

Editorial

Improved resource efficiency and cascading utilisation of renewable materials

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Abstract

In light of various environmental problems and challenges concerning resource allocation, the utilisation of renewable resources is increasingly important for the efficient use of raw materials. Therefore, cascading utilisation (i.e., the multiple material utilisations of renewable resources prior to their con-version into energy) and approaches that aim to further increase resource efficiency (e.g., the utilisation of by-products) can be considered guiding principles. This paper therefore introduces the Special Volume “Improved Resource Efficiency and Cascading Utilisation of Renewable Materials”. Because both research aspects, resource efficiency and cascading utilisation, belong to several disciplines, the Special Volume adopts an interdisciplinary perspective and presents 16 articles, which can be divided into four subjects: Innovative Materials based on Renewable Resources and their Impact on Sustainability and Resource Efficiency, Quantitative Models for the Integrated Optimisation of Production and Distribution in Net-works for Renewable Resources, Information Technology-based Collaboration in Value Generating Net-works for Renewable Resources, and Consumer Behaviour towards Eco-friendly Products. The interdisciplinary perspective allows a comprehensive overview of current research on resource efficiency, which is supplemented with 15 book reviews showing the extent to which textbooks of selected disciplines already refer to resource efficiency. This introductory article highlights the relevance of the four subjects, presents summaries of all papers, and discusses future research directions. The overall contribution of the Special Volume is that it bridges the resource efficiency research of selected disciplines and that it presents several approaches for more environmentally sound production and consumption.

Introduction

Currently, industrial production is largely based on fossil energy resources. The objectives to reduce greenhouse gas emissions and to change the industrial feedstock from finite fossil to sustain-able renewable resources are main drivers for industry to seek alternative raw materials for material and energetic utilisation. Industrial usage options for agricultural and forest plants for the production of materials, goods, and energy are manifold, and their cultivation has increased significantly in recent years. Although the acreage used has remained virtually the same, subsidies have encouraged the production of energy crops. However, because of the limited availability of land, one essential question remains: How does one strive for the efficient use of renewable resources? Among various strategies for improving resource efficiency, cascade utilisation is a much discussed option for the sequential use of biogenous resources to optimise material and energetic (Sirkin and Houten, 1994). Cascade utilisation is designed to optimally use all components of the materials, including multiple usages of chemical resources, before they are used to generate power at the end of their life cycles. An example is the use of lignocellulose; material use, as fibreboard, can be followed by chemical use in the pulp and paper industry; finally, the fibres can be burnt for energy. In addition to cascade utilisation, the utilisation of by-products is another important strategy to in-crease resource efficiency. By-products are secondary products derived from a manufacturing process or chemical reaction that are often minor in quantity or value compared with the main product. Sawmill by-products such as sawdust can be used to produce particle board and wood pellets but also new and innovative materials, such as wood-polymer composites (WPCs). The increased utilisation of these by-products can enhance resource efficiency.

For single companies and particularly for entire supply chain networks, specific challenges arise from incorporating renewable resources into their product design, as well as production and distribution processes. Fluctuations in the quantity and quality of harvested plants, as well as problems that arise from multiple uses, are some of these challenges, which require careful planning on the intra- and inter- organizational levels. Addressing these difficulties can help to reduce the resulting coordination problems between companies and foster cooperation and resource efficiency within the entire supply chain. This Special Volume is dedicated to research on theoretical analysis and applications concerning the value chain of renewable resources in industrial applications. The papers in this Special Volume present current research on planning approaches for renewable resources from forestry and agriculture for material use (non-energy and non-food). Cascading utilisation, on the one hand, and the use of by-products, on the other hand, are at the focus of this analysis. The original call for papers (Geldermann, 2014) invited the submission of quantitative models for cleaner production in networks for renewable re- sources, information systems and information technology in value generating networks for renewable resources and consumer behaviour towards eco-friendly products, and logistics and distribution for cascade utilisation, mainly for the wood processing sector. Overall, the objective of the original call was to combine selected disciplines to present their latest research on resource efficiency, to show the current state of research, and to identify research gaps and directions for future research. Therefore, the articles summarized in the Special Volume should address current research fields as they indicate how research on resource efficiency is expected to develop in the next few years. Additionally, readers who are interested in deeply engaging in resource efficiency are provided with suggestions for further reading in the 15 book reviews.

Accordingly, the articles in this Special Volume are classified into four broad categories: Innovative Materials, Optimisation of Production and Distribution, Information Technology-based Collaboration and Consumer Behaviour. On the one hand, these articles contribute to a scientific examination of

resource efficiency and cascading utilisation of renewable materials by adopting a perspective that reflects the entire value chain. Resource efficiency is thereby the guiding subject, beginning with the extraction and production of appropriate materials, followed by the manufacturing and distribution of production and consumer goods, and the provision of relevant information to the marketing of related goods. On the other hand, those disciplines that primarily contribute to solving the highlighted problems are identified; these are as follows: material science, production science, business information science, and marketing. Therefore, approaching the goals of resource efficiency and cascading utilisation is not the responsibility of an individual discipline because of the various inter-dependencies; rather, it is a highly interdisciplinary endeavour. Hence, interdisciplinary research structures, such as collaborative research centres, research training groups, and interdisciplinary networking hubs, appear to be particularly promising for gaining new insights. This Special Volume shows how interdisciplinary cooperation is essential to increasing resource efficiency and how the involved disciplines can contribute to a growing awareness of these ideas.

Additionally, 15 books are reviewed that consider resource efficiency in the above-mentioned disciplines. The books were chosen based on their timeliness and relevance in their individual research fields. They illustrate how resource efficiency is considered thus far in textbooks. The reviewed textbooks provide a comprehensive overview regarding this interdisciplinary topic. Therefore, the overview shows the aspects of resource efficiency, which are addressed by the different disciplines and book types, and the structure. Additionally, the book reviews indicate to what extent current research has previously been integrated into textbooks.

In the following sections, this article introduces the four subjects and briefly summarizes the Special Volume's articles. This may help readers to find those articles they are interested in, and it shows how the different articles are connected. Thereafter, a paragraph addresses the contribution of the Special Volume and shows directions for future research.

2. Overview of the Special Volume's contribution

2.1. Subject 1: Innovative materials based on renewable resources and their impact on sustainability and resource efficiency

It has often been reported that the use of fossil fuels is accompanied by various problems, e.g., resource limitations, adverse environmental effects, and dependence on oil-exporting countries (Brown et al., 2011; Chapman, 2014; Kim and Song, 2014). Because of these problems, increasing amounts of agricultural and wood products have been used for energy production. This increase, in turn, induces an intensified competition between previous utilisations of agricultural products and the power industry. This development increases resource demand, leading to growing competition for finite resources; thus, an alternative raw material base is required. Therefore, renewable resources are often discussed as a promising raw material base; however, it is commonly agreed that resource efficient utilisation is also needed to prevent environmental, economic and social challenges. For instance, improved resource efficiency is identified as being essential because of the growing competition for different forms of land usage (Godfray et al., 2010), i.e., cultivation for food supply, material, and energetic utilisation. According to the principle of cascading utilisation, it is important to use not only virgin materials but also by-products and waste materials (Fraanje, 1997).

Additionally, it must be considered that nature provides a huge variety of different renewable resources, dependent on geographical region. Reports postulate that this resource richness should be exploited such that biodiversity is fostered, and renewable instead of conventional resources can be used for various applications (nova-Institut, 2010). Nevertheless, reviewing the current literature indicates that, as previously, little is known regarding the possible uses of several renewable resources. Considering the broad range of renewable resources and the associated variety of produced materials, how these different materials contribute to resource efficiency and sustainable production must be investigated. Opportunities to improve the sustainability and resource efficiency should also be identified, for instance, by focussing on material composition or treatments. Thus, special focus should be accorded to a material's eco-friendliness because this is an important sales angle, although typical consumer requirements must be simultaneously fulfilled, e.g., price, quality, and durability. Although there are different fundamental challenges for cleaner production, they can be investigated on the basis of a specific raw material, wood. Wood is often referred to as being essential for mankind because of its wide abundance, renewability and environmentally benign nature, relative ease of working, and outstanding mechanical properties. Because of technological advancements, wood is used for shelter, fuel, tools, boats, vehicles, bridges, furniture, engineering materials, and raw materials for energy. Wood's cellular structure endows it with a high strength-to-weight ratio. However, wood components are easily degraded by microorganisms and susceptible to damage by fire. Moreover, the hygroscopic character of wood hampers its usage because wood shrinks as it dries; conversely, it swells when wetted. To overcome these obstacles, several material science research projects have the objective to develop composites with engineered properties. Particularly from a global perspective, research on composite materials based on plant fibres in general will gain in importance. Wood-polymer composites (WPCs), for example, were invented and developed as a substitute for wood and are made from softwood waste and recycled polymer resins (Li, 2011; Oksman Niska and Sain, 2008). Thus, Subject 1 addresses approaches to extend the service life of wood-based materials. Additionally, WPCs are introduced, i.e., a group of innovative wood-based materials, and how the material composition affects cascading utilisation is examined. Fibres such as bamboo, oil palm, coconut husk, kenaf and coir also have a reinforcing effect because of their chemical structure and composition, comparable to lignocelluloses from wood, and they allow "material design for the environment". Therefore, bamboo is presented as an alternative raw material base for thermoplastic composites.

Based on the review of current literature, Teuber et al. (2016) examine to what extent WPCs, as an innovative group of materials, can contribute to an efficient use of renewable resources. This article indicates that WPCs can support cascading utilisation, e.g., by comprising wood waste and by-products similar to recycled polymers and biopolymers. The recyclability of WPCs and their eco-friendliness are also addressed, for instance, by reviewing life cycle assessments. According to the reviewed literature, WPC cannot compete with solid wood with respect to environmental impact but is an environmentally friendly alternative to neat plastics in several applications.

Although much research focuses on WPCs, other renewable resources can also be used to reinforce thermoplastic composites. Because bamboo is one of these resources, Bin Bahari and Krause (2016) discuss its utilisation for thermoplastic composites. Therefore, the usefulness of Malaysian bamboo species for polyvinyl chloride (PVC)-based composites is investigated using varying particle sizes and loadings. Analyses of performance properties, namely flexural strength, impact bending and water uptake, suggest that bamboo-PVC composites are a promising alternative to traditional wood-PVC composites. These results show that the use of bamboo can not only serve as an alternative for WPCs but can also expand the commercial utilisation of bamboo and the development of greener, cleaner products.

2.2. Subject 2: Quantitative models for the integrated optimisation of production and distribution in networks for renewable resources

As the papers under Subject 1 have highlighted, many technical options contributing to cleaner production in the wood sector are being developed. However, an open research question concerns these products' integration into interorganizational supply chain networks and their influence on cascade utilisation. Planning methods for configuring and optimising resource-efficient supply chain networks for renewable resources are required, e.g., to provide cost reduction, to ensure reliable supply and consistent quality, and to consider the impact on climate change. Such analyses must start with quantitative models of the newly developing networks for renewable resources. In a second step, these quantitative models allow the application of mathematical methods for configuring and optimising resource-efficient supply and production networks for renewable resources.

Over the years, Operations Research (OR), the application of advanced analytical methods for decision support, has been used extensively for optimising environmentally friendly production planning. The main branch of operations research is mathematical optimisation, which is also a helpful tool for implementing cleaner production (Azapagic and Clift, 1999; Hugo and Pistikopoulos, 2005; Klemeš et al., 2012; Spengler et al., 1997). In combination with mass and energy flow models (Geldermann and Rentz, 2004), this methodology can offer valuable decision support for improving resource efficiency in cascade utilisation. However, the quantification of the positive environmental effects and of the trade-offs with other consequences of cascade utilisation remains an open consideration both in theory and practice. The papers on Subject 2 in this Special Volume provide a flavour of the many open decision problems that call for quantitative models for realising cleaner production in networks for renewable resources, be it water, energy or biomass. To implement successful cascade utilisation, an efficient distribution system for the intermediate and end products from the raw material supplier through the end consumer is needed. Central questions are what specific features should be considered in the distribution of products from renewable resources and how these features affect the design of an efficient distribution system. Specifics in the distribution can result from fluctuations in quality, availability and, because scarcity is possible, the prices of products from renewable resources. Furthermore, to implement successful materials utilisation in cascades, it is necessary that all involved parties coordinate their activities. Therefore, different coordination mechanisms are available. One issue that needs more research is whether market-based, hybrid or hierarchical coordination mechanisms are advantageous for the production, distribution and usage of products based upon renewable resources.

The implementation of the cascade principle particularly requires additional logistics operations to realise mass and energy flows between material use, chemical use and energy use, which are normally allocated to different companies, often at distant locations. Taskhiri et al. (2016) addresses a logistic network for wood flow by considering different goods and sectors. An approach is presented for modelling the consequences of additional logistical operations caused by cascade utilisation, and an exemplar case study on wood products, which can be produced to varying degrees from fresh wood and waste wood, is introduced, followed by the consideration of three scenarios. The proposed decision support tool allows comparison of costs and CO₂ equivalents, which are caused by the required logistics processes, for different approaches to implement the

cascade principle. This tool reduces the uncertainties of decision makers in the field because the consequences of operations can be assessed with respect to certain target dimensions.

In addition to CO₂ emissions, the enhancement of water resource management through industrial symbiosis is of major importance for cleaner production. The concept of industrial symbiosis has led to improvements in resource efficiency in corporate networks. One specific aspect is the achievement of economies of scale by having multiple companies located in close proximity to share common utilities, such as chilled and cooling water. Leong et al. (2016) investigate an inter-plant chilled and cooling water network (IPCCWN) to achieve greater overall cost savings. Issues encountered by IPCCWNs include network reliability problems caused by the inconsistency of source availability and cost savings allocations for IPCCWN synthesis caused by the subjectivity of human preference on decision making. Therefore, a decision-making tool to determine a feasible solution that will satisfy all industrial plants in the IPCCWN is developed as a multi-objective linear programming model, satisfying all plants in the network by striving for the highest cost reductions.

Levidow et al. (2016) state that eco-innovations are associated with a decrease in resource burdens and examine eco-efficiency improvements in manufacturing companies. Two industrial case studies were conducted and show that the impetus for eco-innovation originates from the companies' environmental policies, as well as from external drivers such as expected higher costs and future resource scarcity. Both companies represent strong prospects for reducing resource burdens in water-service processes, particularly from chemical inputs and waste water. Such eco-innovations involve more complex interactions beyond the production site; therefore, the options warrant a whole-system comparative assessment. Therefore, the presented EcoWater project engages stakeholders and fosters their interactions to increase the meso-level resource efficiency into any water-service system.

In recent discussions on renewable energy, bioenergy is strongly linked to the extended cultivation of maize as an energy crop and often coincides with negative public perception. Because the German Law on Renewable Energies (EEG 2014) emphasizes the utilisation of resources other than maize for bioenergy production, Pehlken et al. (2016) consider alternative biomass and its contribution to sustainable management of the landscape and energy system. Two case studies in Germany are presented based on a transdisciplinary approach. GIS analyses indicate the availability of alternative biomass and the formation of stakeholder alliances information systems (IS) in the value-generating networks for renewable resources (from forestry and agriculture to consumers). Science and industry are working on how IS and information management (IM) can contribute to meet the requirements in this sector (Zarnekow and Kolbe, 2013). Therefore, several constraints must be considered, e.g., the existence of trust in the involved companies, as well as IT experience and IT-know-how, infrastructure provision and resulting costs. This consideration becomes particularly challenging because many companies that are involved in the supply chain of renewable resources are small and medium-sized enterprises (SMEs), which are occasionally family-operated and long established (Friedemann et al., 2011). Innovations must be introduced deliberately because several SMEs also do not prioritise are identified as requirements for an efficient and sustainable use sustainability considerations (Cote et al., 2006; Klewitz and of biomass. This study stresses the importance of achieving the integration and participation of a variety of actors along the entire bioenergy supply network and highlights the need for cross-sectoral collaboration to exploit the identified alternative biomass potentials and thus, improve the sustainability impact of bioenergy production.

Because the industrial use of renewable resources is characterized by the uncertain nature of many influencing factors, e.g., annual weather conditions, pest infestation, and unsteady prices,

appropriate planning methods are needed to address these uncertainties. Bender et al. (2016) model the problem of finding the optimal harvesting and selling policy with respect to a maximum profit by incorporating price and biomass yield as uncertain factors. Because of the existing uncertainties, optimisation methods are considered. As robust optimisation does not consider dynamic aspects, the authors select online and stochastic optimisation and elucidate it with a case study on short rotation coppices.

To quantify the possible environmental impacts of manufacturing and transportation systems, life cycle assessment (LCA) is an established tool in science and research. However, its integration into manufacturing and transportation decision support systems is hampered by not sufficiently depicting the dynamic behaviour of manufacturing and transportation systems. Stiel et al. (2016) present a conceptual framework as well as conceptual software architecture to foster the integration of life cycle assessment software tools with dynamic manufacturing and transportation decision support tools. The researchers apply methods from the field of design science research on information technology to implement effective environmental-oriented decision support systems for manufacturing and transportation operators.

Progress on scientific challenges should also be shared with individual companies that are striving for cleaner production within their supply chains. In contrast to large corporations, small and medium sized enterprises (SME) usually cannot exploit economies of scale because of their characteristics. However, with their flat hierarchies, SMEs can be more agile and are able to adapt to new market developments much faster. Renatus and Geldermann (2016) argue that SMEs need support in their efforts towards cleaner production; in addition, they present an easy-to-use multi-criteria decision support system based on reference points that can be integrated into corporate environmental management information systems.

2.3. Subject 3: Information technology-based collaboration in value generating networks for renewable resources

The specific characteristics of products from renewable resources lead to several challenges, such as uncertainty in quantity and quality, the optimisation of material flows and the improvement of resource efficiency. These problems can be tackled with the help of modern information technology (IT) and innovative Hansen, 2014). Therefore, drivers of IS and IT introduction must be analysed because they help to overcome barriers during their adoption. It should be considered that benefits not only for the environment and for companies but also for the final consumer may emerge. For instance, a deep information exchange may provide consumers with a foundation for more informed purchase decisions (Choe et al., 2009; Hobbs, 2004). Therefore, a commonly used approach is labelling, which aims to inform consumers about a product's sustainability characteristics (Banerjee and Solomon, 2003; Bradu et al., 2014; Marette et al., 2012; Testa et al., 2015). Overall, Subject 3 focuses on the contribution of network-based collaboration to sustainability and resource efficiency. The presented papers show that the concept of cleaner production has not yet been widely adopted in information technology-based collaboration, one reason being the lack of appropriate tools to identify and evaluate possible process improvements. Based on the Subject 3 papers, future research should be stimulated that addresses the consideration of cascade utilisation (including by-product usages) in IT and IS.

Because network-based collaboration affects environmental sustainability, e.g., by waste reduction and a comprehensive utilisation of by-products, Zander et al. (2016) analyse drivers of network governance. The article develops diverse theoretical paradigms to investigate the emergence of networks that consider environmental aspects. Case studies conducted in the German wood industry reveal four key factors determining the emergence and additional contextual factors influencing the effectiveness of network-based collaboration. This paper also highlights the need for interorganizational information sharing to facilitate and enhance the efficient exchange of knowledge between organizations.

The utilisation of Internet-enabled information systems promises to create significant advantages in terms of inter-organizational information sharing and operational efficiency. However, despite various benefits, Internet-enabled information systems are not widely used in the wood industry; thus, Trang et al. (2016) identify factors influencing e-business adoption. Based on the technology-organization-environment framework and a differentiation between initial e-business adoption and long-term routinization, a study is conducted in the German wood industry regarding how to increase e-business diffusion as an enabler for cleaner technology and cascade utilisation. Thus, the importance-performance analysis technique is introduced in IS diffusion to better identify factors with high potential for improvement. The results reveal that the initial adoption can be effectively promoted by addressing the factors' relative advantage, technological integration, technological readiness, partner pressure, and regulatory environment. The following organizational routinization of the technology can be effectively further stimulated by the factors' relative advantages and partner pressures.

Current research and practice reports indicate the existence of purchase barriers concerning eco-friendly products, e.g., wood products. Appelhanz et al. (2016) propose a solution for a traceability information system, which provides consumers with their valued wood product information items. The conception develops a four-layer system architecture that captures wood product information and provides the information to consumers. Additionally, an analysis of the economic feasibility shows that the implementation of the proposed solution is achievable at acceptable costs. However, sensitivity analyses show that consumers must pay a small surcharge.

2.4. Subject 4: Consumer behaviour towards eco-friendly products

The reuse of materials and products within cascading utilisation requires consumers' support in recycling and their acceptance of products made from recycled materials (Jansson et al., 2010). Furthermore, consumers need to know what problems may arise from direct energetic utilisations. Although various approaches aim at improving the sustainability and resource efficiency of production processes, these efforts will fail if consumers dislike or reject associated materials, products, and services.

Although, in general, a growing eco-sensitivity is reported, consumers' purchasing behaviour does not reflect environmental considerations to the same extent as consumers' expressed concerns may suggest (Biswas and Roy, 2015a; Chen and Chai, 2010; Gleim et al., 2013; Lin and Huang, 2012; Tseng and Hung, 2013). Because of the obvious existence of green purchase barriers, comprehensively understanding consumer behaviour regarding eco-friendly products is essential for the economic success of all parties involved in the value chain of renewable resources (Gleim et al., 2013). Therefore, an investigation of consumers' values, attitudes, and motives has been in the centre of

several studies (Diaz-Rainey and Ashton, 2011; Hartmann and Apaolaza-Ibañez, 2012; Lin and Huang, 2012; Minton et al., 2015; Urien and Kilbourne, 2011). Thus, future studies should consider products consisting of various eco-friendly materials because consumers should not only accept those materials representing the first step of a cascading utilisation, which have been the centre of previous studies but also subsequent ones. A market is needed not only for solid wood products but also for those materials that rely on by-products and waste wood, such as WPC or bamboo-PVC composites, which were introduced in Subject 1. The increased usage of by-products and waste wood has a positive effect on resource efficiency but often a negative impact on consumer acceptance. Therefore, it is important to assess consumer acceptance of a wide range of eco-friendly products and to determine the drivers (Diamantopoulos et al., 2003; D'Souza et al., 2006; Gershoff and Frels, 2015; Luchs et al., 2010). Because several studies report that consumer acceptance of eco-friendly products varies among consumer groups (Finisterra do Paço and Raposo, 2010; Gilg et al., 2005; Thompson et al., 2010; Verain et al., 2012), segmentation is a commonly used approach to address different consumer segments as well as possible. For the economic success of eco-friendly products, a comprehensive assessment of consumers' willingness to pay (WTP) for green products is crucial (Barber et al., 2012; Laroche et al., 2001; Veisten, 2007; Vlosky et al., 1999) because current research indicates that the WTP depends on product category and material (Achabou and Dekhili, 2013; Cai and Aguilar, 2013; Essoussi and Linton, 2010). Because eco-friendly products often require a surcharge compared to conventional alternatives, whether consumers are willing to pay the required price premium must be examined (Barnard and Mitra, 2010; Biswas and Roy, 2015b; Bougherara and Combris, 2009); alternatively, whether the resulting costs must at least partially be covered by other entities such as supply chain participants or

public policy must be examined. However, it must be remembered that the product itself affects not only sustainable consumption but also product packaging. Product packaging that relies on renewable resources may help to decrease the waste quantity and the reliance on fossil fuels (Garrido et al., 2014; Razza et al., 2015); thus, this aspect should also be considered. In addition to sustainable consumer choices, exceeding consumer behaviour such as pre- and post-purchase behaviour is therefore, also in need of investigation.

Developing the previous subjects, the foremost objective of the papers on Subject 4 is combining consumers' expectations with the green supply chain network. A comprehensive consideration of green consumer behaviour succeeds, which leads to more specific behaviours. These include consumers' willingness to pay for green products and assessments of consumer acceptance of eco-friendly products as an investigation of its drivers.

Coskun et al. (2016) strive to connect the green supply chain network with consumers' related expectations. Therefore, a goal-programming model is introduced that distinguishes three consumer segments, based on their purchasing behaviour and green consciousness (i.e., green, inconsistent, and red consumers), and the model's usefulness is supported by a hypothetical example problem. Additionally, several scenarios are examined such that this article fosters a comprehensive consideration of both green supply chains and consumers' environmental consciousness. This approach helps to improve the efficiency of green supply chain networks as it becomes possible to consider consumers' attitudes in the design of a supply chain network.

Because green products often require a surcharge, Medeiros et al. (2016) analyse consumers' willingness to pay (WTP) and investigate the behavioural motivation for green product consumption. Developing a modified version of Zeithaml's (1988) model and an application in the automotive and

furniture industry, this article reveals that consumers are, on average, willing to pay a 10% surcharge for green products. The perceived value of green products is an important driver of consumers' WTP through the reduction of financial, performance and psychological risks. Additionally, demographic variables affect consumers' purchase intention through the product's perceived quality.

Because critical media reports may threaten consumer acceptance of wood-based materials, Osburg et al. (2016a) examine whether the provision of detailed wood product information increases consumers' product trust and purchase intention. An online survey investigates young consumers' information demand and reveals four consumer segments, in which three segments value accessing detailed wood product information. The identified segments differ with respect to their information preferences.

Osburg et al. (2016b) investigate consumer acceptance of WPCs in relation to established materials, i.e., wood and plastics. The eco-innovative materials represent a hybrid solution on the 'two-evils' continuum' constituted by the competition of wood and plastic materials; the former being excessively expensive and resource consuming in mass consumption, the latter cheap but environmentally hazardous. Two online studies reveal that consumers prefer solid wood over full plastics, whereas the choices for WPC products remain central. Additionally, innovative and environmentally concerned consumers are identified as two target groups for WPC products that value WPCs more than the average consumer.

3. Conclusion and outlook

This Special Volume contains articles that consider the broad topic of resource efficiency. The focus of interest is particularly on two aspects: cascaded utilisation and the usage of by-products. According to Sirkin and Houten (1994), cascade utilisation is a method that optimises "resource utilisation through a sequential use of the remaining resource quality from previously used commodities and substances" (p. 215). A typical example is the industrial processing of renewable resources such as wood, which is mainly characterized by the existence of by-products and the various options for cascade utilisation, that is, the multiple sequential utilisation of the same input prior to energetic conversion at the end of the life cycle. The growing importance of cascaded utilisation and the usage of by-products in corporate practice has several reasons. As previously shown, the competition for agricultural products between traditional users and the energy sector has increased significantly. This increase has strengthened the pressure on the affected companies to seek alternative materials and processes. At the same time, governmental and non-governmental organizations have tightened their demands for more efficient usage of resources. For instance, the European Commission adopted a new EU Forest Strategy in 2013 with the goal of using raw wood material in a certain order of priority, according to the cascade utilisation principle, while continuing to adhere to the Renewable Energy Directive (AEBIOM et al., 2013). When using concrete measures, the question arises regarding the total effects they have. However, quantification of the positive environmental effects and of the trade-offs with other consequences of cascade utilisation remains an open question both in theory and practice. The challenges result from the fact that new materials are used; however, their properties are not completely known. Planning with uncertain data calls for robust or stochastic optimisation. A large problem is that a large number of actors with different goals and information needs is involved and must be considered simultaneously. Such issues are

handled in the field of multicriteria decision making. Combining both challenges, i.e., multicriteria decision making under uncertainty, is an important subject for further research (Ehrgott et al., 2014; Ide and Schoßel, 2015). Distant industries must be integrated and must learn how to utilise new value chains of global dimensions and renewable resources (Kircher, 2012). Because interorganizational networks of companies are affected by cascade utilisation, differing perspectives and preferences of network actors must be considered. Challenges in the design of value chains for resource-efficient use of renewable raw materials are the fluctuations in the quantity and the quality of harvested plants and the multiple use changes and variabilities in material that require appropriate planning (Geldermann, 2012). The noted challenges demand sound solutions that can be provided by science, in particular. The structure of this Special Volume shows from which areas these solutions can originate.

The articles in this Special Volume show that much research on innovative material development is underway. It can also be observed that today's consumers are concerned not only with quality and price but also with the social and environmental impacts of products and processes. Information management can support informed decision-making processes for the purchase of sustainable products; however, metrics for resource efficiency remain missing.

Efficiency is a criterion of whether an economic action achieves a predetermined target while respecting the principle of cost-effectiveness. However, how can the efficiency in a complex network of relations in cascade utilisation be determined when several companies along the value chain process raw materials? Here, the simple differentiation into minimizing and maximizing is no longer possible. More sophisticated methods are required and deserve further research for considering differing perspectives of raw material suppliers, processors and, particularly, customers (Geldermann et al., 2016). In particular, the occurrence of trade-offs between different sustainability indicators and of uncertainties inherent in renewable resources prevents a universal definition of resource efficiency (Giljum et al., 2011). Thus, each company must make and justify its individual decisions in the context of the particular business environment. The Journal of Cleaner Production can support the search for best practices by publishing associated case studies, which will form the basis for further scientific research.

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