Cascading Wood-based Construction Products – A Guideline for Product Development

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Abstract. From an overall perspective, the circular use of wood-based construction products can significantly contribute to the mitigation of climate change. To support the development of specific circular wood-based construction products, a general guideline for wood product industry has been created in this research. The guideline is based on the principle of cascade use describing the sequential use of a wooden resource for different purposes before its final incineration for energy use. To enable cascade use, guidance is given on fostering the development of recyclable products as well as on the use of secondary materials in wood-based construction products.

1 General background and research question

Atmospheric carbon dioxide which has been captured in a tree due to photosynthesis before being harvested can be stored as biogenic carbon in wooden products until they are being burned or disposed at their end of life [1]. Hence, by a circular use of wooden resources due to their cascade use possibilities, biogenic carbon remains in the technosphere for a longer period of time resulting in lower environmental burdens [2]. To prevent negative climate impact a wooden resource has to be used until at least the equivalent amount of biogenic carbon has been recovered by the biosphere to compensate the carbon outtake [3, 4].

For wood-based construction products, based on the research of Sirkin, ten Houten [5] and Höglmeier [6], cascade use in this research is described as the sequential material use of a wooden resource in different construction products before energy recovery. Here the term "Wood-based construction products" includes not only products such as derived timber products like e.g. fibre boards but also products for construction purposes like e.g. solid timber beams. By the use of secondary instead of primary resources, the cascade use of wood can lead to the mitigation of climate change through prolonged biogenic carbon storage [7] and to the decrease in waste by avoiding final use for energy recovery or disposal [8]. Additionally, the secondary use reduces the harvesting of primary resources [7, 9] and can decrease emissions in wood-working production processes [9]. The saved raw wooden resources might then be used to substitute non-bio-based resources [8]. As research shows, final use as biogenic fuel [10] or the use of primary resources [2] might in some cases lead to lower ecologic impacts than a cascade use of a product. Husgafvel et al. [11] propose the

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application of life cycle assessment (LCA) to compare the environmental impacts of possible recovery processes for a solid wood product. LCA and Life cycle cost (LCC) of secondary construction solid wood into laminated timber products has been conducted by Risse et al. [12]. They concluded, that the environmental and economic impacts of a cascade use of solid wood into laminated timber are significantly lower compared to incineration at its end of life.

The carbon storage potential [2, 8], of using wooden construction products circularly as well as the potential to mitigate primary wooden resource use [7] shows the importance to enable the transition towards circular wood-based construction products in order to contribute to the mitigation of climate change. The necessity for a circular use of construction products is specified in the European Construction Product Regulation's (CPR) basic work requirement (BWR) 7a aiming to ensure "the reuse or recyclability of the construction works, their materials and parts after demolition" [13]. However, construction products are currently barely used in circles. Many producers in the wood-working industry perceive obstacles by complicated, expensive rules for health and safety [14] and additional rules for wood waste treatment that are fostering the energy use of secondary wood as biogenic fuel [10]. Under normal conditions wood hardly degrades and secondary wood almost has the same properties as fresh, primary wood, if its physical properties were not substantially damaged or influenced by the duration of load [15], excessive moisture or other infestation. Thus, the secondary use of wood is possible even for structural purposes [16]. Materials and products have to be intentionally technically designed to be reusable or at least cascaded.

To overcome such obstacles and to show technical, quantifiable principles and measures for the development of circular wood-based construction products, a guideline for cascading wood-based products has been developed in this article. This leads to the following research questions which should be answered by the guideline: (i) What concepts and criteria should be considered during the development of wood-based construction products to fulfil BWR 7a, (ii) which general principles have to be defined and applied to enable circular wooden resource use in construction products and (iii) how can a guideline, to develop circular wood-based construction products generally be approached?

2 Method – Creating a guideline for product development to enable cascading of wood-based construction products

The cascade use is often applied as general principle to describe the circular use of bio-based resources [10] and hence, it forms the basis for a guideline proposed in this research to develop and formulate circular wood-based construction products. According to Sirkin and ten Houten [5], to enable a cascade use, it is important to consider the design of circular products and the material selection for the composition or formulation of the product, influencing a wooden resource's circular use. Due to the definition and consideration of a general description of the cascade chain of wood-based construction products, this statement has been further investigated in this research.

To implement a guideline and thus, to ease the development of circular wood-based construction products, the framework of the guideline had to be determined. To ensure, that the guideline content is visualised in a comprehensive way, a general "communication sheet" for usability and user experience has been developed (see supplemental material [17]). Its appearance is based on a decision tree (see Fig. 1), aiming for a repeated use at an equivalent level or a cascade use at least at the highest level possible and avoiding incineration.

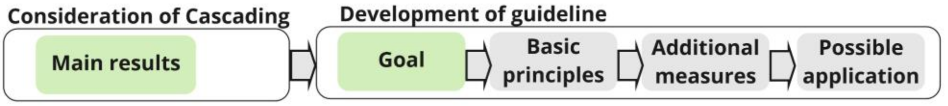

Fig. 1 Method – Creating a guideline for the development of circular wood-based products.

The guideline framework contains two goals as well as the applied principles (see Table 1) and measures to reach at least one of the goals. In addition, different application possibilities following the principles and measures should give practical examples (see Fig. 1). This guideline should enable the development of all kinds of circular wood-based construction products. Moreover, it should support to individually reflected decisions about a specific product and the requirements it has to fulfil from a material technological point of view.

Table 1. List of main cascading criteria for recyclability and secondary material use.

Recyclability of wood-based products and components	**Secondary material as resource for wood-based products**
Identifiable properties and composition of product	Technical quality (e.g. geometry, quantity, technical characteristics)
Low amount of non-bio or primary material	Limit value of contamination
Purity, separability of material or product	Same properties as primary material

3 Cascade chain of wood-based construction products

The guideline should be applied for different wood-based construction products. Thus, compared to the sectoral approach of Höglmeier [2, 6] a more general description of the chain is given (see Fig. 2).

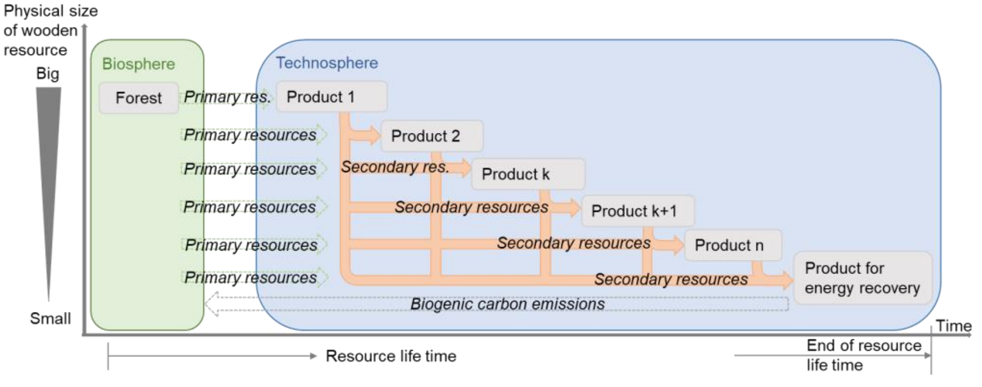

Fig. 2 Cascade use of wood-based construction products based on [5, 6].

In Fig. 2, the cascade steps (product 1, 2, ..n) are not further specified to make clear that the cascade use differs from one product use case to another. Equally to Höglmeier [6], physical size and the specific material properties diminish with every cascade step. Thus, recycling is part of the cascade chain. In contrast, a product's reuse is not part of the cascade chain, because it does not influence the resource’s size. In parallel, this leads to a decrease in utility, meaning that the ability to perform different functions with diverse requirements diminishes [5]. Looking at Fig. 2 and based on the findings of Sirkin, ten Houten [5], the use of secondary wooden resources coming from a wooden construction product within a new product has to be feasible in terms of technical requirements and functions. In addition, the product itself has to be technically designed in such way that it can be used in cascades. If one of these criteria is not fulfilled, this would interrupt cascade use, the resource would become waste and its typical final utilisation as biogenic fuel takes place, leading to the release of the material embedded biogenic carbon.

4 Communication sheets for the development of circular wood-based construction products

4.1 Development of Communication sheets

Based on the guideline framework and the consideration of the cascade chain, two communication sheets have been created for the development of circular wood-based construction products complying with BWR 7a (see [17]). The content and the application of the sheets are further explained in the following chapters.

4.2 Recyclability of wood-based construction products

The material formulation or the design of wood-based (construction) products influences the material quality, hence the product functionality in terms of strength, durability, weight, and cascadability [18]. Thus, based on literature findings [5, 19–23], principles to develop wood-based construction products have been defined for materials and components (see [17]).

Products or product parts are inevitably declared as waste according to the waste legislation when a product’s life cycle ends because a product owner wants to get rid of it [24]. For the cascade use, it has to overcome this theoretical (legislative) stage of waste and regain economic value [25]. The stage of waste can be overcome by taking measures following the waste hierarchy [26]. For recycling, a differentiation can be made between recycling (recovery for same (closed-loop) or different (open-loop) purposes) and downcycling (open-loop recovery with quality losses) [27].

4.3 Secondary materials as resource for wood-based construction products

To exploit the substitution potential of secondary wooden resources, the goal should be an increased use of secondary instead of primary material within wood-based construction products (see [17]). According to Höglmeier et al. [28], cascade use possibilities depend on the resource’s basic characteristics like corresponding product group, geometry, quantity and contamination. Standards for wood-based construction products show, that technical characteristics (moisture, mechanical strength, density etc.) are important for the utilisation of raw wood in new products. Thus, cascade possibilities also depend on secondary materials’ technical characteristics. To ensure sufficient quality of secondary materials, quality control is an important means, still showing improvement potential [10].

A secondary material should show the same properties as a substituted raw material does. If it shows minor quality, one measure could be to blend secondary with raw material to ensure the required quality [18, 29]. Moreover, to restore and remanufacture the quality or to adapt the material to the required properties, measures like e.g. drying, cutting, milling, planing [10] or decontamination processes [30] might be necessary. Further, to ensure the required quality of a secondary material used for specific wood-based construction products, "Producer Standards" like the European Panel Federation's Industry standard [31] might be useful to describe the required quality and thus to overcome obstacles of such secondary use.

4.4 Possibilities of secondary material use following cascade steps

To ensure the circular use of a wooden resource in different products, its further usage should be considered during product development [3]. Dependent on the principles and measures taken during the development, the possibilities for further cascade use differ. Hence, the guideline gives an overview of different cascade use possibilities for wood-based construction products dependent on the product groups shown by Höglmeier [4] (see [17]). Based on the specific product being developed, possible applications can be considered.

4.5 Application of the guideline

For its evaluation, the guideline has been applied to develop a foam-formed insulation product from BASAJAUN project, funded by the Horizon 2020 programme (see Fig. 4).

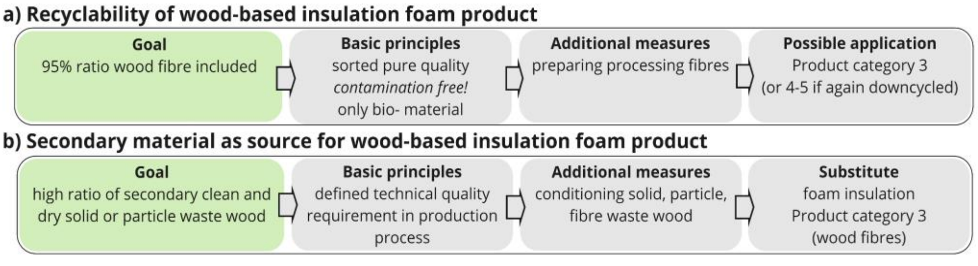

Fig. 3 Application of cascading criteria for (a) recyclability of foam-formed insulation product, (b) secondary material sourced for new foam-formed insulation product.

The goal was to develop an innovative, recyclable wood-based product (see Fig. 4a) containing mainly secondary resources. Applying the guideline showed that the basic principle to develop a contamination free product is not fulfilled, because chemical fire retardants (5%) contaminate the fibres, thus energy recovery is the most likely end of life scenario. To overcome this obstacle and in order to keep the foam's functional equivalent, the product could be taken back by the producer at its end of life for a closed-loop recycling process (reaching product category 3 (fibres) and circularity goal). To use secondary material as resource for insulation foam (see Fig. 4b), technical requirements have been defined for the resources. Dependent on the resource's properties, conditioning of the resource was necessary. Due to the application of the guideline, raw wood fibres for the insulation foam could be substituted by these secondary fibres (category 3 (wood fibres)).

5 Discussion and conclusion

In this research general principles were defined, enabling the development of circular wood-based construction products. As the considered cascade chain showed, to overcome obstacles of the industry for such a development and hence, the mitigation of climate change, it is crucial to ensure the product's recyclability and the use of secondary materials in the product. A guideline based on these influencing factors has been created to support the development of wood-based construction products. A first assessment of the guideline showed that the basic principles support to identify obstacles which might result in product category or in resource quality degradation. Producer responsibility is appreciated, but technical interventions to innovate products might be more fruitful to comply with circularity and to achieve functional requirements. To evaluate and increase its impact on product development, further research should be conducted by applying the guideline for specific product development scenarios. Besides supporting the development of circular wood-based construction products, it will additionally be necessary to adopt the guideline to other sectors or to cross-sectoral application. Further, Jarre et al. [18] state how challenging it is to assess and compare the environmental impacts a product has containing secondary instead of primary wooden resources. To generate comparable results, it will be necessary to analyse different end-of life scenarios for specific wood-based construction products based on a consistent approach.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 862942.