Review

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Outlook for modified wood use and regulations in circular economy

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Abstract: Circular economy may play a key role in the future success of modified wood products. The European Union (EU) aims toward a circular economy, i.e. increasing resource efficiency by waste minimization in production processes, cascade uses of materials, elimination of landfill wastes, and maximizing the value of raw materials. The policy has great expected impact across all sectors, and will influence countries with strong wood modification industries, such as Finland, Germany, Norway, and the Netherlands. It also means considerable economic efforts and sets transformation challenges to the societies and industries. Challenges have country-wise differences depending on production structure, environmental circumstances, local policies and regulations, as well as economic resources. This paper is an outlook of the renewed waste legislation in the EU, based on which it assesses the possible impacts of circular economy development on the future of wood modification. One of the key indicators for resource efficiency is € kg^{-1}, which allows pursuing increased efficiency by minimizing material input (and waste) and/or by maximizing the value. In the case of modified wood, both of these approaches may be considered market opportunities, while the key challenge and the consequent need for action relate to improved waste management.

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Introduction

The change in wood product industries' operating environment has been tremendous during the past decade, and it is expected to be considerable during the next one as well (Hetemäki and Hurmekoski 2016). Climate policy actions, political uncertainties reflecting into product trade and markets, overall increase in environmental awareness of consumers, and development in timber construction practices (e.g. Lazarevic et al. 2019) tend to support the growth expectations of wood products. Simultaneously, the emerging circular economy policy pushes industries and consumers from a waste intensive linear economy system toward a less waste-producing and longer lifetime production-consumption system (Domenech and Bahn-Walkowiak 2019; Wilts and O'Brien 2019). This calls for (i) product design for better durability and recyclability, (ii) systems improving the waste management processes and market uptake of recycled post-consumer wood, and (iii) improved logistics solutions for packaging and transportation of goods, raw materials, and wastes. All these changes challenge the reactivity and adaptability of the industries.

Overall, the starting position and expected development in the recycling rate of solid wood waste, for example, in the packaging sector are still modest in comparison to other materials (Table 1). Most of the wood waste from building construction and demolition sites ends up in energy production in northern Europe. In southern and central Europe, on the other hand, the majority of the recovered wood ends up in particle and fiberboard production (e.g. Heräjärvi et al. 2010a,b). However, wood products support climate actions through substituting emission-intensive materials and energy carriers, and as long-term carbon storages (e.g. Rüter et al. 2016). The challenge is to react to the growing volumes of modified wood products in the markets, which may, on the one hand, extend the lifecycle of

Table 1: Recycling objectives of different packaging materials in the EU in 2025 and 2030 (http://europa.eu/rapid/press-release_IP-18-3846_en.htm).

	2025	2030
Year		**Recycled (%)**
Plastic	50	55
Wooden	25	30
Iron/steel	70	80
Aluminum	50	60
Glass	70	75
Paper and paperboards	75	85
All packages	65	70

products, yet, on the other hand, influence their waste management options.

Modified wood products will increasingly affect the recyclability of wood products and structures, thus also influencing their environmental footprint in comparison to products made of other materials or non-modified wood. Heräjärvi et al. (2010b) paid attention to the fact that not much work was devoted to the possibilities and challenges in re-use and recycling of modified wood. This concern is of pronounced current interest because of the revised legislative framework on waste (Directive (EU) 2018/851) and the European Union (EU) Action Plan for the circular economy (European Commission 2015).

This article is based on the assumption that the circular economy development will continue in the EU. Furthermore, we assume that the current modified wood products continue existing in markets. Finally, we expect that some new modified wood products enter the markets during the coming years, causing growth in the volume of modified wood sales even if the demand of currently existing products remains constant.

Circular economy development has an effect on virtually all industrial production and consumption in the EU. In terms of forest industries, some discussion and scenarios have been published by Kunttu et al. (2019) and Näyhä (2019). However, the position of modified wood in circular economy discourse has not been analyzed and no publications deal with the role of modified wood in the circular economy development. Furthermore, the consequences of modification on wood's re-usability, recyclability, or waste management have not been discussed, yet the topic has been debated, for example, in the course of COST action ModWoodLife (https://www.cost.eu/actions/FP1407). This article points out questions and challenges related to circular economy development from the viewpoint of modified wood, in the context of evolving EU waste legislation and circular economy ambitions.

Methodology

The EU circular economy strategy, which is implemented by, for example, renewing the waste legislation, is the driving force behind the expected changes in industries, logistics, and, finally, consumer behavior. Therefore, it is reasoned/necessary to analyze the key measures of the circular economy strategy before being able to discuss its implications for wood modification industries and modified wood markets. Thus, this article is based on (i) literature and internet searches aiming at updated understanding on circular economy-related drivers and actions affecting wood modification industries, (ii) inductive reasoning of the effects of point (i) on wood modification (opportunities and challenges), and (iii) synthesizing analysis on the role of modified wood in circular economy development, in the crossroad of production-consumption system and policy guidance.

To get a more narrowed overview of the opportunities and challenges of modified wood in the context of circular economy, we carried out a literature search in university database collection (UEF Finna) from over 400 databases including, e.g. SCOPUS and EBSCO. By using keywords “circular economy” and “modified wood”, the search did not result in articles, but by switching “modified wood” into “wood”, the search resulted in 11 e-articles, two conference proceeding papers, and five newspaper articles. Next, we analyzed the content of the search results, which further reduced the number of relevant articles down to three. These articles were included in closer analysis: (i) Jarre et al. (2019), “Transforming the bio-based sector towards a circular economy – what can we learn from wood cascading?”, focusing on wood cascading and stating that the main challenges are the policy limitations, market acceptance, and technical limitations such as quality, additives, and particle size; (ii) Husgafvel et al. (2018) “Forest sector circular economy development in Finland: a regional study on sustainability driven competitive advantage and an assessment of the potential for cascading recovered solid wood” highlighting the need for national and EU-level tools to boost cascading of solid wood products, market enhancement in the construction sector, and lifecycle thinking; and (iii) Augustsson et al. (2017) “Persistent hazardous waste and the quest toward a circular economy: the example of arsenic in chromated copper arsenate–treated wood” stating that the waste streams of treated wood including hazardous preservatives have increased, major share of those streams are not traceable, and current policies are unable to monitor these streams.

Although the literature search did not result in many objects in number, the main themes could be extracted to construct this review: (i) what are the main policies directing the use of modified wood products and their end-of-life utilization, (ii) how the markets will likely develop in terms of modified wood products and their waste wood applications, and (iii) what categories modified wood products have and how they are treated in waste management. The main challenges and opportunities will be discussed within these frames in the following sections.

EU waste legislation and circular economy strategy

According to the circular economy policy of the EU (European Commission 2015), materials traditionally treated as wastes should not be wasted (landfilled) anymore. Materials recovered from demolition, construction, packaging, or virtually any kind of industrial or private processes should be re-used, recycled, or at least incinerated. The conceptual difference between re-use and recycling is that re-using means that material or product is used in the same end use for a second time, whereas recycling refers to using materials or products in different end use after their primary lifecycle (see Oliveux et al. 2015). Circulation, in turn, refers to the processes of re-using and recycling in circular economy system (e.g. Genovese et al. 2017; Korhonen et al. 2018). In this article, we use the term "waste" for all materials after their primary use. Thus, "waste" includes both landfill waste and recovered materials collected for re-use, recycling, or energy production.

Construction and demolition wastes that account for 25–30% of all wastes generated in the EU are even more important than the municipal wastes from the environment and business points of view. Therefore, the EU has defined construction and demolition waste as a priority waste stream (European Commission 2018) that has high value materials involved and has, thus, high potential for recycling and re-use. Because modified wood products have been in the markets for less than 20 years, there is only little such material in municipal or construction and demolition waste streams so far. This is expected to change in the future, as some hundreds of thousands of cubic meters of modified wood products are consumed in Europe annually (e.g. Möttönen et al. 2018), and the volume is expected to grow in the future (e.g. Kiseleva et al. 2017).

According to Eurostat (2018b), many EU member states have gradually improved their waste management practices in accordance with the EU waste hierarchy principle (Directive 2008/98/EC) during the last two decades. On average, 64% of municipal waste ended up in landfills in the EU in 1995. Five years later, the percentage was 55, and the share of recycled waste was 25%. The latest statistics (Eurostat 2018a) indicate that the shares of household waste ending up in landfills and recycling were 24% and 46%, respectively, in the EU in 2016. There are, however, great country-to-country differences, and some countries have already practically banned landfilling of household wastes. Sweden, for instance, landfills just 1% of all household wastes, and actually imports wastes to keep its recycling plants running. Good results in Sweden are based on the policy to avoid the opportunity costs: it is cheaper to recycle than to pay the sanctions of landfilling. The share of landfilled household waste still exceeds 50% in as many as 10 EU countries.

The new waste directive of the EU, EU Directive 851 (2018), aims at preventing waste generation. When prevention is not technically or economically possible, such as in the case of packaging and municipal waste, recycling is supported. The original proposition of the European Commission from year 2015 was part of the Circular Economy Package (EC 2015), where one of the key aims is gradual decrease of the volume of landfill waste. Now the new legislation commits the member states to waste generation prevention, re-use of materials, and recycling of them instead of incineration and landfilling. Landfilling of wastes is not seen as rational in a circular economy due to the resulting pollution of water, soil, and atmosphere. The new obligations are supposed to stimulate the transition of the EU to put the circular economy into practice. The Circular Economy Package indicates that the EU seriously aims at economic transformation via new business opportunities and increased competitiveness that result from fundamental changes in the concept of product lifecycle. Development is expected both in production and consumption practices, which means systemic transformation challenge (see Scheel 2016).

According to the European Commission, the new waste legislation is the most forward-looking one in the world, and gives the EU a reason to act as a model to other countries. The aim is to recycle 55%, 60%, and 65% of the municipal waste in years 2025, 2030, and 2035, respectively. Only maximum 10% of the municipal waste can be landfilled in 2035.

Already the previous waste legislation obliged the EU member states to organize recycling of paper, paperboard, glass, metal, and plastic wastes. The new obligations aim at further improvement of the quality and usability of wastes, transforming them into materials. Separate recycling systems will be required for dangerous household wastes in 2022, organic wastes in 2023, and textile wastes in 2025. In addition, there will be a ban on landfilling of separately collected waste. Material re-use and industrial symbiosis (Domenech et al. 2019), i.e. turning one industry's by-product into another industry's raw material, and forming new business collaborations around this activity (Veleva and Bodkin 2018), have very high rank among the promoted actions of the waste legislation. The new legislation relies mainly on economic guidance and incentives that support the countries to follow the waste hierarchy. In addition to the national investments, 650 million euros of Horizon 2020 funding and 5.5 billion euros from EU structural funds are allocated for waste management development in the circular economy. Presumably there will be funding instruments designated into these topics also within the next framework programme.

The producer responsibility principle will be extended from its current status (Marques and Da Cruz 2016) in order to improve its effectiveness. In practice, manufacturers are bound to manage product's re-use or recycling after its primary lifecycle, i.e. closing the loop (Richter and Koppejan 2016). In addition to the recycling rate objectives (see Table 1), extended producer responsibility systems will be required, for instance, from producers of packaging materials already in 2024 (e.g. Watkins et al. 2017). Organizing re-use or recycling of the packaging materials is expensive, particularly in sparsely populated areas, and it is expected that consumers pay these investments (Klaiman et al. 2016). Not only re-usability and recyclability but also extended durability is expected from packaging materials and products, and modified wood offers one possibility to achieve this goal. While the price of modified wood products is currently too high for packaging purposes, the situation may change in the future when "packaging materials" gradually turn into "packaging products" with higher value and longer lifecycle.

The aim of the European waste hierarchy principle and waste legislation being high-minded, i.e. extracting the maximum value and use from all raw materials, products, and wastes, fostering energy savings, and reducing CO_2 emissions, there are still many problems involved (e.g. Van Ewijk and Stegemann 2016; Kirchherr et al. 2018). In terms of product manufacturing, not only energy efficiency and durability but also reparability and recyclability of products have to be considered. These requirements are likely to cause resistance among industries who do not have circulation in the core of their existing business strategy and who, thus, may consider their market position threatened. However, the policy signs toward closed loops are so strong that anticipatory and agile firms will pass through the transformation successfully. Finally, waste legislation sets a need for new simpler and univocal definitions as well as harmonized calculation methods for recycling rates throughout the EU.

The circular economy ambitions are mirrored also to voluntary schemes. For example, the green building certification systems, such as Leadership in Energy and Environmental Design (LEED) (Kubba 2009), set requirements for the raw materials used in construction or renovation. When applying for green building certificate, one of the elements evaluated is the proportion of recycled materials used in the buildings: the more the recycled materials, the higher the score. If modified wood products do not have well-functioning recycling or re-using systems, they lose their competitiveness in green building certificate systems.

The waste legislation should not only be seen as a threat to modified wood product business. It will also create economic incentives for manufacturers who provide markets with greener products and support recovery and recycling schemes (Esposito et al. 2017). If operationalized in a meaningful manner, this is likely to cease resistance and facilitate wood product industries in the transformation to circular economy.

Modified wood in relation to circular economy indicators

The EU waste hierarchy does not accept burning of wood waste as a recycling procedure. Many countries with considerable need for heat and electricity are about to face difficulties as soon as burning non-hazardous wood wastes for energy will be regulated, more expensive, or in the worst case, prohibited. There are substantial unsolved challenges in recycling of all wood materials. Especially hazardous wastes such as creosote treated railway sleepers and utility poles have pronounced challenges not only in recycling but also in disposal. Non-hazardous construction and demolition wastes that may contain metal joints, glass, impurities, coatings, adhesives, etc. set requirements for classification and segregation of materials (e.g. www.gov.uk/government/publications/classifying-waste-wood-from-mixed-waste-wood-sources-rps-207) and in the presence of inorganic remnants, challenge crushing or chipping machinery too. Modified wood material, on the other hand, should not be more problematic than unmodified wood, as modification, by definition, does not introduce any environmentally harmful or health risky chemicals in wood. Thus, if recovery of modified wood products results in hazardous wastes, their hazardous character is not caused by modification, *per se*, but other reasons, such as surface treatments or adhesives.

There are essentially two core indicators for a circular economy: the lifetime of a material (or the rate of recycling), i.e. the circularity, and the relative value assigned to material inputs. One of the core aims of circular economy is to maximize the circulation of products, components, and material flows by recycling, re-use, and sharing (Sitra 2016). The European Commission defines € kg^{-1} as a key indicator for circular economy. Optimizing the value of this indicator requires either reducing material input (and consequently waste) or increasing the value of materials (EC 2015). Both aspects emphasize minimizing the use of virgin raw materials, yet they have very different implications when applied to the modified wood product industries. Using the € kg^{-1} indicator, the scoring for modified wood depends on what it replaces. Compared to unmodified wood, the density of modified wood is typically not much different, but the value can be considerably higher. If it replaces plastic, for example, in decking, both the price and the material input may be higher, leading to no real advantage. The same applies to the way of quantifying carbon substitution benefits; the displacement factors (e.g. tons of carbon avoided per ton of wood products used) can be as high as 7.8 tC tC^{-1}, but only when material input remains low compared to the replaced element (Leskinen et al. 2018). Therefore, low-added value end uses such as decking do not create much climate benefits either. Such indicators for material efficiency may be of interest only on the level of countries or product-specific functional units. For example, substituting concrete in construction can be highly beneficial, as it essentially reduces the total material input without affecting too much the value of the building, i.e. it avoids greater material use and waste due to different material densities. A lighter structural frame also allows reduced material input to the foundation and saves energy in logistics and construction phase. Cross-laminated timber (CLT) and laminated veneer lumber (LVL) represent products that actually compete with hollow-core concrete slabs and wall elements, but are considerably lighter in weight. This is not only an advantage but causes also a need to anchor especially high-rising structures heavily against wind loads, which obviously narrows down the material substitution benefits. Modified wood or veneers are, however, not commercially used in CLT or LVL so far.

A common feature to all modified wood products is that their lifetime is typically longer than that of an unmodified product (e.g. Hill 2006; Sandberg et al. 2017; Möttönen et al. 2018). From durability point of view, the maximum attainable lifetime is not realized in products intended for, for example, fashion-dependent applications, such as interior decorations, or products that are completely replaced after a minor damage in a limited area, such as decking or cladding. The same is true in some demanding load-bearing structures that are exposed to weather, such as bridges and traffic barriers that have to be replaced even after a minor damage. This means that a considerable proportion of the replaced material is in a relatively good condition for either re-use in less demanding structures or recycling. If wood modification causes even minor restrictions to the possibilities to re-use or recycle it, modification ultimately impairs the material's lifecycle performance relative to normal wood products that do not suffer from such restrictions. Hence, the actualized product lifetime, as well as its environmental performance, depends on the type of its use and success in streamlining the cascading principle in the production and consumption system.

The idea of improved recyclability favors materials that have higher durability than the competing ones. The most valuable wastes are the most efficiently recycled. Wood-based panel industries can use recovered modified wood or modified wood processing residues as a raw material, as long as their chemical and physical properties are applicable for their processes. The technical applicability might be compromised by, for example, low pH value or flammability of the modified material. Therefore, it is not self-evident that all recovered modified wood materials fit in the current production processes of wood-based panels. Novel solutions are necessary in countries where wood-based panel industries are marginal or do not exist and incineration has been the only way to use recovered wood.

Products' resistance against decay, mold, or insects, as well as its durability against moisture, ultraviolet (UV) radiation, and fluctuating temperatures are features in keeping with the end uses of modified wood products: all modification methods aim at improving one or several of these properties (Table 2). The improvement can be achieved with (e.g. Accoya®, Belmadur®, Kebony®, crude tall oil impregnation) or without (e.g. thermo-mechanically modified wood, Thermowood®) added non-biocidic chemicals. Obviously, also secondary products made of recovered modified wood will perform differently than unmodified products (see e.g. Tricoya®), which set interesting research, product development, and design challenges. A great majority of modified wood products is currently used in cladding, decking, and window frames. Surface treatment is typically applied in order to further improve product's durability and

Table 2: General property requirements of modified wood products by end use category.

	Property							
	Resistance against							
End use group	Weather/ UV light	Abrasion	Decay, mold or insects	Strength	Appearance	Dimensional stability	Treatability (paint, etc.)	VOC emissions
Cladding	+++	–	++	–	++	++	+++	–
Decking	+++	++	++	+	++	+	++	–
Window frames	+++	+	++	–	+	+++	+++	–
Garden furniture	++	+	++	++	++	+	+	–
Interior furniture	–	+	–	++	+++	+	+	+++
Fixture or cabinet	–	–	+	+	++	++	+	+++
Utility poles	+++	+	+++	+++	+	–	–	–
Other exterior uses[a]	+	–	++	+	+	+	++	–
Marine structures	+	+	+++	+	+	+	+	–
Packaging	+++	+++	+++	+++	+	+	+	++

+++, Very important or a precondition; ++, important; +, necessary; –, usually unnecessary. Table updated from the original version of Heräjärvi et al. (2010b).
[a]Such as fences, poles, posts, pergolas, etc.

appearance. Surface treatments may turn into an issue as soon as recycling becomes topical. Type of paint, varnish, or oil on the surface of recovered modified product may limit the possibilities for second lifecycle uses. Surface treatments can be removed, but depending on the size and shape of the recovered member as well as the penetration depth of the surface treatment, sanding or planning may be too expensive or technically difficult. In addition to surface treatments, emissions of volatile organic compounds from recovered and re-processed modified wood have to be taken into account in the recycling value chains.

Market prospects for modified wood in circular economy

Wood modification, based on various techniques, is one of the most successful innovations seen in the wood products sector during the 2000s (e.g. Hill 2006, 2011; Sandberg et al. 2017; Möttönen et al. 2018). Modified wood products have become a “new normal” in consumer markets during this millennium. This development is expected to continue as new modification methods are developed. Traditional preservative impregnated wood products suffer from their environmental harmfulness or toxicity, which opens new possibilities to less harmful products, such as modified wood (see Hill 2006; Möttönen et al. 2018). Furthermore, logging of naturally durable tropical hardwoods suffers increasingly from unsustainability issues, which creates demand for modified wood.

Besides the technological challenges, a key question is how to ensure the safety of recovered raw materials and subsequent products, thus preventing dangerous chemical compounds ending up indoors or in the environment. Indoor volatile chemicals and formaldehyde emissions are a safety hazard and could harm the competitiveness of recycled materials (Yu and Kim 2012). While some coatings and treatments are possible to detect visibly in the waste separation processes, most of the chemical treatments cannot be noticed without analytic procedures (Yu and Kim 2012). While there are no binding waste wood classification systems in Europe currently, among other things traceability of materials becomes difficult. On the other hand, if the share of modified wood in recycling systems remains low or if the number of commercial modification methods remains small, it is easier to manage the material flows and ingredients in the production-use-circulation chains. Possibly, the costs of analyzing the shares of waste for re-productions would remain relatively low too.

Modified wood products not only contribute to the circular economy development but are also affected by it. Thermowood® with its 200 000 m^3 annual production (Figure 1) is the most widespread modified wood product group so far (e.g. Sandberg and Kutnar 2016; Möttönen et al. 2018). Thermowood® is mostly used in planed products, such as decking, cladding, and window frames (see www.thermowood.fi). Therefore, the manufacturing processes of Thermowood® products result in an annual output of approximately 3000–6000 tons of thermally modified residues (sawdust, shavings, cutoffs), which are partly used in composite manufacturing

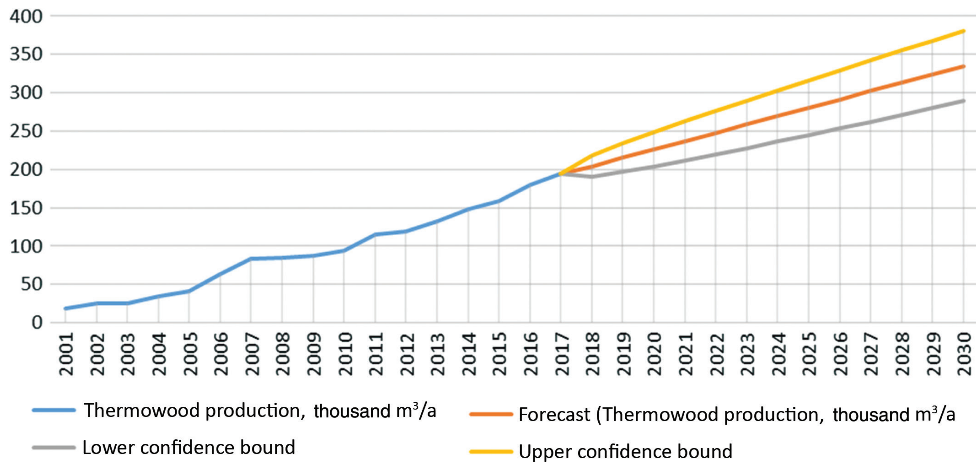

Figure 1: Production of thermally modified wood (thousand cubic metres per year) by the member companies of the International Thermowood® Association between 2001 and 2017 (www.thermowood.fi), and linearly extrapolated production trend forecast up to 2030.

but mostly incinerated for energy production nowadays. Thermowood Plastic Composites (TWPCs), for example, utilize sawdust and shavings of thermally modified solid wood, which provides the TWPC composite with better dimensional stability than ordinary wood would. Another example of utilization of modified wood residues is Tricoya®, a dimensionally stable and durable medium density fiberboard that is made of acetylated radiata pine planning residues.

Although modified wood still plays a minor role in the circular economy, the market share of durable and environmentally sound products, including modified wood and wood-based composites, is likely to increase (Sommerhuber et al. 2015). Market-based solutions, such as green building certificates, support, among other things, use of modified wood products. Also with regard to the climate policy actions, long-lifetime uses are preferred over the short-time ones (Varho et al. 2018). All this favors modified wood. As a probable consequence, also the volume of modified wood waste will increase in the markets gradually, causing a subsequent need to recycle these materials. Recycling of modified wood products may decrease the raw material costs and consequently boost the competitiveness of these products (Petchwattana et al. 2012). Whether the impact on production costs is positive or negative depends on the processing efficiency.

Measures to adapt to changing legislation

To reap the full benefit of the changing legislation, a number of actions need to be taken. These relate primarily to product design, business model development, improved information systems such as classification schemes, as well as research and development projects supporting these aspects.

The importance of sustainable product design is recognized in the circular economy strategy. With some preconditions related to management and control of possible chemical treatments or coatings applied, modified wood products can be used in particleboard or fiberboard production after their primary lifecycle. Once recycled into new products, modified wood can provide the panel industries with raw materials that have unconventional stability, durability, or emission properties, for instance. Special products based on modified wood residues or recovered modified wood could be an interesting option in small-scale production. Plausibility of these products will require standardized or at least trustworthy traceability of the product's earlier lives. As the conventional production of wood-based panels is typically in a scale of tens or hundreds of thousands of cubic meters, the output of modified wood residues is so far too small to feed a continuous wood-based panel production.

Mixed material products are challenging to recycle due to complex material separation techniques, thus higher recycling rate may require investments in the industry and common waste classification system throughout Europe. Another solution to increase the recycling energy efficiency of modified wood waste is pre-designing products for end-of-life processing (Petchwattana et al. 2012). Smart product design with operable and efficient re-processing in mind may represent a competitive advantage for a segment of companies in the modified wood sector.

Harmonized waste grading system will be evidently required in Europe soon, to replace the various national systems. Differing definitions for construction and demolition wastes make the international comparisons impossible. For example, some countries define materials that are used for land levelling as construction and demolition wastes. Harmonized classification would help in many ways. One critical advantage is collection of statistical information that would enable effective regulative guidance and policy actions that promote circular economy development, and finally, generate business and markets around wastes. A large-scale certificate system could also be a competitive solution to ensure the safety and improve the market uptake of recycled products (Yu and Kim 2012). In view of recycling, modified solid wood products differ slightly from non-modified solid wood products. Presence of adhesives, for example, is not very common in modified wood products, as their most typical end uses (cladding, decking, etc.) do not necessitate gluing. A special character of these end uses is that the entire structure is replaced because of damage in limited area. Thus, a lot of cladding or decking material will be recovered in good or even perfect condition, which calls for second hand markets and recycling systems. In comparison to unmodified solid wood, modified wood products have characteristic odor, combustibility and mechanical performance, low equilibrium moisture content, and slow rate of biodegradation (e.g. Hill 2006; Möttönen et al. 2018). Furthermore, these properties are characteristic of the particular modification treatment applied. Accordingly, the recycling systems as well as second lifecycle product options have to be considered separately for each modified wood product category.

Not only private companies but also public actors (state, municipalities) have a strong role in circular economy development in terms of tenders and sustainable product procurement policies (e.g. Witjes and Lozano 2016). Strong political guidance and clear regulations presumably result in a situation where circular economy discourse has a more visible role in media (Chamberlin and Boks 2018). This may contribute to the renewal of the business models (e.g. Lewandowski 2016; Geissdoerfer et al. 2018), generate new firms that take advantage of the circular economy principles, and, in particular, change the consumer behavior due to increased awareness of environmental impacts of different product types (Jonsson et al. 2008). We expect that pricing mechanisms guide the consumer behavior more strongly toward circular economy in the future. Furthermore, it is plausible that the systemic transformation will actualize in a way that recyclable modified wood products have both positive image features and competitive pricing, which improves their market position and further facilitates the systemic transformation.

Conclusions

This outlook analyses questions and challenges related to circular economy development from the viewpoint of modified wood products, in the context of evolving EU regulation, notably the EU Directive 851 (2018). The analysis is based on the literature and internet survey, followed by inductive reasoning. According to the results, circular economy development offers a number of business opportunities, and the EU policies support it. However, there are also questions and possible pitfalls that need to be addressed, analyzed, and tackled.

In terms of recovered wood, most work is needed with construction and demolition wastes – not only modified but all kinds of construction and demolition wood wastes. Among other things, the green building certification systems call for recycled materials. Harmonized statistics and classification methods for different recovered wood categories have to be developed before one can expect that real business emerges on recovered modified wood in the EU.

The societies are expected to set their focus on savings, energy efficiency, and durable products with high recyclability and optimizing circulation in the production-consumption system. Modified wood products can and will be a crucial part of this development. Attention should be addressed also to develop products that utilize recovered wood and, possibly, take the advantage of the chemicals involved in them. If the environmental risks caused by chemicals in recovered wood are low enough, these materials can be used in civil engineering and earth structures, for instance, lightening component of crushed concrete, rock, or stone materials. Environmental problems caused by excavation of virgin mineral materials would also decrease to some extent. All this would be beneficial not only in terms of material properties and circular economy strategy but also in terms of logistics costs. Cost reduction is still the password that gets industries interested in new applications, systems, or methods.

Circular economy development will play an essential role in the wood modification businesses and their transformation along the anticipated systemic change. Specifically, the renewed EU waste legislation hints about economic incentives for manufacturers who provide markets with greener products and support material recovery and recycling schemes, making it clear that the evolving legislation not only requires measures to adopt to it, but offers also market opportunities for those willing to take the chance.

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