one of the most competitive and dynamic knowledge-based economy, capable to achieve economic growth with more and better jobs, all this with greater social cohesion. This should happen in the own and specific way i.e. "The European Way of Life" (European Commission, 2005).

The emergence and use of ICT have impacts in all human activity fields. Presently there are several projects dealing with questions related to the use of ICT. The "digital revolution" of the last two decades influenced a lot of aspects of our daily lives and changed our planet irreversibly (Beutler, 2011) and not necessarily changes for increasing the resource use efficiency.

2   Sustainability in the Information Society

Sustainable development had arisen as a possible solution for the global complex ecological, economical and social problems. After the Conference for Environment in Stockholm in 1972 and the first report of the Club of Rome "The Limits to Growth" (Meadows & Meadows, 1973) was understood that besides wanted effects of technological progress, undesired and negative effects can appear. It was clear that the created regional and global (environmental) problems are very serious and need to be solved.

Nowadays we confront us with a series of global problems. "World Problematique" is a concept created by the Club of Rome (www.clubofrome.org) in order to describe the set of crucial problems – political, social, economic, technological, environmental, psychological and cultural ones - facing humanity. Some of them have been discussed a lot in the past, like world population growth, increase of energy and resource consumption as well as environmental pollution. Other elements of the

"world problematique" have arisen in the last years. For instance issues related to the development and use of ICTs can be mentioned in this category, like digital divide, new technologies, global society etc.

Discussions on political, scientific and social levels began worldwide already in the 70' years in order to find solutions for the problems shown above, which could be applicable to the developed as well as to the developing countries by taking into considerations regional differences.

The concept of sustainable development was for the first time defined 1987 in the Brundtland Report (WCED 1987) and was very large discussed on the Conference for Environment and Development in Rio de Janeiro 1992 as well as in the closing document "Agenda 21" (Tulbure 2003). Many actions after this time emphasise that the evolution of technical, social and ecological systems has to be analysed in synergetic relation (Jischa 2005). The aim is to help the decision making process and to define such measures which can be applied on different levels depending on the specific problems in different parts of the world, by taking into consideration particularities of specific regions. The reality shows that specific regional conditions, as for instance presently in some Eastern European countries, can become very relevant and can make the process of establishing a sustainable information society a difficult one (Tulbure & Jischa, 2006).

The comprehensive question with which the projects in the ICT-field are actually dealing can be formulated as follows: Does the Information Society assure per se the sustainability of our society? What are the sensible factors, which will play an important role in this context? There are a lot of impact fields of ICT, but one of the most important is the environmental one. The developments in the last years did show that an increase in the efficiency of technological applications does not implicitly lead to a decrease of energy use and of environmental stress because of simultaneous changes in human lifestyles (Jischa, 2005). It has been demonstrated that so called "rebound-effects" do over-compensate the effects of efficiency increase by giving more and more possibilities to spend free time in a very energy intensive way (Schauer, 2000).

The EU-project "TERRA-2000", that started 2001 for a time of three years, was broadly concerned with understanding changes associated with the Networked Society and particularly their medium and long term sustainability implications (www.terra-2000.org).

In order to get answers to the specific question regarding environmental impacts of using ICT, each ICT-application has to be considered and analysed by taking into account its possible impact on environment during the whole life cycle, as usual in the context of life cycle assessments (RAND Europe, 2004). For this goal there is a need to build a connection among so-called "old" indicators like energy consumption, paper con-

sumption or pollutant emissions and "new" indicators related to IT-based applications, like infrastructure for the use of IT-applications and effective use of IT-applications.

In the presented example in this contribution especially two IT-applications will be considered: on-line-informing and eWorking. The conditions in which rebound-effects do appear will be discussed for these two IT-applications by developing and evaluating different scenarios. The evaluation of the developed scenarios will be carried out by using environmental indicators, like pollutant emissions in the air.

Related to sustainability the evaluation issue is a relevant one. Criteria chosen for evaluation have to refer global issues, but on a regional level. In our dynamically changing society the comprehensive evaluation is very difficult (Jischa, 2005). Very often aggregated or hardly quantifiable entities are neglected in the evaluation processes or taken into account as limitations. It is necessarily to develop new methods for evaluation especially related to technology assessment (Tulbure, 2013). These methods have to enable dynamic evaluations, when evaluation criteria change in time. The methods should be also transparent and robust. A promising method is the fuzzy logic based one, which enables to integrate highly aggregated entities or qualitative descriptions in mathematical models (Ludwig, 2001).

3   Methodical Problems

Part of what engineers usually do is to evaluate developments in technological field. Their evaluation has up to recent time almost without exception been focused on technical aspects, like functionality and safety, and on economic aspects following legal and financial boundary conditions (Jischa, 2005).

With respect to sustainability more criteria have to be considered like environmental quality, social and human values and quality of life. This kind of evaluation needs interdisciplinary co-operation in order to develop new comprehensive and integrative methods (Jischa, 2005). Applying sustainable development by using technology assessment means investigating complex dynamic systems (Tulbure, 2013). In this context there are many fields where research is needed; as for instance when dealing with uncertain knowledge, for improvement of methods and instruments when developing sustainable development indicators, or in the field of modelling and simulating dynamic systems (Jischa, 2005).

Methodological problems appear in the step of aggregation, because of using weighting coefficients, which very often are not transparently defined. In the step of modelling qualitatively different variables have to be

coupled in the so-called *integrative models*. Very often qualitative information goes lost or is taken into account by coefficients or parameters which are not transparently calculated (Ludwig, 2001). The issue of selecting relevant indicators or evaluation criteria has to consider also regional differences (Tulbure, 2003). All this procedure has no weight if relevant data are not available. New achievements in the field of methods should assure a better integration of qualitative or hardly quantifiable entities or uncertainties in mathematical procedures. Such a possibility is given by fuzzy logic, which is a generalisation of classic logic and was introduced by Lotfi Zadeh in the 60' years (Ludwig, 2001).

4 Environmental Assessment of using some IT-Applications

A possibility to evaluate potential environmental effects of using different IT-applications is represented by developing different scenarios, taking into account certain IT-users behaviour. For helping the scenario development process, an integrative model, named EFENIA, has been developed (Tulbure, 2003) and is presented in Figure 1. This integrative model makes the connection among so-called "old" indicators, like energy consumption and paper consumption, and "new" indicators, related to IT-based applications, like infrastructure for the use of IT-applications and effective use of IT-application.

Integrative modeling is a relatively new direction in the field of modeling dynamic systems. The concept of integrative modeling means to integrate different aspects from different scientific fields into a mathematical model (Alcamo, 1994, Tulbure, 2013). This modeling direction is a relevant one, especially in the context of sustainable development, where qualitatively different aspects from different fields, like technological, economic, environmental and social fields, have to be taken into account.

A simple definition for integrative models says that such models are ones which incorporate knowledge from more than one field of study (Mesarovic & Takahara, 1989). To develop an integrative model a top-down and a bottom-up approach is needed (Tulbure, 2003). There are several examples of integrated models, like the Club of Rome world model World3 (Meadows, 1973), International Futures world model (Hughes, 1999), climate models (Alcamo, 1994) or regional models, as the mentioned EFENIA model (Tulbure, 2003), which will be presented in the following.

The main parts of the model EFENIA, presented in Figure 1, are the following (Tulbure, 2003):

- Infrastructure for the use of IT-applications: by considering the number of computers, as well as Internet accesses
- Effective use of Internet-application: by considering two possible applications: on-line-informing (index 1) and e-working, (index 2)
- Energy and paper consumption: by considering the energy consumption of computers during production and during use, as well as the energy consumption for paper production, and because of travelling to the work office of e-workers or non-e-workers
- Environmental field: by considering pollutant emissions and quantity of e-scrap because of the old computers.

In order to use and test the developed model, several simulations have been carried out by using the software VENSIM and sensitivity analyses have been done (Alcamo, 1994; Tulbure, 2003). Some relevant simulation runs have been stored in form of scenarios and are presented in Table 1.

In the phase of data accumulation several difficulties did occur concerning some parameters of the model. There are mainly four changeable parameters, for which the data provision has been very difficult. These parameters can be found in Table 1 and have been used for developing different scenarios regarding the use of mentioned IT-applications:

- Percentage of use of on-line-informing possibilities (index 1) and
- Percentage of use of e-working possibilities (index 2).

The following applying example is referring to the specific conditions of the EU-countries, before the enlarging of the EU to Eastern Europe. The presented scenarios have been developed by taking into account specific usage cases of the two considered IT-applications, as it is to be observed in Table 1: 5 % (almost nobody does use the application), 50 % (the technological application is used by about the half of the population) and 95 % (almost everybody does use the application).
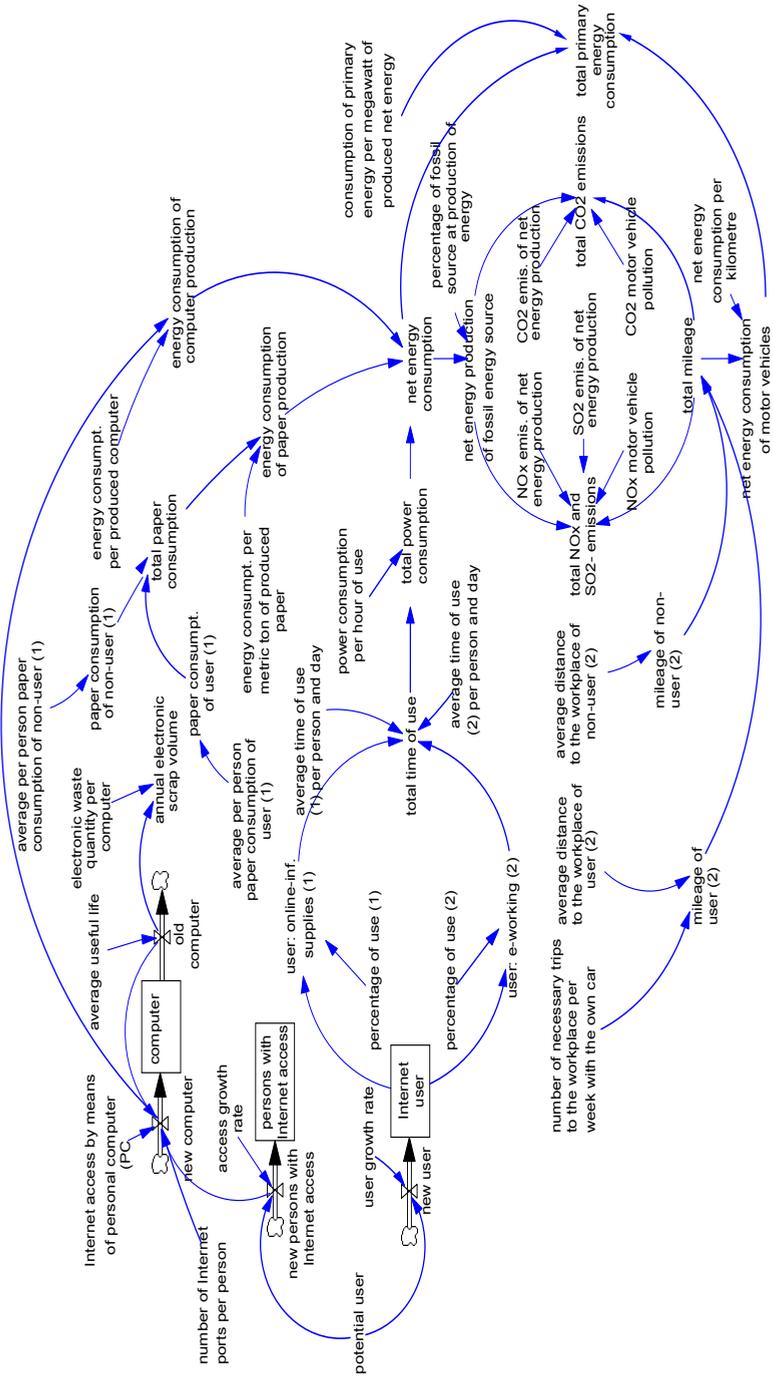
Figure 1: The structure of the integrative model EFENIA to analyse possible environmental effects of IT-applications

Table 1: Parameters with changeable values in the model EFENIA and their combinations for the developed scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Percentage of use (1) (on-line- informing)	5 %	50 %	95 %	95 %
Percentage of use (2) (e-working)	5 %	50 %	95 %	95 %
Average distance to the workplace of user (2)	100 km	100 km	100 km	100 km
Average per person paper consumption of user (1)	0,16 t	0,25 t	0,16 t	0,25 t

Regarding the average distance to the workplace of the e-workers (index 2) the value of 100 km has been considered, which is more than a realistic value, taking into account that e-workers will not travel so frequently to the working place (once or twice a week). Regarding the average paper consumption of the users of on-line-informing possibilities (index 1) the current average value in EU about 160 kg/year has been considered for two scenarios and for the other two scenarios a higher value of 250 kg/year, as on European level the tendency is the increase of the paper consumption (http://www.forestindustries.se/documentation/ppt-files/international_1/ per_capita_paper_consumption).

5   Results

Results of the simulation runs are given in Figures 2 – 5. Results are presented for the total primary energy consumption (Figure 2), for the CO_2-emissions (Figure 3), for the energy consumption without motor vehicles (Figure 4) and for the total mileage (Figure 5). Depending on the specific problem it is possible to monitor other model variables too, the presented ones being chosen as being relevant for the analysed problem.

It is to be observed that for scenario 1 the primary energy consumption because of the two considered IT-applications remains almost constantly. For the other three scenarios the primary energy consumption will increase in time. In order to analyse the role of the traffic in the energy consumption, in Figure 4 the net energy consumption without motor vehicles is given. One can observe that for all four scenarios the net energy consumption without motor vehicles will decrease. Making the connection

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viour of each user of the IT-applications. If an e-worker will travel once a week 200 or 300 km to the workplace, then the fact that the e-worker is travelling rarely cannot compensate the total mileage increase and the possible reduction of the energy consumption will be overcompensate. And this fact does not encourage the resource use efficiency in the Information Society. Such case studies can be carried out for other specific IT-applications as well.

In order to carry out the environmental assessment of using some IT-applications, it is relevant to start with presenting pollutants emissions, starting with CO_2-emissions. It is to be mentioned that for emphasising using impacts and future development tendencies by using different IT-applications, also gradients of the considered parameters are actually relevant, because these are pointing out the change (increase or decrease) of the specific parameter.

6   Conclusions

In Europe the "Information Society for All" is nowadays a reality, but this does not mean automatically that the sustainability of our society will be assured, as the hope of the European Commission was actually several years before.

Scientists from different fields started several projects in order to research and analyse the possible effects of the emerging information and knowledge society. One very important aspect is the environmental one.
In order to analyse possible environmental effects of using ICTs, different scenarios have been developed and interpreted. In order to help the scenario development process, an integrative model has been developed, which makes the connection among so-called "old" indicators, like energy consumption, paper consumption and "new" indicators, related to Internet based applications, like infrastructure for the use of IT-applications and effective use of IT-applications. Two IT-applications have been considered: on-line-Informing and e-working.

Taking into account the developed scenarios by using the presented model EFENIA, as well as the results interpretation, one can observe that just the use of ICTs does not assure per se the sustainability of our society. Under certain conditions rebound-effects could appear, which have as a result an increase of energy consumption and of environmental pollution.

It was very clear that social factors are very important and do influence in a decisive way the scenarios. It follows that the issue of educating population for energy saving is a very important one. Although the scenarios have been developed for specific conditions in EU-countries, it is pos-

sible to consider that such development tendencies are a reality in other parts of the world as well, but without making too big mistakes. Further scenarios can be developed for single European countries and for countries worldwide, depending on the availability of needed data for these countries. Regional comparisons are very important in the context of Sustainability in the Information Society.

The developed model has also importance in the methodological field. It shows the potentials of integrative models compared to other usual mo-dels. For instance integrative models allow considering "weak" factors under certain conditions. Nevertheless development of methods is still needed in order to allow a transparent integration of qualitative aspects into mathematical models.

In the context of analysing Sustainable Development in the Information Society new indicators have to be defined, which evaluate systems in a comprehensive way from ecological, economic, technical and social points of view. Not always is the resource use efficiency guaranteed even in the Information Society, because sometimes social aspects can play a not negligible role in this context and their influence should be taken carefully into consideration.

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Wood Products Certification, Consumer Behavior and its Climate Policy Potential

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Abstract

Since the early 1990ties wood processing got involved into environmental certification. Environmental certification of wood products as well as mitigation of greenhouse gas emissions by using wood is addressing similar consumer segments and needs. The main objective of this study is to investigate available consumer surveys on environmental wood certification response in order to carry out a meta-study that: gives an overview regarding the existing and the lacking aspects of this research, sums up the major findings made on this topic so far and finally delivers conclusions in context to climate policy and wood products. The greatest challenge uncovered by the meta-analysis in relation to climate policy is the rather weak adequacy of houses as products for environmental certification as the construction sector was found the most effective application field in terms of carbon storage. Hence, this topic definitely needs further considerations and research e.g. by analyzing the effects of subsidies and consumer information and campaigns.

Keywords (required)

Wood products certification, consumer behavior, WTP, HWP, meta-study

1 Introduction

By photosynthesis CO_2 is converted to oxygen released to the air and carbon stored in wood as celluloses, hemicelluloses or lignin. Hence wood and wood products are a terrestrial and biological form of carbon sequestration. Increasing consumption of wood products would therefore help mitigating greenhouse gas emissions in a cost effective and technically available way. It has been found especially suitable for emissions from

non-point sources such as from all kind of transportation (Han et al., 2007). While long-term wood products form a storage pool of wood-based carbon, wood as raw material and energy source can substitute more energy-intensive materials and fossil fuels. The material and the energetic use of wood are at least partly competing for wood as a raw material, creating conflicting interest interactions (Schwarzbauer & Stern, 2010).

Accordingly long-term wood products can be seen as an extension of the forests original carbon pool. Again it is possible to mitigate carbon dioxide emissions by increasing the pool of long-term wood products. Anyhow this possibility has so far not been part of the conventions made within the Kyoto-protocol but it may however been added at a later stage. Apart from the national emission accounting and reporting actions, the wood industry shows a high interest in the achievement of competitive advantages from the positive effects of their products. Therefore the topic of carbon storage effects of wood products and their economic impacts is an actual and important matter.
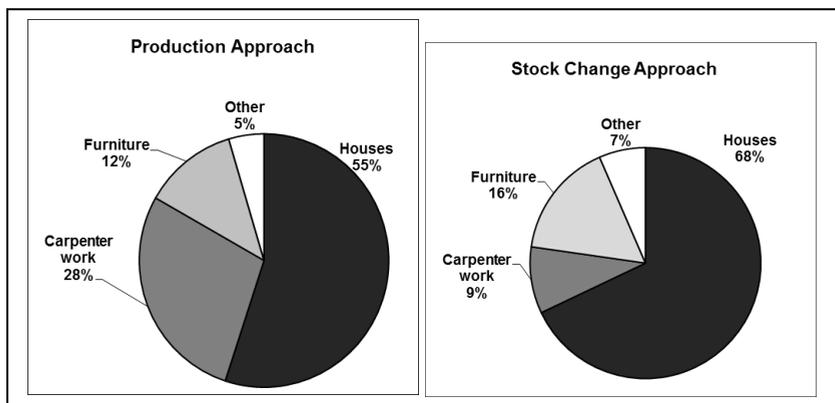
Figure 1: Share of carbon stored in wood product categories in Austria under different calculation approaches

One of the very first studies dealing with the topic of carbon storage in wood products (Can increasing wood consumption help to mitigate the CO2-problem in Austria?) was carried out by Wimmer (1992). Due to the fact that it was published in German, it is so far very little known in the international community. A second study about the storage effects of wood products in Austria was undertaken by Baur (2003) a decade later. Both authors conclude that doubling the annual consumption of long-term wood products in Austria would be equivalent to a reduction of the annual Austrian emissions by 4.3% (Baur, 2003) to 6.0% (Wimmer, 1992). In accordance with the results of these two and many other studies on the international scale (Eggers, 2002) we can conclude that the construction sector is the by far most important application field in relation to carbon

sequestration in wood products (see figure 1). The construction sector not just stores the greatest amounts annually it also delivers the longest life spans for the products. Wimmer (1992) made suggestions for improving the carbon storage effects of Austrian wood products, these were:

- Utilization of wood waste for energy
- Improvement of wood products life span
- Increase wood utilization in construction
- Recycling of wood products
- Reduction of wood imports - intensify harvesting
- Improvement of tree growth
- Substitution of other materials by wood and development of new applications

Of these suggestions the increasing wood utilization in construction, the substitution of other materials by wood and development of new applications seem to have the greatest manageable impact. First of all these possibilities offer the greatest potentials in terms of the amounts stored. Secondly they all seem to offer options to systematically manage the development of carbon storage.

In order to increase wood utilization in the construction industry, substitute other materials by wood and develop new wood products and applications a basic idea might be to promote the wood products' positive effects on carbon balances. Environmental oriented consumers may choose wood products instead of other materials and domestic wood products instead of imported ones due to their positive effect on carbon balances.

Unsurprisingly this is not a completely new idea. Since the early 1990ies wood processing got involved into environmental certification (e.g. Ozanne & Vlosky, 1997; Ozanne & Smith, 1998; Cai & Aguilar, 2013) of wood products. Very similar interests and goals led to the idea of sustainability certified eco-labeled wood products. Furthermore it is a similar topic, addressing similar consumer segments and needs. Fortunately wood products certification and labeling in relation to consumer marketing was subject of intensive research activities since 1995. If we assume that the development of wood certification (regarding sustainable forest management) is very much in analogy to what can be expected in context to carbon sequestration, these results are of great importance. Learning from the past can be applied by carrying out a meta-study on consumer response to wood certification. As it is well-known, a meta-analysis approach can be defined as the study of studies (e.g. Barrio & Loureiro, 2010). It refers to the statistical analysis of a large collection of results from individual studies with the purpose of combining the main findings (Glass et al., 1981). Recent meta-analyses have been conducted in the field of economic valuation

of environmental resources, impacts and services (Brander et al., 2007), contingent valuation forest studies (Barrio & Loureiro, 2010), determinants of protest responses in environmental valuation (Meyerhoff & Liebe, 2010), total economic value of threatened, endangered and rare species (Richardson & Loomis, 2009), income effects on global willingness to pay for biodiversity conservation (Bredahl Jacobsen & Hanley, 2009) and consumer's willingness-to-pay premiums for certified wood products (Cai & Aguilar, 2013).

2   Objective

The main objective of this study is to investigate available consumer surveys on environmental wood certification response by means of a meta-study that:

- gives an overview regarding the existing and the lacking aspects of this research,
- sums up the major findings made on this topic so far,
- assesses the differences between different studies
- and finally delivers conclusions in context to climate policy and wood products.

3   Materials

An intensive search of studies has been conducted in different databases such as SCOPUS among others using keywords (e.g. wood products, certification, WTP). The data come from a review of the literature valuing environmental wood products (various sorts) certification since the 1990s.

Some studies reported incomplete data and were eliminated from our final data set due to a large number of missing values. As a consequence, the final data used for this meta-analysis comes from a total of 27 studies originating from 1997 to 2007 including 56 surveys covering about 33 000 data points from all over the world. These studies include quantitative as well as qualitative approaches using different methods (e.g. focus group sessions, consumer surveys, test markets, conjoint analysis, contingent valuation). Most frequently these studies investigated the proportion of consumers interested in certified wood products, the valuation of environmental certification as a product attribute by the consumer, typical consumer segments preferably buying certified products and to a lesser extend how the additional value of certified products can be delivered to the consumer. We used the meta-study approach to analyze the effects of

product and application, nationality, methods and time on consumer acceptance and valuation.

Comparing the willingness to pay measured in 39 of the total 56 surveys it is very important to distinguish between absolute and relative values, a fact rarely discussed in the literature. The absolute willingness to pay in this study is the average premium stated by those respondents willing to pay extra at all. Whereas the relative willingness to pay refers to the average value of all respondents including those not willing to pay extra rated zero. Hence the absolute willingness to pay always exceeds the relative. For seven surveys only an absolute willingness to pay for certified wood products was mentioned by the authors. In case of 6 surveys the authors referred to both values and in the remaining cases the relative values were given. For the purpose to increase the number of comparable surveys we transferred all absolute values into relative ones.

4   Results

Over all 39 surveys observed an average of 55.6% (SD +/-14.8%) of the respondents who perceived additional value from certification as they declared a willingness to pay premiums or did really pay them in test market situations. Taking all the differences between these surveys into account (methods, products, regions, populations) the result seems to be surprisingly stable with a standard deviation of just 14.8%. Although only two results from test market surveys can be taken into account it becomes very likely that the proportion of consumers really paying premiums might be much lower as they average 33.4% with an according standard deviation of only 4.9%. This indicates that at least one third of consumers perceive additional value from certification that exceeds the one of buying cheap. It does not necessarily mean that all other consumers do not perceive additional value from certification at all. For those the additional value may just not exceed the one of saving money when buying cheap.

As 26 results came from surveys conducted in the United States of America and 12 in Europe we could compare the proportions of consumers stating a willingness to pay. Although the average proportion seems to be higher in Europe, the difference is not statistically significant. At least the result from a Malaysian survey suggests that the proportion of consumers stating a willingness to pay might be lower (38%) there but it must be noted that many methodological differences may be responsible for this difference. Methodical aspects such as sampling, surveying (mail, telephone or interviews) or measurement (conjoint analysis versus contingent valuation) did not produce significant differences regarding the proportion

of consumers stating a willingness to pay. Especially the last comparison is very interesting as in the conjoint analysis the willingness to pay is measured indirectly whereas in contingent valuations the respondent is directly asked. Veisten (2007) assumed that the conjoint analysis should consequently produce the lower and more reliable results as "yeah saying bias" is avoided. In fact the average proportion is lower (49.9% to 56.7%) in studies applying conjoint analysis but due to a very low number of observations (3) and a very high standard deviation this difference is not significant.

A very important point to assess the consumer's response to environmental certified products is whether there are developments over time. In order to analyze this, we used the years when the surveys were made if available. In other cases we assumed that the surveys were made two years before the studies were published. The analysis uncovered significant differences between the results of the surveys conducted in the year 2000 compared to the years before and thereafter. The proportions of consumers stating a willingness to pay were found to be highest in the year 2000. During the years before they were lower, but still higher than after the year 2000. This development observed correlates with the developments of the world economy as measured by the OECD (2008). The number of observations in each single year is of course comparably low (1 to 3). Anyhow, Cai and Aguilar (2013) observed increasing values over time.

Most interesting point for this study is whether there are preferences for certain wood products in context of their contribution to climate policy. Of the total 37 surveys (excluding test markets) some used very vague product descriptions leaving the specification to the respondent. Six of them did just mention wooden furniture in general whereas in one survey the authors referred even to wood products in general. In three cases the authors gave summarized results for a bundle of wooden products that were also separately analyzed on a one product basis. More concrete product descriptions were given in the remaining 27 cases. Most often used products were a wooden table (7 cases), houses (5 cases), chairs (4 cases), dining sets and kitchens (3 cases each). Other wood products were shelving boards, racks and studs. A significant difference was found in the proportion of respondents stating a willingness to pay between these products (ANOVA $p < 0.05$). The proportions of respondents stating a willingness to pay were lowest for shelving boards and racks followed by houses. This is surprising as the literature (Ozanne & Vlosky, 1997) found an inverse relationship between product price and willingness to pay. A possible explanation for the difference between these two results is that the average level which respondents are willing to pay relative to product price is something very much different from the average proportion of respondents stating a willingness to pay at all (Cai & Aguilar, 2013).

The average willingness to pay extra relative to a certain product price indicates value a respondent perceives from certification. Hence, the willingness to pay concept is a valuation method (Mitchell & Carson, 1989) and not necessarily connected to price premiums that can be achieved in the real market place. Most likely the willingness to pay indicates a price level that will not be exceeded in reality. Anyhow the willingness to pay may deliver important information about the consumer's valuation of environmental certification and therefore the value added to the product.

The average relative willingness to pay was found at 8.9% of the product price with the standard deviation at 6.5%. Compared to the average pro-portion of respondents willing to pay at all these values were found to spread much stronger indicating that the level of the willingness to pay may much more depend on additional factors whereas the pure willingness is much more a common sense.

What factors may influence the WTP?
Analyzing the same factors applied to the proportion of respondents willing to pay we found several significant results. The surveys conducted in the USA for example referred to significant higher values than those from other parts of the world ($p<0.05$). The values were found to increase over time ($R=0.32$; $p=0.052$) although time delivers only a weak explanation, so that other factors should explain differences better. Survey techniques for example were found to have a significant influence (ANOVA $p<0.05$). Mail surveys produced higher values than telephone and much higher values than personal interviews. As compliance bias (Mitchell & Carson, 1989) would have been expected to have an adverse effect it is very likely that a non-response bias caused these differences with only motivated and involved respondents reacting on the mail survey.

In relation to the different wood products we found the lowest willingness to pay can be observed in case of vague product descriptions. Houses also perceived comparably low average values but with a high standard deviation. Dining sets, chairs and kitchens perceived the highest values. According to the literature (Teisl et al., 2002; Cai & Aguilar, 2013) the usage context of the product is of greatest importance for the value perceived by the customer. Probably the fact that a dining set or a kitchen are much more social status products may explain these results.

5   Conclusions in Respect to Climate Policy

The meta-analysis applied on the marketing research on certified wood products delivered several results relevant to possible carbon labeling on wood products. The frequently measured willingness to pay is not useful to estimate possible price premiums (Anderson & Hansen, 2004a,b). Much more the willingness to pay is a valuation method that allows assessing an additional value perceived by the respondent but is not necessarily including any real payment. Hence, price premiums seem to be irrelevant in general terms but an additional value may be delivered to the consumer which can be crucial in the decision making process. Therefore environmental certification and labeling could be a tool to increase wood products consumption if the label delivers a base for decision taking (Teisl et al., 2002; Teisl, 2003). Teisl et al. (2002) found that some kind of rating included in the labels would be preferable for the consumers to distinguish between products.

In context to carbon storage and wood products, two bases for such ratings could be applied. In the first case the amount of carbon stored in the product could be used to distinguish wood products from other materials to improve substitution. The second rating could refer to the carbon dioxide produced in the production process to distinguish between wood products. Domestic wood products (Bigsby & Ozanne, 2007) using state of the art production processes would become preferable to imported products. In both cases between 33 and 56% of the customers can be expected to perceive additional value. These proportions seem to be achievable in the USA, as well as in Europe; most likely depending on the recent economic situation. As many authors noticed a certain consumer segment can be defined most likely to buy environmental certified products including most likely females, environmental concerned, educated, politically liberal and so on. Also it might be possible to target these consumers by certain marketing activities. Socio-demographic factors have been proven bad predictors of consumer behaviour (Haley, 1968). This was also confirmed by several studies (Veisten & Solberg, 2004; Bigsby & Ozanne 2002; Ozanne & Smith, 1998) concerning environmentally certified wood products. More likely the product usage context is a key factor to assess values perceived by consumers (Warlop & Ratneshwar, 1993).

The greatest challenge uncovered by the meta-analysis in relation to carbon storage and wood products is the rather weak adequacy of houses as products for environmental certification as the construction sector was found to be the most effective application field in terms of carbon storage. This topic definitely needs further considerations and research e.g. by ana-

lyzing the effects of subsidies and consumer information analysis (Stern et al., 2009b) and campaigns.

If eco-labeled products are always preferred to non-labeled products of the same price, wood products could gain from certification competing with less environmental friendly products, especially if they are not based on wood. Furthermore, if other probably less environmental friendly products competing with wood products do get environmental certifications there is high need for wood products to provide equal labels.

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Distribution of Intermediate and End Products from Renewable Resources

Separation of cattle slurry:

Technical solutions and economic aspects

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Abstract

German cattle farming is characterized by a strong regional concentration. The limited regional availability of agricultural land and the increasing livestock densities mean that more and more nutrients will have to leave the areas of forage production. In this regard, the transport of manure is one issue that must be addressed. In the past, the separation of slurry into a fluid and a solid phase was a frequently discussed approach to solving regional nutrient problems and improving the transportability of nutrients (Rawert, 1995; Weiland, 2002). Therefore, the question arises whether the separation of slurry could be an economically viable solution after all.

The objective of this paper is to present preliminary results concerning technical solutions and economic aspects of cattle slurry separation. Experiments were carried out for assessing technical solutions for the separation of cattle slurry. It was found that the solids have a higher methane content compared to raw slurry. Furthermore, it can be stated that separation costs are mainly determined by the costs of energy as well as repair and maintenance. A comparison of raw slurry and solids revealed that the transportability of the solids is higher, mainly influenced by the separation costs. The results have interesting implications for livestock, biogas and arable farmers as well as for policy makers.

Keywords

Separation, slurry, biogas, transportability

1 Introduction

German cattle farming is characterized by a strong regional concentration. The limited regional availability of agricultural land, high livestock densities and predicted continuing growth of dairy production in the most competitive areas (Lassen et al., 2008) mean that more and more nutrients will have to leave the areas of forage production. This is necessary so that farms can grow and operate economically within the applicable legal framework concerning the dispersal of slurry on agricultural land (Fastje, 2010).

In this regard, the transport of manure is one issue that must be addressed. Due to the high water content, the transport of slurry from pigs and cattle often incurs high transport costs. Therefore, nutrient use and manure shipments may become a major cost factor for livestock farms, especially when large transport distances need to be overcome.

In the past, the separation of slurry into a fluid and a solid phase was a frequently discussed approach to solving regional nutrient problems and improving the transportability of nutrients (Rawert, 1995; Weiland, 2002). Bearing in mind the recent sharp increases in the regional concentration of dairy farming, the tightening of the legal framework and the rising price of mineral fertilizers, the question arises whether the separation of slurry could be an economically viable solution after all. Besides the so-called fertilizer value (which describes the economic value of replacing mineral fertilizers through slurry), an additional value can be generated if the solids are used for energy production in biogas plants. Against this background, the separation of slurry seems promising on farms in regions with a high animal density and the opportunity to ship the solids to biogas plants in arable regions (Kowalewsky, 2009). In this case, it would be possible to close nutrient cycles, decrease the application mineral fertilizers, which are expensive and energy-intensive and/or have limited availability in arable farming regions, and reduce the area under cultivation for renewable resources.

Some studies have already been conducted on the separation of slurry. Most of these focus on process engineering aspects and the differing concentrations of nutrients in the different fractions. Only a few studies consider the separation of slurry from an economic perspective (Meier 1994; Rawert, 1995; Møller et al., 2000). So far, the cascade use of solids as biogas substrates and as a substitute for mineral fertilizer has only been studied using pig slurry (Project "Bioenergieregion Südoldenburg"). The cascade use of cattle slurry has not been analyzed at all. With this in mind, a project was funded by the German Agency of Renewable Resources (FNR) which focuses on the use of separated cattle slurry as an alternative

biogas substrate and examines technical and economic aspects. It is the objective of this paper to present preliminary results of this study.

2 Material and methods

2.1 Experiments

The following analysis is based on data collected through an experiment with five separators from different manufacturers. The experiment took place in October 2012 in the town of Bokel, Lower Saxony, which is in the northwest of Germany. Five separators were tested under practical conditions with cattle slurry. All the separators tested used a screw press with individual adjustments (Table 1). The target for all participating manufacturers was to create a product with a dry matter content of at least 25 % that would be stackable and transportable. In addition, no flocculants should be used.

Table 1: Overview of the tested separators

Separator	Company	Machine	System
ITE	ITE GmbH	AgrarSEP	Press screw separator (with vibration screen)
Regenis	Regenis GE	Akkupress AL 200 industrial design	Press screw separator
FAN	FAN Separator GmbH	PSS 3.2-780	Press screw separator
UTS	UTS Products GmbH	FSP A 52/15	Press screw separator
AgriKomp	AgriKomp GmbH	Quetschprofi	Press screw separator

All the separators considered were operated in the same standardized test environment. The raw cattle slurry was stored in a slurry lagoon for about four weeks. It was constantly mixed during the test days in order to ensure homogenization. The raw slurry came solely from the dairy farm where the tests were located. Shortly before starting a run, a slurry tank was filled with the homogenized raw slurry. During the separation, the raw slurry was taken from the slurry tank. The separator separated the solid fraction into a collection pan while the liquid fraction was pumped into another slurry tank.

Throughout the separation process, samples were taken from each separation product as well as from the raw slurry to determine nutrient and biogas content. To obtain reliable data, each separator did three trial runs, each about 45 minutes long. From each attempt, three samples from the separation products were taken to form a composite sample. The raw slur-

ry was sampled once before each attempt to test its homogeneity. All samples taken were analyzed by a state-owned laboratory (LUFA Nord-West) using standard methods for dry matter content and nutrient composition. The mass of solid and liquid fraction was added to the output. Furthermore, the raw slurry, the solid fraction and the liquid fraction were analyzed for biogas potential. These analyses were also carried out by LUFA Nord-West as batch experiments (practical fermentation test VDI 4630).

To determine the separation costs, additional data was collected during the experiments. An extra electricity meter was installed to calculate the energy demand. Cost estimates for maintenance and repair as well as for the additional work required were collected in face-to-face and telephone interviews with several manufacturers of separators.

2.2   Technical solution

For the separation of slurry, there are various technical solutions. In the experiments only press screw separators were used. Here, press screw technology will be examined in greater detail.

In a press screw separator, the raw slurry is fed through an inlet into the housing of the screw press separator in free flow or with the help of a pump. An electrically driven auger transports the slurry into the slotted sieve basket. The water squeezes through the slots and exits through an extra outlet. In the course of this process, solids are pressed against the screen and held back. Inside the sieve an auger transports the filter layer into the press housing. During this process, particles smaller than the width of the sieve slots are deposited. In the press housing the solid fraction is generated by pressing the deposits against the plates.

All five separators tested used a screw press to perform the separation. The gap widths ranged between 0.5 and 0.75 mm. The screen lengths ranged from 520 to 959 mm. The pressure was set using weights on the flaps at the ejection point. Solids were discharged in free fall, using a screw conveyer or a conveyor belt. The separator produced by ITE GmbH had an additional vibration screen, which was up streamed the press screw.

3   Results

3.1   Separation costs

Separation costs were calculated based on full costs. The aim was to determine the separation costs per ton of raw cattle slurry. The assumptions

for the cost calculation are shown in Table 2. The investment costs ranged between € 22,500 and € 97,000. Investment costs of about € 97,000 can be explained by an additional installed vibrating screen and slurry tanks. The AGRIKOMP separator (5) had higher investment costs because it incorporates two parallel working screw presses. The manufacturers specified an expected useful life of between 10 and 20 years with an annual capacity of about 20,000 tons. For the calculation of the separation costs, a period of 10 years is assumed. According to the manufacturers of the separators tested, the costs of repair and maintenance range between 4% and 23 % of the total investment. The high expense of the first separator can be explained by the vibrating screen. For the high expense of the fifth separator, no reason is known. As the manufacturers have estimated, separating 8 hours/day requires maximum additional work of 0.5 hours.

During the test, the energy demands and performance of the separators were measured. The energy demand ranged between 0.42 and 2.77 kWh per ton of separated raw slurry. To determine the output the slurry tanks of the raw slurry and the liquid fraction were weighed full and empty. This procedure was repeated with the solid fraction. The output is calculated as the sum of the liquid and the solid fraction. The weight of the raw slurry is used as a control variable. The technical performance varies between 1.3 and 16.6 tons of raw slurry per hour. For the calculation of the separation costs, an annual performance of 20,000 tons was assumed. Furthermore, an interest rate of 5 % was supposed. The assumed electricity price was 0.21 €/kWh and the assumed wage for farm labour € 15/hour.

Table 2: Overview of the assumptions

	ITE	REGENIS	FAN	UTS	AgriKomp
Manufacturer's information					
Investment [€]	97,000	22,500	28,590	28,500	79,000
Useful life [years]	15	10-20	10	10-15	10
Useful life *(assumed)* [years]	10	10	10	10	10
Additional working time *(per 8 hours/day)* [hours]	0.5	0.2	0.2	0	0
Repair and maintenance *[% of the investment by 20,000 t/year]*	11	23	5	4	6
Information out of the experiments					
Ø Dry matter content [%]	28	24	26	23	22
Ø Output per hour [t]	9.50	1.30	16.60	11.20	8.90
Ø Energy demand per ton [kWh]	1.16	2.77	0.47	0.42	0.53

The calculation shows that the separation costs ranged between 0.36 and 1.60 €/t of raw slurry (Figure 1). The various cost items influenced the cost structure of the separators differently. Least important were the addi-

tional labor costs. Separation costs were mainly influenced by annual performance. As a consequence of a decreasing performance on about 4,000 tons of raw slurry a year, costs increase and range between 1.22 and 6.65 €/t of raw slurry.
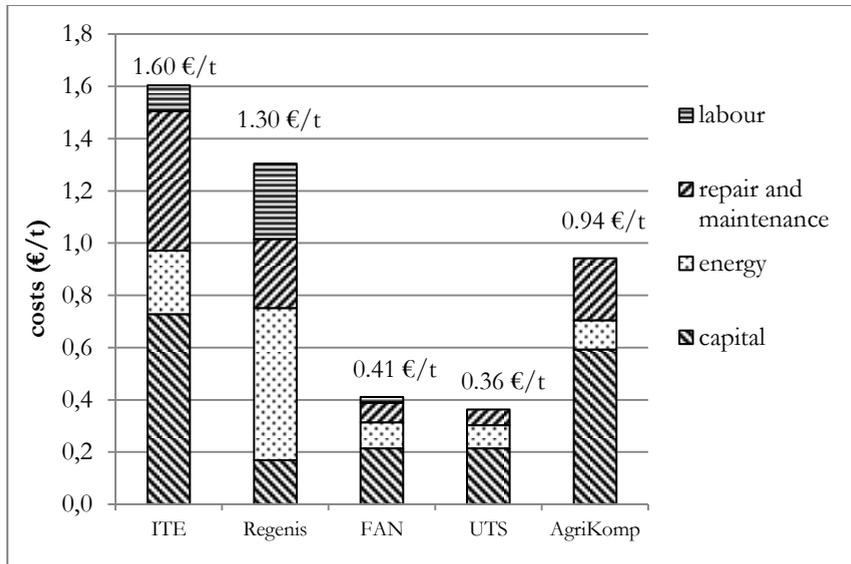
Figure 1: Separation costs

3.2 Monetary value of the three fractions

To calculate the monetary nutrient value of the fractions (including consideration of stabling and storage losses), the nutrients of the fractions are valuated with pure nutrient prices (Table 3).

Table 3: Calculation of the nutrient values

	Nutrient prices €/kg	Raw slurry		Solid fraction		Liquid fraction	
		kg/t	€/t FM	kg/t	€/t FM	kg/t	€/t FM
N	1.05	4	2.5*	5.3	3.3*	3.8	2.4*
P_2O_5	0.93	1.6	1.5	2.1	2	1.6	1.5
K_2O	0.72	3.6	2.6	3.2	2.3	3.8	2.7
MgO	0.34	1	0.3	1.3	0.4	0.9	0.3
CaO	0.08	3.2	0.3	5.6	0.5	2.8	0.2
Nutrient value			7.2		8.5		7.1

*Nitrogen value reduced 30 % because of losses in barn and stock.

The nutrient prices are calculated from the proportions of nutrients of selected mineral fertilizers multiplied by the prices of these mineral fertilizers. For the calculation of the monetary nutrient value, the nutrient price is

multiplied by the nutrient content of each fraction. The nutrient content of the nitrogen is reduced by 30 % because of losses in barn and stock. For the raw slurry, a nutrient value of about 7.2 €/t FM (FM = fresh matter) can be calculated. On average around 18 % of the mass of the raw slurry is deposited in the solid fraction by the separation. For all the separators tested, about 24 % of the N was deposited into the solid fraction. For the other nutrients the following degrees of deposit into the solid fraction were determined: P_2O_5 = 22 %, K_2O = 16 %, MgO = 24 %, CaO = 31 %. In accordance with the nutrient values for the solid fraction, a nutrient value of 8.5 €/t FM was calculated. The nutrient value of the liquid fraction was 7.1 €/t FM.

The energy value of the three fractions was calculated in accordance with the method proposed by Toews and Kuhlmann (2009). It assumed that corn silage is substituted as a biogas substrate. The methane yield of corn silage is approximately 106 m^3_N/t FM (KTBL, 2007). The purchase price of corn silage is 31 €/t FM (adopted in accordance with the calculation data published by the FNR, 2010). If the purchase price for corn silage is divided by methane yield, the result is the price for each unit of methane. Using this calculation, the methane price is about 0.29 €/m^3_N. To calculate the energy value of the three fractions, the methane yield of each fraction was multiplied by the methane price. The raw slurry had a methane yield of about 13.8 m^3_N/t FM, the solid fraction of 29.9 m^3_N/t FM and the liquid fraction of 9.0 m^3_N/t FM. Thus, the raw slurry has an energy value of 4.0 €/t FM, the solid fraction of 8.7 €/t FM and the liquid fraction of 2.6 €/t FM. In addition to nutrient and energy value, the three fractions have the following monetary values: raw slurry = 11.2 €/t FM, solid fraction = 17.2 €/t FM, liquid fraction = 9.7 €/t FM.

3.3 Transportability

To analyze and evaluate the transportability of the solid fraction compared to the raw slurry, it is assumed that a dairy farmer wants to export 1,000 kg of nitrogen. Based on the average values of the practical tests on the N content of raw slurry, this means that about 250 tons of raw slurry would have to leave the farm. To export the amount of nitrogen in the form of the solid fraction, 189 tons of solids would have to be exported. To get about 189 tons of solids, 1,048 tons raw slurry have to be separated.

The monetary value of the raw slurry and the solids are offset by the costs of separation and transportation. In this example separation costs of 0.7 €/t raw slurry are assumed (see Figure 1). Trucking has turned out to be the most flexible and, thus, the dominant solution for transporting both slurry and solids. Transport costs are mainly influenced by the transport

distance. The calculated costs for transportation by truc are 10 €/t for about 50 km, 16 €/t for about 100 km and 21 €/t for about 150 km. The costs apply for raw slurry as well as for the solid fraction, because the costs are based on weight rather than volume. The costs for land application of the raw manure and the solids are not considered because, after the fermentation in a biogas plant, the fermentation residue must be applied regardless of the input substrate and application costs do not depend on input materials. It is generally not possible to reduce transportation costs by finding a cargo for the return trip due to hygienic and sanitary requirements (Kowalewsky, 2009). Therefore, revenues for return cargo are not taken into account. The results of the calculation are shown in Table 4.

Table 4: Calculation of the transportability

		Raw slurry			Solid fraction		
Transport distance		50 km	100 km	150 km	50 km	100 km	150 km
Nutrient value	€/t	7.2	7.2	7.2	8.5	8.5	8.5
Energy value	€/t	4.0	4.0	4.0	8.7	8.7	8.7
Total value	€/t	11.2	11.2	11.2	17.2	17.2	17.2
Separation costs	€/t	0	0	0	3.9	3.9	3.9
Transportation costs	€/t	10.0	16.0	21.0	10.0	16.0	21.0
Total costs	€/t	10.0	16.0	21.0	13.9	19.9	24.9
Total	€/t	1.2	-4.8	-9.8	3.3	-2.7	-7.7
Total per kg N	€/t	0.3	-1.2	-2.4	0.6	-0.5	-1.4

The total costs for the transportation of raw slurry range between 10.0 and 21.0 €/t FM depending on the transport distance. The total costs of the solid fraction are 13.9 to 24.9 €/t FM. As seen in Table 4, the transportation of the raw slurry and the solid fraction is not profitable over a distance of 100 km or more. Exact calculations reveal that the maximum transport distance for the raw slurry is about 70 km and for the solid fraction approximately 84 km. Further analyses have shown that increasing separation costs reduces the difference between raw slurry and solid fraction with regard to transport distance. The critical value is separation costs of 1.1 €/t FM. From this value on, the transportation of raw slurry is less costly than the shipment of the solid fraction.

4   Discussion

Figure 1 shows the separation costs of the five tested press screw separators. It can be seen that, with regard to full costs, there is a big cost range between the separators. According to Meier (1994), the separation costs

are 2.5 to 4.5 CHF/t FM of raw slurry (1.7 to 3.7 €/t FM; exchange rate 1 CHF = 0.81 €). Møller et al. (2000) calculated costs of around 0.44 GBP/t FM for a press screw separator (0.52 €/t FM; exchange rate 1 GBP = 1.17 €). A comparison of the costs of the separators we tested shows that these costs are lower than the cost numbers known from the literature. This difference can, on the one hand, be explained through cost savings due to technological development over the last years. On the other hand, it can result from the assumed yearly amount of separated raw slurry.

The calculation of the full separation costs is based on data provided by manufacturers and the results from the experiments recently performed in Bokel. As shown in Table 2, the assumptions differ considerably between the manufacturers. Until now, no long-term experiments have been conducted on the technical life-span or repair and maintenance costs of this equipment. Thus, the critical assumptions underlying the cost calculations cannot be confirmed. This must be taken into consideration.

The nutrient and energy values of the fractions are essentially influenced by the degree of separation and the technology used. The results of the experiments in the framework of the Bioenergieregion Südoldenburg project showed that solids separated by a centrifuge also have a higher methane yield than those separated by a press screw separator (Hothan et al., 2011). Thus, an increase of the nutrient value of the solid phase is technically possible. Higher nutrient levels and a higher methane yield increase the value of the solid fraction. Therefore, it seems likely that with the use of other technologies, transport over longer distances can become economically attractive. However, the higher nutrient and energy values are offset by higher separation costs due to higher energy consumption, as studies by Meier (1994) and Møller (2000) have shown.

Furthermore, according to Kowalewsky (2009) it also has to be assumed that the theoretical and practical values of the fractions are not completely consistent. It is assumed that the practical value is less than the theoretical value. Therefore, it can be assumed that the monetary value of the fractions is lower than calculated so far. Reasons for this are (a) that biogas plant operators will achieve a cost reduction compared to the use of corn silage, (b) that the residence time will be shorter because of the larger volume of slurry and (c) that the farmers will use the separated slurry as fertilizer because slurry is cheaper than mineral fertilizers. Therefore, the practical value of the slurry is only 50 to 70 % of the theoretical value. A practical value of about 70 % reduces the maximum transport distance of raw slurry and the solid fraction to less than 50 km.

The transportability is influenced by many factors. The difference with regard to transport distance between raw slurry and the solid fraction is mainly determined by the energy values of both substrates. Given its rising energy value, the transportation of the solid fraction is better than

that of the raw slurry. The energy value is determined by the price of the replaced biogas substrate. Given an assumed corn price of 31.0 €/dt, the transport of the raw slurry and the solid fraction is not profitable over a distance of about 70 km, respectively 84 km. An increase in the price of corn silage to around 40 €/dt would lead to a profitable transport of the solid fraction of about 100 km. A profitable transport of raw slurry over a 100 km distance would require an increase in the corn silage price to more than 68 €/dt. However, such enormous price increases for substrates used for biogas production are unrealistic. Of course, the transportability of the solids could be enhanced if return cargoes were possible, as this would reduce transport costs. However, for hygienic reasons and due to the lack of transport needs in arable farming regions where biogas plants are located, this solution is not easy to implement.

5   Conclusions

Until now, there has been little awareness of slurry separation. The possibility of fermenting the solid fraction in biogas plants has been studied only for pig slurry so far. But more recently the problem of nutrient surpluses has been affecting more and more dairy regions. Against this background, in Germany, slurry separation is becoming increasingly important in the context of the forthcoming amendments to the Renewable Energies Act (EEG) and the Federal Fertilizer Act (DÜV).

To realize the advantages resulting from slurry separation, the procedure has to become better known in the agricultural sector. As the calculations have shown, the separation would be economical if larger quantities of raw slurry were separated. In dairy regions where nutrient surpluses occur more frequently (north-western parts of Lower Saxony and various regions of Bavaria), one dairy farm alone often cannot provide the necessary quantities of raw slurry. Therefore, an important aim of the agricultural extension services should be to make slurry separation better known and, thus, increase their acceptance by farmers and service providers such as agricultural contractors. Furthermore, incentives for an increasing use of the solid fraction in biogas plants should be set, for instance in future amendments of the Renewable Energies Act (EEG). Research into the separation of cattle slurry and the use of the solid phase as a biogas substrate needs to be advanced. Against the background of the "food or fuel"-discussion which has strongly contributed to a much more skeptical assessment of this type of renewable energy production (Zschache et al., 2010), this could lead to a higher acceptance of the biogas production by the wider population and other stakeholders.

To enable a cross-regional use of the solid fraction and to close nutrient cycles, it is necessary to build up an effective and efficient logistical network. This can support the collection of required quantities of raw slurry and, thus, contribute to the reduction of separation costs. The network could also help to establish one-to-one business relationships between dairy farms suffering from nutrient surpluses and biogas plants in arable farming regions. Prior research, for instance into the organization of meat supply chains, have shown that network agencies such as cooperatively managed organizations can help to establish longer-term relationships between buyers and suppliers in the livestock sector (Petersen et al., 2010). A similar approach could enhance the establishment of a network of farmers between livestock-intensive and arable farming regions. Furthermore, transportation costs can be reduced by finding suitable return cargoes which also requires a network approach due to the challenging hygienic conditions which have to be met and the limited availability of goods in rural areas which can be considered as potential return cargo. Such a network might be constructed, for example, based on the already known and field-tested networks of manure exchanges which have been established in regions with high livestock densities.

The results of our study show that there is a need for more application-oriented research on slurry separation and the use of the separation products. Furthermore, from the present study arise several other suggestions for further research: Other separation techniques should be considered in the economic analysis. Further research is needed in awareness and acceptance of slurry separation. Finally, research is needed into how to develop a logistical network which could help to get slurry separation and nutrient exports started.

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Estimating Carbon Stocks and Flows in the Wood Product Chain in Austria

GHG accounting for the forest-based sector

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Abstract

Carbon stocks and flows for Austria were estimated in a coupled model alongside stocks and flows in the wood product chain in a first modelling approach and simulated within a period ranging from 2000-2100. Several policy scenarios (Reference, wood for energy, intensified cascade use, and reduced timber utilisation) are being utilised to assess the future development of wood products and associated carbon stocks and flows.

Keywords

Forest-based sector, wooden biomass and energy production, simulation model, carbon stocks and flows

1   Introduction

A coupled dynamic simulation model covering the entire forest-based sector from forestry over intermediate to end product was developed to simulate carbon stocks and flows in the wood product chain. It addresses several scenarios impacting distribution of resources addressing economic as well as political developments. Such trends have an impact on carbon flows and will thus be of cardinal importance of anticipating future developments within the context of national reporting on greenhouse gases (GHG).

For the model, parts of an older model (Schwarzbauer, 1993) written in Dynamo Plus were translated into isee system's Stella (Clark/Kurono, 1995), completely reworked and coupled with a model simulating accompanying carbon flows alongside the wood production

chain.. It uses short-term and mid-term projections for GDP (OECD, 2012; PWC, 2011) and continues the trend of the farthest projections. The model considers supply behaviour and development of the Austrian forestry sector as well as previous studies covering this topic (Schwarzbauer 2012; Schwarzbauer/Huber/Stern 2012). It evaluates the impacts of different policy options, currently in three different scenarios (i.e. wood for energy, intensified cascade use, reduced utilisation; described below). Based on stocks and flows for each product category the coupled carbon model estimates carbon stored in wood products based on the production approach (cf. Stern et al., 2009; according to IPCC, 2006), considering retention with product half-lives.

Stock change = (stock change forest) + (stock change domestic-grown products)
= (forest growth - slash -wood production) + (wood production - decomposition/combustion of wood grown in country)
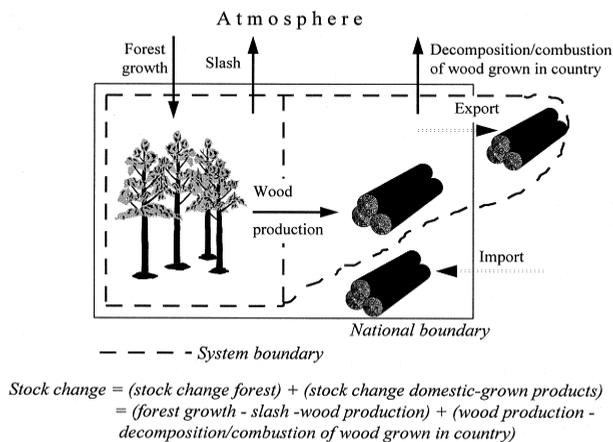
Figure 1: System boundaries of the production approach
(Lim/Brown/Schlamadinger, 2006)

Because the model is still under development, only Tier 1 was considered for a first analysis[1]. For this model, the "production approach" was used, since it best represents processes in forest products (Marland et al., 2010).

2 Model structure and methods

To reduce complexity, Austria is abstracted as one region, which is simulated depending on economic developments in interaction with import and export flows from a hypothetical rest-of-the world region (RoW). Thus the model is very flexible to project future policy developments onto the wood production chain in a "what-if"-approach.

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[1] Tier 1 is the simplest method of estimating uncertainties by using emission factors (default values), not considering country specific emission factors and other data. There are 3 Tiers with increasing complexity (cf. IPCC, 2006, Vol. I, Chapter 4 – Uncertainties).

2.1 Scenarios

Apart from the baseline-scenario, the model covers three specific policy scenarios for Austria:

Scenario 1 – Reference
The demand for wood and forest management follows recent trends. The National Renewable Energy Action Plan (NREAP; BMWFJ, 2011) is implemented and utilisation increases until 2020. There is no further political intervention for utilising wooden biomass for energy use. Sawmills, panel and paper industries follow market conditions.

Scenario 2 – Wood for energy
The NREAP is developed further (BMLFUW, 2006). Demand for fuel wood rises considerably through increased subsidies. Subsequently, more biomass power plants are used and the energy mix is shifted towards wooden biomass. Wood forest management thus intensifies utilisation.

Scenario 3 – Intensified cascade use
Promotion of utilising wood for construction purposes through incentives and legal measurements. Additionally, technological development extending the spectrum of use is encouraged. Wood-for-energy use is reduced and wood waste valorisation is optimised.

Scenario 4 – Reduced utilisation
Because of policy decisions, forest areas available for wood supply are set aside for conservation purposes through incentives and subsidies targeting reimbursement for loss of utility and carbon sequestration.

2.2 Structure

The model consists of two coupled sub-models. Part one is modelling wood stocks and flows alongside the wood production chain and consists of four parts, the second one consists of two parts utilising data from part one to perform accounting on carbon stocks and flow based on sequestration and substitution effects as well as product half-life times.

Sub model one
(1.1)   General economy: Uses exogenous data
(1.2)   Timber industry: Supply, demand, prices and foreign trade for each end product (only for end products except fuel wood; this is treated as forestry end product)

(1.3)   Forestry: Raw wood supply. Potential demand for raw timber results from the "timber industry" module. Effective demand (=effective supply), prices and foreign trade are a result of the interaction of "forestry" and "timber industry"

(1.4)   Forest resources: Forest areas, stocks and increment

Sub-model two

(2.1)   Carbon stocks and flows for product markets: Accounting of carbon through sequestration and product half-lives for currently five main final product categories.

(2.2)   Carbon stocks and flows for raw timber markets: Accounting of carbon through sequestration, product half-lives (or assumptions) and substitution effects, fuel wood accounting and half-lives

(2.3)   Carbon stocks and flows for forest resources: Distinguishing three ownership categories (Small forest owners, large private forests >200 ha, state-owned woods), 2 age-classes (<= 60 years; > 60 years)
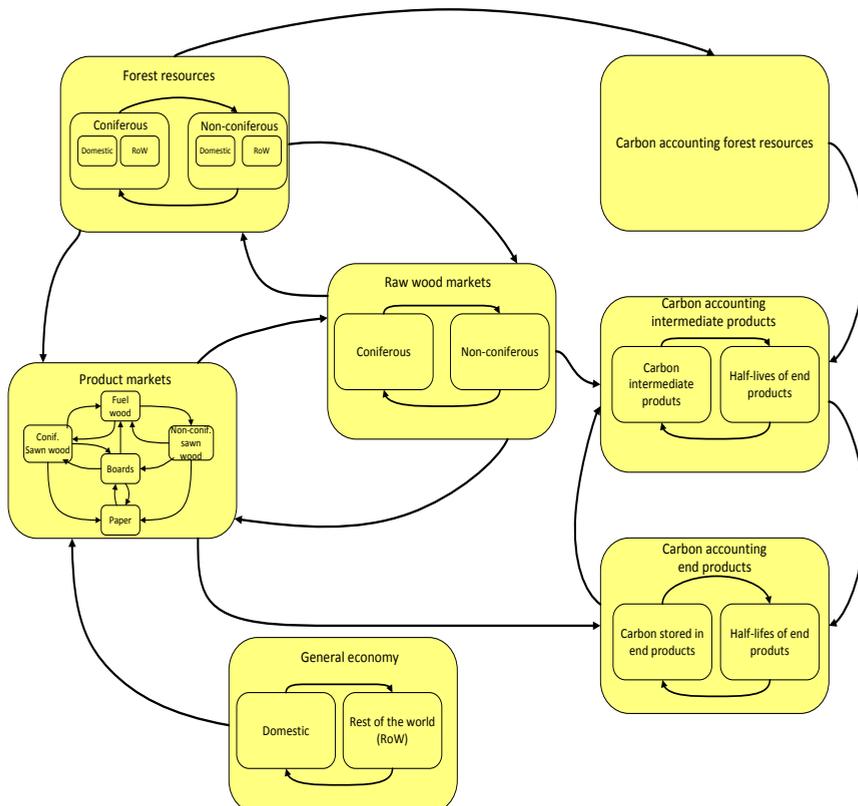

Figure 2: Schematic model overview

2.3 Model description

Sub-model one

Currently, there are four intermediate (i) and five final (f) product groups considered in the model:

1. Coniferous logs (i)
2. Non-coniferous logs (i)
3. Coniferous pulp wood (incl. residues) (i)
4. Non-coniferous pulp wood (incl. residues) (i)
5. Coniferous sawn wood (f)
6. Non-coniferous sawn wood (f)
7. Reconstituted panels (particle and fibre boards) (f)
8. Paper and paperboard (f)
9. Fuel wood (incl. residues) (f)
    a. Coniferous
    b. Non-coniferous

Some items used as model inputs e.g. scrap paper are modelled as exogenous factors (and thus not listed above) dependent on domestic demand of paper. Other items such as pulp are being modelled as factors dependent on domestic consumption and production[2].

For intermediate demand of the timber industry there is no differentiation between timber from wood and waste wood - this is being formulated over the course of production of c/d (coniferous/deciduous) sawn wood as distinct products. This is done similarly for fuel wood: Because of the separation into c/d, forest fuel wood calculations result in coniferous fuel wood and deciduous fuel wood. Additionally there is a distinction made between fuel wood from timber resources and fuel wood from waste wood.

Sub-model two

Based on stocks and flows for each product category the model estimates carbon stored in wood products by factors (as CO2eq) considering retention with product half-lives for GHG accounting. Product half-lives are based on several other studies (Stern et al., 2009; SBSTA, 2005).
Half-lives are computed according to IPCC using a first order exponential decay function (IPCC, 2006):

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[2] e.g. pulp is modelled from consumption of pulpwood and production of paper & cardboard with consideration of foreign trade.

$$N(t) = N_0 \cdot e^{-\lambda \cdot t} \text{ with } \lambda = \frac{ln(2)}{T_{1/2}} \qquad (1)$$

Since the model is still work-in-progress, the following half-life-times were used modified from several sources (IPCC, 2006; Stern et al., 2009; Marland/Marland, 2003; Skog/Nicholson, 2000):

Table 1: Selection of half-life values selected for the model

HWP Category	Half-life in use (years)	Fraction loss of each year (Ln(2)/Half-life in years)
Fuel wood	2	0.3466
Paper	2.5	0.2773
Sawn wood	18	0.0385
Boards	15	0.0462

The respective units of materials were converted to metric tonnes and their carbon content was calculated according to the following table (Halbwachs et al., 1993; Rüter, 2011; Kurschera/Winter, 2006; Rolland/Scheibengraf, 2003):

Table 2: Selection of carbon content used for simulation

HWP Category	C-Content in %
Coniferous timber/sawn wood	39
Deciduous timber/sawn wood	53
Boards	50
Paper	44

3   Results and Outlook

3.1   Results

Because some of the stocks start with zero, a first run was conducted with historical data from 1965-2010. These values were used to compare historical developments to available data and to have initial values available for the stocks. To date, half-lives were only considered for final products, because data for average duration of storage for intermediate products is still being investigated.

Utilising the data from the known-data run, simulations were made for the time span between 2000 and 2100. A selection of results is available in Table 3 below.

While the carbon stock from coniferous forest increment is rising, it cannot make up for a diminishing overall carbon stock (i.e. the forest resources), because of an expectable increase in demand. This effect is also shown in increased carbon content of logged timber, which is not because of accumulation, but because of increased logging behaviour.

Table 3: Selection of data from model runs

Assessment of carbon stocks in the base scenario [in Mt of carbon]				
	2010	2030	2050	2100
Carbon stock from coniferous forest increment[3]	478.5	519.5	567.9	727.9
Carbon stock from deciduous forest increment	135.8	147.8	151.5	169.2
Logging coniferous	2.92	3.81	4.62	6.37
Logging deciduous	Minimal stock accumulation, because nearly 100% are used for further production			
Assessment of carbon in the base scenario including product half-lives [in t of carbon]				
Consumed coniferous sawn wood[4]	37.68	45.38	45.33	40.77
Exported coniferous	17.17	20.52	18.86	10.94

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[3] Changes to existing stock mainly through increment and logging

[4] Consumption from domestic production (without exports and imports)

sawn wood[5]				
Consumed boards	10.71	16.40	15.31	8.679
Consumed paper	8.08	8.13	7.91	8.15
Exported paper	4.16	4.07	3.73	3.24
Consumed fuel wood[6]	4.98	11.64	12.09	12.47
Consumed total fuel wood	6.12	11.68	12.09	12.51

Because production is peaking and then declining or remaining stable in some sectors, also the carbon stocks are diminishing for those products, after an according half-life time-lag respectively. The delays are easily visible from Figure 3 showing a delay of the diminishing of carbon stocks for coniferous sawn wood.
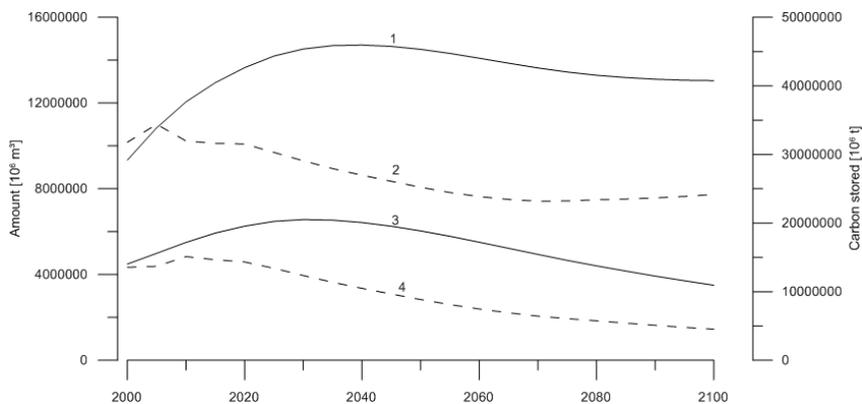

Figure 3: Coniferous sawn wood carbon (1) and consumed amount (2) as well as carbon in exported coniferous sawn wood (3) with corresponding amount (4).

Figure 4 shows an obvious time lag for the peak in carbon stock from carbon stored in particle- and fibre boards which is due to the relatively long half-life time of 15 years. In contrast to this, the break in the graph of pulp and paper nearly doesn't show this delay, since the half-life time is only 2.5 years.

Generally the model shows, that the overall wood stock of forest resources is decreasing because developments on the demand side cannot be met by domestic production anymore, resulting in increased logging and exports (as emphasised by other studies e.g. Mantau, 2010). Also the

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[5] Assumption: Same half-lives in the country of export

[6] Only fuel wood from the forest; Assumption: Previous model run starts with Stocks at 0 in 1965 (runs based on historical data), resulting with an initial stock of 4.43e6 t in 2000.

import cannot develop unbraked, since it is very likely that other countries in Europe will develop their industries similarly and wood-for-energy consumption will increase to meet the EU 20 by 2020 goals. Also fuel wood consumption increases considerably because of measures anticipated in the NREAP. A focus on biomass for energy will further increase fuel wood utilisation.
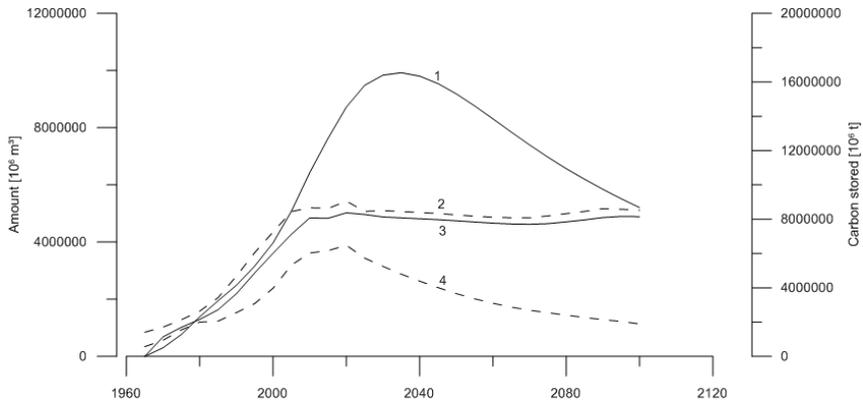

Figure 4: Carbon stored in particle- and fibre boards (1) and corresponding amound produced (4). Analogously, for carbon in paper (2) and produced amount (3).

Since this model is under development, there is still more modelling, data and validation needed to assess the overall forest-based sector.

3.2 Outlook

Currently, partial model testing (Homer, 2012) is applied to evaluate preliminary results and compare them with historical data (back-testing). After that, the model will be refined to the product level and validated (Martis, 2006). Afterwards a sensitivity analysis will be conducted.

Even though a lot of research was conducted for half-life times and GHG accounting for HWP there is still more detailed data needed for a thorough assessment on the product level. Additionally it is necessary to break stocks and flows down to the product level. With regard to this further material flow analysis is needed to determine streams for products.

Another goal is to improve the simple approximation that a change in stocks is just a function of the production rate (i.e. single pool approach), but to consider distributed pools for expected life times for products with regard to their year of production as outlined in Marland & Marland (2003) and Marland et al. (2010) based on Gamma distribution which seems to represent better decay patterns for HWP (Vacha, 2011).

A further task currently in development is the integration of substitution effects into carbon accounting and to break down model results into products instead of product categories. For this more data about HWP-flows has to be collected.

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Uncertainties in the Distribution of Products from Renewable Resources:

An Empirical Study in the Forestry and Wood Cluster

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Abstract

The growing demand for products from renewable resources makes their efficient usage and distribution steadily important. In comparison to other raw materials, renewable resources exhibit a number of distinctive features which also affect the design of the distribution system. The objective of this paper is to analyze the specific uncertainties in the distribution of products from renewable resources. It shall be examined to what extent the companies in the German forestry and wood cluster are affected by uncertainties with regard to the availability, quality, prices and origin of the used renewable resources and what problems can be caused by these uncertainties in the distribution of the products. Therefore, a survey was conducted in the forestry and wood cluster and then evaluated in the form of a qualitative content analysis.

Keywords

Uncertainty, renewable resources, distribution

1 Introduction

The global population growth and aspiring developing countries like China and India lead to a rising demand for raw materials. However, the availability of many traditional raw materials is limited. Therefore, the focus of the public and corporations shifts more and more towards renewable resources. The usage of renewable resources is seen as one way to secure the raw material supply permanently. This process is reinforced by the growing

environmental consciousness of the consumers especially in the western industrial countries. Sustainability and the environmental friendliness of products become increasingly important. This results in a growing demand for products from renewable resources and makes their efficient usage and distribution steadily important.

Renewable resources are products produced through agriculture and forestry that are industrially used outside the food and feed sector (FNR, 2013). In comparison to other raw materials, renewable resources exhibit a number of distinctive features which also affect the design of the distribution system. On the one hand, renewable resources are subject to natural variations in quality that are due to different weather, growth or storage conditions for example (Friedemann & Schumann, 2010; Geldermann, 2012). For this reason, there may be differences when it comes to their physical-mechanical, chemical and optical properties. On the other hand, the availability of renewable resources may vary. Fires, pest infestation or severe weather may reduce the available offer (Dennis et al., 1985). These quality and supply fluctuations can, in turn, result in increased price fluctuations. Apart from the fluctuations already mentioned, the origin of the renewable resources can also be of importance, as the example of illegally harvested timber clearly shows. All these factors result in specific uncertainties that hamper the distribution of products from renewable resources.

The mentioned uncertainties in the context of products from renewable resources should be examined in this study in more detail. So far, these uncertainties were analyzed mainly in connection with the development of stochastic mathematical models to determine the optimal amount of harvest and the optimal harvest policy (Saphores, 2003). One possible goal is here to maximize the amount of harvest without endangering the continued existence of the renewable resource. The developed mathematical models assume for example uncertain growth rates or variable environmental conditions. Frequent areas of application are the forestry and agriculture (Dennis et al., 1985) as well as the fishery (Sethi et al., 2005). But the assumed uncertainties are usually not investigated further. Additionally, they appear randomly selected and are often modeled unrealistic, for example as a simple random variable. The causes for these uncertainties as well as their significance and consequences for the companies are not discussed.

First approaches that deal with the causes and consequences of uncertainty with regard to the availability, quality and prices of renewable resources can be found in Friedemann & Schumann (2010) and Geldermann (2012). In these works, the specific uncertainties of renewable resources and especially their consequences for the production planning are examined. However, in this paper the focus should not be on the area of

production but on the exchange and distribution of products from renewable resources. In this context, uncertainty with regard to the origin, which is not discussed in the above mentioned works, can also be of importance, as the example of tropical wood and the associated trade restrictions show. Need for research consists especially with regard to the question to what extent the specific uncertainties influence the distribution of products from renewable resources. To clarify the practical relevance of the uncertainties from a company perspective and to investigate the associated consequences for the distribution, empirical research is required, whereby the study presented here represents a first step in this direction.

Due to the large number of renewable resources, the forestry and wood cluster will be exemplarily examined in the following. The forestry and wood cluster covers the industries participating in the wood-based value chains (Seintsch, 2010). In Germany, 1.3 million people are employed in this sector which is more than in the automotive or electrical industry (Mrosek, Kies & Schulte 2005). Within the framework of the study presented here, it shall be examined empirically for the first time to what extent the companies in the German forestry and wood cluster are affected by the above-mentioned uncertainties and what problems can be caused by these uncertainties in the distribution. In particular, this study addresses the following research questions:

RQ1: Do the fluctuations and/or uncertainties regarding availability, quality, prices and origin of the resources in fact exist in the forestry and wood cluster? What are the causes of these fluctuations or uncertainties and are all industries analyzed affected by them to the same extent?

RQ2: How significant are the fluctuations or uncertainties investigated to the respective industries?

RQ3: Which concrete problems and challenges may arise for the businesses in the industries analyzed due to the fluctuations or uncertainties observed for renewable resources? Which problems and challenges affect distribution in particular?

RQ4: What expectations are there for the future on the part of the business associations interviewed concerning the fluctuations or uncertainties observed?

The remainder of this paper is structured as follows. First, Section 2 presents the methodology. Afterwards, the findings of the study are systematically presented. Section 3 highlights the existence and causes of uncertainties with regard to the availability, quality, prices and origin of products from renewable resources in the forestry and wood cluster. Section 4 shows the significance of these uncertainties for the different industries in the forestry and wood cluster. Section 5 discusses the various problems

and challenges which may result from the specific uncertainties in case of renewable resources for the companies in general and specifically in the field of distribution. Section 6 points out the future expectations of the business associations interviewed concerning the extent and significance of the uncertainties. The paper concludes with a summary in Section 7.

2 Methodology

To answer the research questions, several industries within the German forestry and wood cluster were analyzed as part of a broad-based study. This enables an analysis along the entire value chain and a comparison between various industries. In the context of this study, the sawmill industry, the pulp and paper industry, the packaging industry, the wood material industry, the furniture industry, the laminate industry as well as the wood-plastic composites (WPC) industry were analyzed (see Figure 1).

In order to obtain well-reasoned answers that are as detailed as possible and to do justice to the explorative character of this study, a qualitative research design was chosen. For the factors quality, availability, price and origin, it was asked if fluctuations and/or uncertainties do exist with regard to the distributed products, how significant they are for the companies, what problems can result due to this and what the expectations are for the future. In order to analyze the relevance of the represented uncertainties for the respective industry independently of the situation of the individual companies, the survey was conducted at the level of the industrial associations. The resulting low sample size was another reason for choosing a qualitative research design. In the time period from March to May 2013, the industrial associations were asked to participate in the survey by filling out a structured, qualitative email questionnaire. Figure 1 gives an overview of the surveyed associations and the respective industries.

Analysis was carried out in the form of a content-structuring qualitative content analysis (Mayring, 2010). Qualitative content analysis is a method for systematic, rule-guided and theory-based evaluation of qualitative texts. Special Qualitative Data Analysis (QDA) Software supports both the actual evaluation as well as the subsequent documentation and therefore increases the verifiability and thereby the quality of the results. In this study, the most commonly used QDA Software in Germany MAXQDA was used. In the following, the findings of the study are presented.
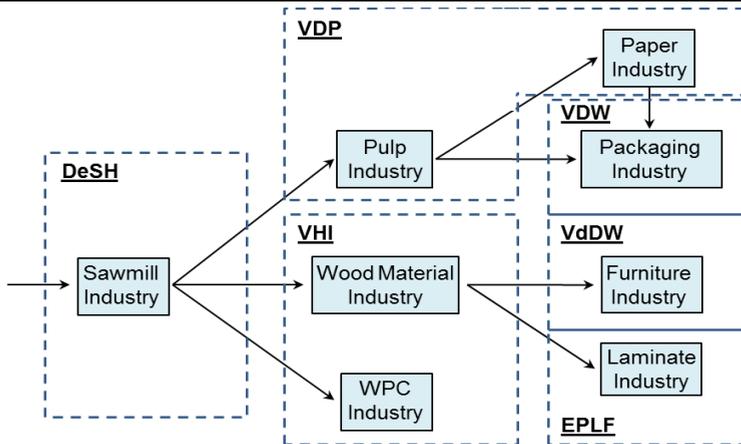
Figure 1: Examined industries and their respective industrial associations

3 Existence and causes of uncertainties in re-newable resources

As part of this study, it should be determined first to what extent there are indeed availability, quality, price and origin uncertainties present for the products distributed in the forestry and wood cluster and what causes these uncertainties can be led back to. The answers provided by the associations are given below.

Availability uncertainty
Findings of this study show that among four of the six associations, availability fluctuations occur for the resources required by them. Merely the EPLF stated that there are no resource availability fluctuations. As triggers for such fluctuations, besides general causes determining the availability of all types of resources such as transport problems, economy-related demand fluctuations, or suppliers' capacities and capacity utilization, also natural causes were given, as well as causes specific to renewable resources. These include availability fluctuations due to calamities (e.g. windthrow, insect infestation), weather conditions (e.g. long winters), silviculture (conversion of coniferous forests to deciduous forests) as well as increasing restrictions to forest exploitation (e.g. nature reserves). The cause for availability fluctuations given most in this was competition in material and energetic usage, a factor mentioned by four of the six associations.

Quality uncertainty
Four of the six associations additionally stated that quality fluctuations, i.e. fluctuations in the mechanical, optical and chemical characteristics of the

resources occur. Causes given for this were e.g. differences in resource composition and processing, but also specific natural causes such as quality fluctuations due to calamities (e.g. insect infestation) or due to deterioration during transport and storage (e.g. drying up, fungal infestations). Only the EPLF noted that no quality fluctuations occur in the resources. The reason for this is that the used medium-density fiberboards (MDF) are relatively homogeneous products due to their production methods and structure, so that quality fluctuations are of minor importance in this.

Price uncertainty

All associations interviewed stated that price fluctuations occur for the required resources and that these are generally due to fluctuations in supply and demand. Accordingly, the causes for price fluctuations given were economy-related demand fluctuations, demand developments in other countries and suppliers' capacities and capacity utilization. Yet also in this category, causes were mentioned which occur specifically in renewable resources, such as price fluctuations due to calamities (e.g. windthrow) or the existing competition in material and energetic usage.

Origin uncertainty

All associations interviewed stated that in principle, proof of resource origin is fully or at least partly possible and also provided in conformity to legal stipulations. The VDP pointed out, though, that e.g. for recovered paper, provision of proof of origin is so far possible only to a limited extent, quoting as the cause for this the differences in registration systems world-wide. The DeSH also stated traceability of the wood along the entire supply chain to the original felling location to not be possible, as in part, only the immediate previous supplier is known.

Intermediate conclusions

The results show that the above-mentioned uncertainties do in fact exist with regard to the distributed products. Four of the six associations stated that there are variations in the quality of the products that are, either in whole or at least in part, due to natural causes (e.g. freshness of the material or fungal infestation). Four of the associations also stated that the availability of the products concerned would vary. Both the supply fluctuations due to natural events (e.g. calamities or transportation problems caused by the weather) as well as the fluctuations in demand were listed as reasons. In addition, all associations stated that there would also be price fluctuations with regard to the products due to theses supply and demand fluctuations. Concerning the origin, the associations stated that a proof of origin is possible in principle and is also provided within the framework of legal requirements. However, it also became apparent that this partially only refers to the immediate pre-supplier and that the traceability along the entire supply chain is sometimes only provided in a restricted manner.

4 Significance of the uncertainties to the forestry and wood cluster industries

After describing in the previous Section that availability, quality, price and origin uncertainties concerning distributed products do in fact occur in the forestry and wood cluster, the next step now is to examine how significant these uncertainties are to the various industries. Table 1 provides an overview of the associations' answers to this.

Table 1: Significance of the uncertainties

Associa-tions	Significance			
	Availability Uncertainty	Quality Uncertainty	Price Uncertainty	Origin Uncertainty
DeSH	very significant	very significant	very significant	less significant
VHI	very significant	significant	very significant	significant
VdDW	very significant	very significant	very significant	significant
EPLF	less significant	significant	significant	very significant
VDP	very significant	very significant	very significant	very significant
VDW	significant	significant	very significant	significant

What becomes clear is that all uncertainties are considered by the associations to be significant or very significant. In particular the resource price fluctuations are categorized as very significant by nearly all associations. Yet also in this, there are industry-specific characteristics to be considered. Thus, e.g. proof of resource origin is less significant in the sawmill industry than in the paper industry, where proof of origin is considered to be of great importance. The reason why tropical wood or illegally felled wood is hardly a problem in the sawmill industry is that due to high shipping costs, sawmills have only regional procurement areas. In contrast, pulp for the paper industry is procured world-wide and to a great extent imported. Accordingly, proof of origin is much more significant. This shows that the procurement and sales markets of the industries observed are to some extent very different, as reflected in the respective associations' answers.

Additionally, factors were identified which influence the degree of significance of the uncertainties investigated to the different industries. Thus the significance of availability uncertainty can, at least for a short term, be reduced by existing resource stores. Yet in the medium and long term, it depends on the availability of alternative suppliers and the possibility of using alternative resources. These two factors can be combined in the term resource dependency. The more strongly businesses depend on a resource, the more significant availability fluctuations become. The importance of quality uncertainty, however, is dependent on the tolerance limit concerning quality fluctuations in production. Thus, resource quality fluctuations are more easily tolerated in the wood material industry than in

the paper industry. Accordingly, the problem of quality uncertainty is classified as more significant by the paper industry. Finally, the significance of origin uncertainty is defined by legal requirements and customer requirements. The resulting pressure on the businesses affects how great the significance attributed to proof of origin of the resources is. Along these lines, the DeSH states for example that in the sawmill industry, proof of origin is mostly insignificant to product marketing due to a lack of demand, while in the paper industry, the VDP considers it to be of great importance. Once more, this shows that there are industry-specific differences.

5 Problems and challenges in distribution due to uncertainties concerning renewable resources

So far, the existence and significance of specific uncertainties concerning renewable resources has been addressed. In the following, the problems and challenges resulting from these to businesses in general and specifically in the field of distribution will be examined in greater detail.

Availability uncertainty
The problems due to resource availability fluctuations mentioned include e.g. complications in production planning and higher production costs, the danger of production shutdowns as well as greater difficulties in investment decisions. Problems also named were specific to distribution and sales. For example, in the event of availability fluctuations, more cost-intensive storage organization is required. They also lead to resource price fluctuations and thus more complicated sales calculations, to supply problems and penalties for breach of contract as well as loss of orders and customers. What is remarkable in this is that differences in markets and products notwithstanding, all associations reported similar problems. A further striking fact is that serious problems were also mentioned which reach beyond the matter of distribution or the individual business enterprise. Resource availability uncertainty can thus even lead to plant closures and the migration of entire industries to areas richer in resources. According to the DeSH, the first signs of this can already be observed.

Quality uncertainty
According to the associations, quality fluctuations can limit the intended use of the resources and lead to operational faults in production, higher production costs, more complicated production planning as well as reduced quality in the end products. Further, distribution-specific problems

caused in connection with quality fluctuations were mentioned, such as the requirement of more cost-intensive storage as well as rejected deliveries and a possible loss of orders and customers. What was revealed in general, though, was that the associations' answers were less uniform and more industry-specific than for availability fluctuations. Thus, for example, inferior qualities tend to lead to reduced yield in the sawmill industry, while in the paper industry, they can lead to production breakdowns and damage to the paper machine as well as reduced quality in the end products.

Price uncertainty

In the field of distribution and sales, resource price fluctuations lead to more complicated sales planning and calculation as well as to problems with having to pass on costs to the customers. In general, the associations' answers were similar, and especially the problems of passing on costs were mentioned by the majority of associations. These problems can have grave consequences and according to the associations lead to funding problems, plant closures and shifts in the markets. This means a continuing consolidation process in the industries, loss of jobs and relocation abroad with corresponding consequences also for distribution. As already mentioned, the DeSH stated that first signs of this trend can already be seen.

Origin uncertainty

According to the associations, resource origin uncertainty leads to exclusion of certain intended uses. Thus, e.g., recovered paper of unknown origin may not be used in the manufacture of food packaging due to possible harmful substance content. Additionally, it was revealed that especially problems in distribution occur due to origin uncertainty. In this respect, unknown resource origin may result in trade restrictions, loss of certifications and thus in market access obstacles, loss of orders and customers and greater difficulties in risk assessment concerning critical deliveries as part of the legally stipulated due diligence system.

Intermediate conclusions

It has been demonstrated in this Section that all the uncertainties examined lead to specific problems and that these are partly very similar across all the industries observed. On the other hand, there are also industry-specific differences, as was shown for the consequences of quality uncertainty. What became clear further is what problems can occur particularly in distribution due to uncertainties. It should be remarked that according to the associations, the consequences due to availability and price uncertainty are serious, such as plant closures or migration of entire industries. This also explains the great significance of the uncertainties to the industries in the forestry and wood cluster, as described in the previous Section.

6 Expectations of future developments concerning extent and significance of the uncertainties

In conclusion to this study, the associations' expectations of future developments concerning extent and significance of the uncertainties shall be summarized. The answers provided by the associations are given below.

Availability uncertainty
Four of the six associations expect a future resource shortage and therefore an aggravation of the problems incurred in connection with it. The main cause of this named was competition in material and energetic usage of renewable resources. Only the EPLF and VDW assume the supply level to remain constant. Once again, this demonstrates that there are industry-specific differences. Thus, the VDW almost exclusively utilizes raw materials from recovered paper, for which no competition in energetic usage can be observed. As in addition, an established recycling system for waste paper exists in Germany, a relatively stable resource supply is expected. Industry-specific are also the causes of this prognosticated resource shortage. Thus for the sawmill industry, the DeSH states the causes to be silviculture and increasing exploitation restrictions for forests, while for the paper industry, the VDP names developments in foreign demand as the cause.

Quality uncertainty
Four of the six associations indicated that resource quality fluctuations will continue to gain in significance, e.g. due to stricter legal stipulations concerning limits and standards. Accordingly, the problems in connection with this become more serious. Only the VHI and EPLF expect quality to remain constant in its significance. Again, industry-specific differences are the reason for this. In this respect, the tolerance level concerning quality fluctuations is higher in the wood material industry than e.g. in the paper industry, which explains the VHI's answer. The response from the EPLF is also plausible, as its companies mainly use MDFs, whose homogeneous structure make quality fluctuations a factor of minor importance.

Price uncertainty
Four of the six associations expect resource prices to keep increasing, naming the cause of this to be the competition in material and energetic usage of renewable resources. This entails an aggravation of the problems given in Section 5. Once more, this demonstrates the grave consequences of resource price uncertainty, leading to expectations among several associations of a change in market structures due to plant closures and industry migration, with according effects also on distribution.

Origin uncertainty

All associations stated that in future, proof of resource origin will become significant or very significant, naming as causes for this both customer requirements and legal requirements. At the same time, the majority of associations declared that providing proof of origin will become easier in the future, as the appropriate certification systems and required infrastructure are being developed continuously due to legal pressure.

Intermediate conclusions

This Section clearly showed that the importance of the represented uncertainties for the companies and the distribution of the products will continue to increase according to the associations. This also entails an aggravation of the associated problems.

7   Conclusions

The purpose of this study was to examine whether businesses are affected by availability, quality, price and origin uncertainty concerning products from renewable resources and what problems to distribution such uncertainties can lead to. This was done empirically for the first time by means of a broadly based study extending to several industries, using the concrete example of the German forestry and wood cluster. The results of the study show that the specific uncertainties with regard to products from renewable resources do in fact exist in the analyzed industries and are considered to be significant by the associations. In this, though, also industry-specific differences due to the different products and markets need to be considered. Further, the causes for these uncertainties were analyzed in greater detail. The cause mentioned most frequently for availability and price fluctuations was competition in material and energetic usage of renewable resources. It could also be shown that these uncertainties have a direct impact on the distribution of the products. Thus, availability uncertainty can e.g. lead to cost-intensive storage and supply problems, quality uncertainty to rejected deliveries and loss of orders, price uncertainty to greater difficulties in sales calculation and origin uncertainty to trade restrictions. Furthermore, it became clear that the importance of the represented uncertainties for the companies and the distribution of the products will continue to increase according to the associations.

There is a need for further research in the matter of whether and to what extent the specific uncertainties concerning renewable resources also lead to information asymmetries between buyers and suppliers which make trade in these products more difficult. What became clear further with regard to availability uncertainty is that its significance is dependent on the

existence of alternative suppliers and usability of alternative resources. Such resource dependencies and their consequences can be analyzed in further studies by means of the resource dependence theory. Due to the expected resource shortages, an interesting and important area of application for the resource dependence theory seems to be emerging. Further, resource dependence leads to differences in corporate power. An analysis of the effects of such differences in power between the actors on the distribution of products from renewable resources provides a further interesting field of research for the future.

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Renewable raw materials are becoming increasingly important as an alternative resource base in industrial networks. Consequently, research for methods improving the efficient use of renewable resources in production processes with by-products is crucial. The aim is cascade utilization, thus the multiple utilization of a raw material before its conversion into energy. The International Conference on Resource Efficiency in Interorganizational Networks (ResEff) brings together interdisciplinary researchers developing strategies and solution concepts for efficient resource utilization. It is therefore a platform for scientific exchange both between experts as well as interdisciplinary groups from agricultural and forestry science, mathematical optimization, operations research, marketing, business informatics, production and logistics. The following facets of the challenging topic of resource efficiency in interorganizational networks are covered: Materials, technologies, planning of production and value-added networks for renewable resources as well as governance, coordination and sale of products from renewable resources.

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