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ORIGINAL ARTICLE

Developing and evaluating strategies to increase the material utilisation rate of hardwoods: a hybrid policy Delphi-SWOT analysis

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Abstract
The indigenous hardwoods in German forests have a substantial ability to store carbon, and forestry reconstruction measures are anticipated to result in an increase in availability of hardwood on the wood market. Despite this, its material usage is declining with over two thirds of the harvested quantity being used for energy production. This study aims to identify policy measures and promising strategies for increasing hardwood utilisation using a combined policy Delphi-SWOT approach with literature review undertaken to identify the barriers and driving factors for an increase in its material use. The results were then ranked by a panel of experts and used as basis for the SWOT analysis, which was then applied to an extended SWOT approach. The resulting strategies were then discussed by the panel and ranked further in the 2nd and 3rd Delphi round. After three Delphi rounds, three strategies and associated policy recommendations were ranked as most effective by the experts: innovative hardwood products including manufacturing processes, research transfer and lobbying. This study provides both strategic analyses and effective strategies to stimulate the production of hardwood-based products and ends with a concise description of these strategies and policy recommendations, which are benchmarked against current literature and best practise examples.

1 Introduction

The European Green Deal aims to shape a circular bioeconomy since forest ecosystems are a key in reaching the goals of climate neutrality, sustainable products (EC 2019), and long carbon captures (Sillanpaä and Ncibi 2017). The material use of low-value forestry by-products achieves better economic and ecological results than the use for energy production (Lu and El Hanandeh 2019). Wood-based products "can provide additional carbon storage services and a substitution for carbon-intensive materials and fuels" (EC 2018). The climate mitigation potential of hardwood remains high since the direct energy utilisation from it is substantial (Weimar 2011; Mantau 2012; Bösch et al. 2015). The sustainable utilisation of wood is crucial in preparing the ground for resource-efficient, circular bioeconomy (FAO 2018) and mitigating climate change (Winkel 2017; Toppinen et al. 2020; EC 2019). Supporting companies and industries in the development of new products and production processes can strengthen the circular economy in the wood-based sector (Da Silva et al. 2020).

In Germany, indigenous hardwood forests have abundant wood supply potential, which is still increasing as a result of forest reconstruction (BMEL 2017). However, development of marketable hardwood products remains challenging (BMEL 2017), hardwood-based value-added products are still rare (Stängle et al. 2015; Kühle et al. 2019; Teischinger 2019d) and are not diffuse within the market. The Charter for Wood 2.0 (BMEL 2017) places great emphasis on the potential of value-added hardwood products (Purkus and Lüdtke 2020), but strategic analyses and development of effective strategies stimulating the production of hardwood-based products are still missing. They are, however, essential for the transition towards a wood-based bioeconomy (Purkus et al. 2018).

For strategy development, a few SWOT analyses (Rauch 2007, 2017; Rauch et al. 2015; Etongo et al. 2018) as well as SWOT-ANP analyses (Falcone 2019; Di Lallo et al. 2016) have already been conducted within the wood-based sector.

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However, Hurmekoski and Hetemäki (2013, p. 17) see "potential advantages in complementing the current modelling approach dominant in the forest sector" by Delphi combined with strategy development, evaluation and implementation. In a wood-based bioeconomic context, Delphi studies and SWOT analyses have been conducted highlighting different strategic topics, such as forest sector transformation towards a forest-based bioeconomy and its limitations, and future prospects for the forest energy industry (Pätäri et al. 2016; Pätäri 2010; Toppinen et al. 2017; Falcone et al. 2020; Brunnhofer et al. 2019; Hurmekoski et al. 2019). To improve the reliability and validity of the results it is worthwhile combining Delphi with other qualitative or quantitative methods (Turnbull et al. 2018; Hurmekoski and Hetemäki 2013). Complex challenges in forest management and multiple stakeholder interests require the application of more than one method in order to improve the strategic planning process (Pesonen et al. 2001; Di Lallo et al. 2016; Kajanus et al. 2012).

Therefore, a hybrid policy Delphi-SWOT study was applied to analyse the German hardwood sector from a strategic perspective, and to evaluate strategies facilitating the material use of hardwoods in order to identify promising strategies and the necessary policy measures.

2 Material and methods

A hybrid policy Delphi-SWOT methodology was considered suitable for capturing the complexity of a sector affected by the direct and indirect influences of political, economic, ecological and social factors (Loë et al. 2016; Turoff 2002).

SWOT (Strengths, Weakness, Opportunity, Threats) analysis was developed in the 1960s (Pesonen et al. 2001). It is a common and successful management tool for strategy development in the forestry and wood sector (e.g., Rauch 2007; Gerasimov and Karjalainen 2008; Rauch et al. 2015; Štěrbová et al. 2016). However, the isolated use of SWOT as strategic management tool casts some doubts on its effectiveness (Pesonen et al. 2001).

The Delphi method was introduced in the 1950s by the RAND Cooperation in cooperation with the U.S. Air Force. It is now used for forecasting and decision making in many disciplines (Rowe and Wright 1999; Okoli and Pawlowski 2004).

Delphi is applied during complex discussions to facilitate consensus among experts (Linstone and Turoff 2002) and takes the form of a survey conducted multiple times with revision options (Landeta 2006). Individuals are able to change or to adapt their opinion through the rounds based on feedback, without losing face in their peer group (Rowe and Wright 1999). Delphi fits to large groups of experts, who are geographically dispersed (Rowe and Wright 1999) and has been proven to be a sound method for the systematic investigation of complex situations where data is lacking (Toppinen et al. 2017). Since consensus, in the context of this paper, is not primarily needed, the Delphi process stops after obtaining sufficient information for the development of strategy and policy measures.

Figure 1 summarises the methodological approach combining SWOT and Delphi techniques that is described in depth in the following subchapters.

Since "online" is the best method of conducting a policy Delphi (Turoff 2002), this study followed the guidelines for conducting an e-Delphi (cf. Cole et al. 2013). Questionnaires were developed and pre-tested by persons not involved in the panel (cf. Delbecq et al. 1975).

2.1 Participant panel

Personal involvement, commitment of participants regarding the study´s topic and their motivation to be part of the study are significant for a study's success (Landeta 2006; Delbecq et al. 1975). Participants do not need to have expert knowledge in each topic of the Delphi study, since it is more desirable to combine various experts' opinions (Turoff 2002) to fully appreciate the scope of the hardwood supply chain (Rowe and Wright 2001). Thus, the participant panel was designed to be as heterogeneous as possible (Fig. 2) (Loë et al. 2016; Turoff 2002). Rowe and Wright (2001) argued that 5–20 people with heterogeneous backgrounds are reasonable, whereas Okoli and Pawlowski (2004) state 10–18 participants are required. Turoff (2002) however, considered approximately 10–50 people in each group as appropriate in policy Delphi studies.

Participant selection was basically carried out according to the Knowledge Resource Nomination Worksheet procedure (KRNW) (e.g., Brunnhofer et al. 2019; Delbecq et al. 1975; Okoli and Pawlowski 2004) as follows: preparation of the KRNW, population of the KRNW, nomination of additional people, ranking of participants, and invitation. In the first step, the groups (A) forestry, (B) industry, (C) governmental organisations (GO), NGOs, NPOs, and associations, and (D) research, were identified. In a second step, members of groups (A)–(C) were recruited based on internet research and personal/institutional contacts and ranked based on the following criteria: balanced demographics within the participant group and expert knowledge of producing and processing products together with the application possibilities of hardwood. Group (D) participants were identified by Google Scholar research, European and German project databases (http://www.cordis.europa.eu and http://www.foerderportal.bund.de) based on keyword searches (e.g., "material utilisation", "hardwood", and "wood"). Researchers fulfilling the selection criteria (research concerning hardwoods in forestry, in wood processing or development of wood-based

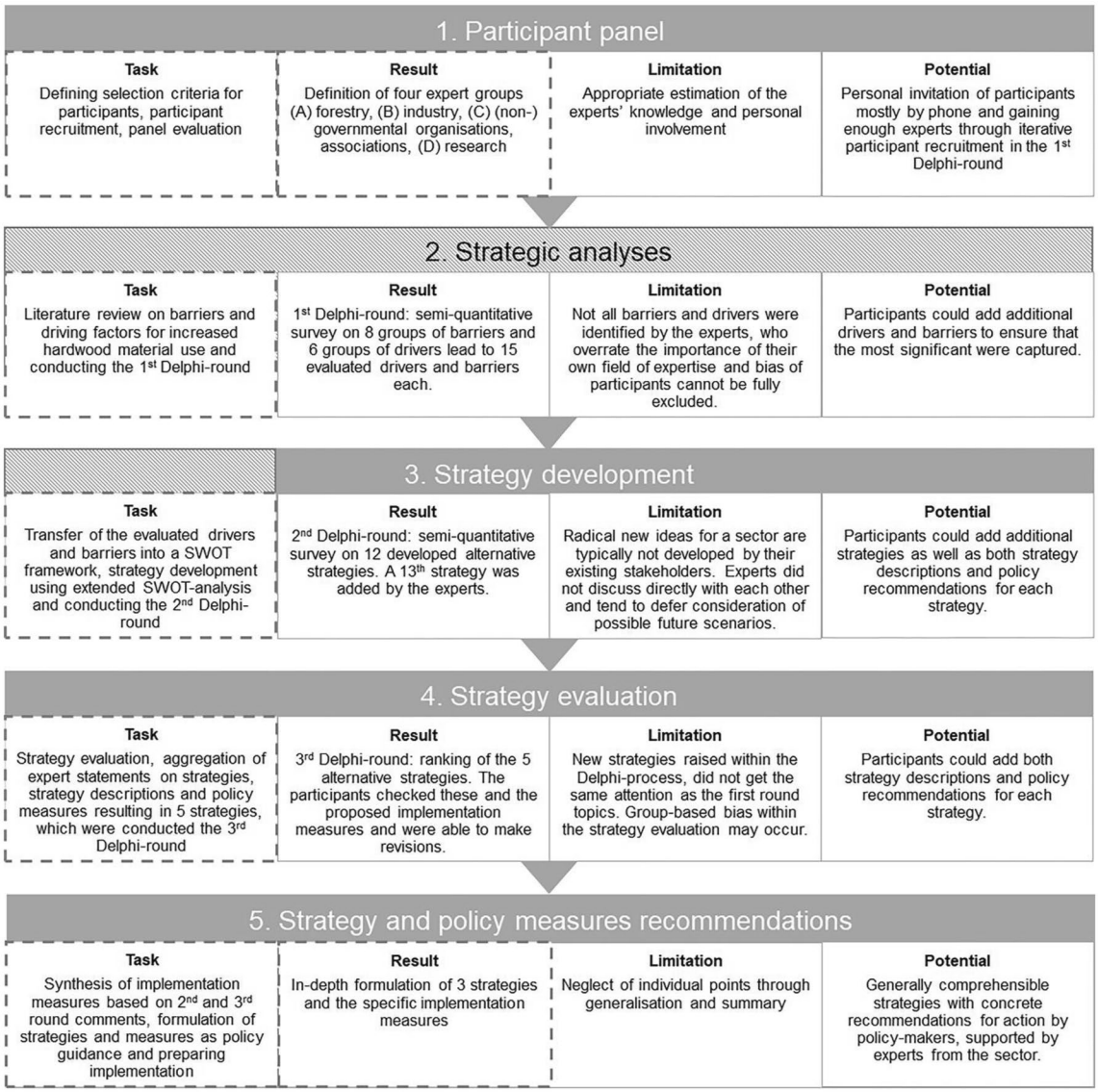

Fig. 1 Research design of the strategy development and evaluation (Delphi process = full grey shading, SWOT analysis = crosshatched grey shading, authors' contribution = dashed line frame)

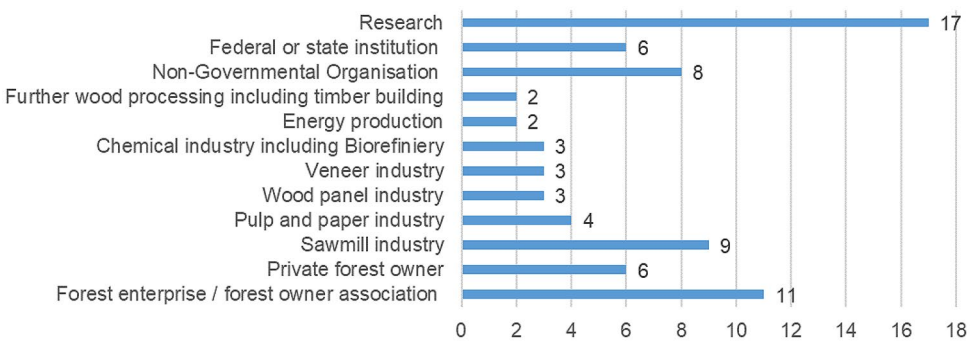

Fig. 2 Profession of participating experts (multiple answers possible)

product with at least a doctoral degree and working in Germany, Austria or Switzerland) were ranked according to the number of publications registered in Scopus (http://www.scopus.com).

As recommended by Delbecq et al. (1975), the first nine participants in the ranked group lists were contacted and invited to the online questionnaire. After approximately two weeks, the next nine people were invited. If the number of questionnaires answered per group reached a value between 10 and 18, the invitation process was stopped, otherwise more people were contacted.

Participants were handled in a quasi-anonymous way, as every person completing the questionnaire in the prior round was invited for the next round (cf. Haynes and Shelton 2018) using pseudonyms. The quasi-anonymous survey and pseudonym allocation were supported by the software QuestorPro.

2.2 Strategic analyses

To gain an overview of the barriers and driving factors influencing hardwood material utilisation, a literature review was conducted. From the results obtained (Tables 2 and 3), 26 drivers and 31 barrier statements were identified and delivered to the participant panel within the 1st Delphi round. Participants stated their opinion as to what extent a driver or barrier contributed to the increase in hardwood material use by applying a five-point Likert scale. Participants could add additional drivers and barriers to ensure that the main drivers and barriers were captured by the panel as required in a policy Delphi (Turoff 2002).

The 1st Delphi round took place during November and December 2019.

2.3 Strategy development

The SWOT-framework was applied since it aims to identify competitive advantages and the factors influencing strategy (Pickton and Wright 1998). SWOT factors were deduced from the ranked drivers and barriers of the 1st Delphi round by transferring them to internal strengths/weakness and external opportunities/threats of actual hardwood utilisation (Tables 4 and 5). Factors in each SWOT field were limited to maximal six (Lombriser and Abplanalp 2018) due to limited possibilities for strategy development.

To create strategies based on the SWOT analysis, the extended SWOT approach was applied. Logical strategy combinations concurrently maximizing strengths and opportunities or minimizing weaknesses and threats were scanned within the SWOT matrix. The following questions were used to identify strategies (Lombriser and Abplanalp 2018):

- Which strength fits to what opportunity (SO-combination)?
- Which strength fits to what threat (ST-combination)?
- Which weakness fits to what opportunity (WO-combination)?
- Which weakness fits to what threat (WT-combination)?

The potential SWOT combinations result in four generic strategy types:

1. SO-strategy: internal strength can be utilised in order to take an external opportunity (ideal case),
2. WO-strategy: internal weakness is reduced in order to realise an external chance,
3. ST-strategy: internal strength is used to reduce an external threat,
4. WT-strategy: internal weakness is reduced to mitigate external threat (worst case).

As suggested by Lombriser and Abplanalp (2018), for each strategy the underlying SWOT issues were listed accordingly applying the following nomenclature. For example, S1/O3 added next to the developed strategy means that this strategy mainly relates to the strength listed in the first position (#1) and opportunity listed in the third position (#3) on the SWOT table (cf. Rauch 2017).

The strategies thus developed were presented to the panel for evaluation and discussion within the 2nd Delphi round. Additionally, extended descriptions of the strategies as well as new strategies could be added.

The 2nd Delphi round took place between December 2019 and January 2020.

2.4 Strategy evaluation

In the 3rd Delphi round, participants checked the developed strategies and implementation measures. Afterwards, the panellists evaluated the strategies according to the following criteria: desirability (regarding efficiency and benefit), priority, feasibility, likelihood of implementation, and impact (cf. Turoff 2002), applying a five-point Likert scale.

Finally, panellists ranked alternative strategies with respect to their overall ability to increase the utilisation of hardwoods as an economically useful material. This procedure facilitated the estimation of impacts, consequences and acceptability of the strategies developed as required for a policy Delphi (Turoff 2002).

The 3rd Delphi round took place during February and March 2020.

2.5 Strategy and policy measures recommendations

Panellists commented on and added to the results of the 1st and 2nd Delphi rounds. In the 2nd and 3rd Delphi round, they gave their opinions on the strategies and measures created. Based on panellists' votes and comments after the 3rd Delphi round, the authors substantiated the specific

strategies and measures to provide policy guidance for implementation.

3 Results and discussion

3.1 Participants

56 people, of which 51 men (91%) and five women (9%), participated in the first Delphi round.

Table 1 shows the development of the number of participants of the three Delphi rounds.

Table 1 Number of participants of the three Delphi rounds clustered by participant groups

#	Group	1st round	2nd round	3rd round
A	Forestry	13	8	7
B	Industry	15	11	10
C	Association/ GO/NGO	13	12	11
D	Research	15	12	11
Sum		56	43	39

3.2 Drivers and barriers to increasing the material use of hardwoods

Literature review results were clustered, and drivers (Table 2) and barriers were extracted.

On the barrier side (Table 3), some conflicts must be considered: firstly, nature conversion approaches restrict wood harvesting and the increasing wood utilisation (Bolte et al. 2016a); secondly, competition for material versus energy use of the resource and for traditional versus new products (Bolte et al. 2016b).

Participants evaluated to what extent drivers and barriers contribute to the potential increase in hardwood material use. Table A1 and Table A2 in Supplementary Information list the 15 highest ranked issues.

3.3 SWOT and strategy development

Factors within the SWOT categories were ranked according to the ratings of 1st Delphi round (cf. Table A1 and Table A2). Factors O4 and T5 as 1st round comments were rated within the 2nd round. Thereupon, factor T5 was evaluated as the most significant threat (Table 4).

Applying the extended SWOT approach, 12 strategies to increase the hardwood material use were deduced (Table 5).

In the second Delphi round, the participants rated the strategies which had been developed (Table 6). Strategy

Table 2 Drivers for the material utilisation of hardwoods

Driver	Description	Sources
Development of new products	An innovative research and development environment fosters new product development. Initially, products were developed based on: small-diameter hardwood, the variety of special mechanical properties and the fibre properties of those hardwoods. Low-value forestry by-products are economically and ecologically superior to their use for energy production	Bolte et al. (2016a, b), Hetemäki et al. (2017), Luppold and Bumgardner (2003), Wolfslehner et al. (2013), Hassegawa et al. (2018), Lu and El Hanandeh (2019), Krackler et al. (2010), Patterson and Titmuss (1988), Butterfield (2006), Teischinger et al. (2019), UPM (2020)
Wood-based bioeconomy	Repurposing of pulp and paper mills into biorefineries, new chemical pathways for material utilisation	Roos (2016), Jungmeier et al. (2015), Hetemäki et al. (2017), Brunnhofer et al. (2019), NFP66 (2017), Krackler et al. (2010), Teischinger et al. (2019)
Resource potential	Hardwood is abundant and sufficiently available. Untapped wood potential in small scale forests, high industrial roundwood share, supply risks for softwoods, climate change induced transition to mixed (hardwood) forests	Bolte et al. (2016b), Schier et al. (2018), Wolfslehner et al. (2013), Teischinger et al. (2019)
Hardwood competence	Traditional forest management, hardwood processing competence, established mass to niche products	Bolte et al. (2016b), Buehlmann et al. (2010)
Public opinion	Positive image of wood, growing acceptance of green economy approaches, governmental willingness to mitigate climate change and foster sustainability (e.g., CO_2-taxes, subsidies, research projects, regulations)	Bolte et al. (2016b), Schier et al. (2018)
Sustainability	The use of hardwood improves resource and energy efficiency. Value added hardwood products create new jobs at local and regional level	Bolte et al. (2016b), Wolfslehner et al. (2013)

Table 3 Barriers for the material utilisation of hardwoods

Barrier	Description	Sources
Uncoordinated research	Lack of research resource concentration, and no content-related research cooperation	Bolte et al. (2016a), Teischinger (2019a)
Slow innovation	Lack of innovative hardwood products, low market acceptance, lack of standardization	BMEL (2017)
Missing process technology	Process adjustments to increase the material use of hardwoods are currently not profitable. Lack of technological knowledge regarding the processing of hardwood species	Wolfslehner et al. (2013)
Wood species specific properties	Dimension instability, difficult technical drying, short durability, difficult workability	Krackler et al. (2010), Patterson and Titmuss (1988), Teischinger (2019a)
Non-transparent material and information flows	Information deficits, complex interdependencies between stakeholders	Bolte et al. (2016b), Teischinger (2019b)
Supply chain challenges	Mixed hardwood forests provide only low quantities of certain hardwood species (e.g., ash, maple), demand oligopoly, high export volume of roundwood	Lenglet et al. (2017)
Risks	Seasonality of harvest, high share of private forest owners, extensive conservation of forest land, climate change impacts, long rotation lengths for hardwoods, deficit of qualified workforce	Polley et al. (2014), Rauch et al. (2015), Teischinger (2019c), Bolte et al. (2016b), Rauch (2017)
Use for energy production	Hardwood primarily used for energy production, especially within private households, subsidies for bioenergy production biasing markets, low cascade utilisation	Bolte et al. (2016a), Jochem et al. (2015), Mantau (2012), Weimar (2011)

Table 4 Strengths, weaknesses, opportunities and threats within material utilisation of hardwoods

Strengths	Weaknesses
S1 Traditional and qualified forest management	W1 Lack of knowledge, technology and coordination of research projects to develop a wide range of competitive hardwood product innovations
S2 Innovative research and development environment investigating hardwood products	W2 Domestic value added of hardwoods—especially for roundwood—and the number of cascades is low
S3 Hardwood suitable for material use is sufficiently available	W3 Technical process adjustments to increase the material use of hardwoods are not profitable
S4 High level of hardwood processing competence	W4 Forestry sector lacks economic sale options for hardwoods, which could be processed to products
	W5 Seasonality of hardwood supply and non-transparent material and information flows
Opportunities	**Threats**
O1 Hardwoods improve the sustainable performance of the wood value chain	T5 Low domestic demand for hardwood products (especially in the construction sector)
O2 Climate change promotes (mixed) hardwood forests	T1 Cheap fossil resources disadvantage wood-based biorefinery products
O3 Supply difficulties for coniferous woods	T2 Lack of national and international strategies to promote the material use of hardwoods
O4 Alternative energy production methods reduce the contribution of (hard) woods in bioenergy production	T3 Subsidies for bioenergy production distort the market price of hardwoods
	T4 Supply volatility due to external risks (e.g., calamities, enlargement of protected areas, lack of qualified workers)

Table 5 Developed SWOT strategies

#	Strategy	Type	Considered SWOT factors	Strategy's focus
1	Image campaign	SO	S1/S2/S3/S4/O1/T5	Image campaign for material wood use in general, for wood use and forest management as sustainable measures against climate change, and for the use of domestic hardwoods
2	Development of innovative hardwood products	SO	S2/S4/O1/O2/O3	Complexity of hardwoods (different assortments, low yield per tree with high crown wood content, low sawable wood content and high by-product content) requires a holistic approach that includes the development of manufacturing processes and products using as many assortments as possible materially
3	Substitution of softwoods	SO	S3/W1/O3	Development of innovative hardwood products to reduce the dependency on imported softwoods
4	National hardwood strategy	ST/WT	S1/S3/S4/T2, W1/W5/T2	An overarching programme with a holistic approach implementing supporting (1) policies and international research, (2) country-specific initiatives, and (3) guidelines for forest conversion based on a cooperative strategy development with representation of the interests of all stakeholders (forest, economy, ecology, research, society)
5	Vocational education and training system	ST	S1/T4	Targeted continuing vocational training for highly qualified workers
6	Substitution of tropical woods imports	ST	S1/T5	Substitution of imported and often not sustainably produced tropical hardwoods by eligible hardwoods from domestic, sustainable forestry
7	Supportive legal framework	ST /WT	S2/S4/T2/T5, W2/O4/T3, W2/T2	Implementation of standards and legislation (e.g., regulation on the compulsory return of waste wood, CO_2-dependent product taxation)
8	Research transfer	WO	W1/O1	Improve the flow of knowledge from research to manufacturing
9	Support for biorefineries	WO	W1/W2/W3/O4	Establishment of biorefineries for the use of small diameter hardwoods and for the production of bioenergy, biorefining enables an additional cascade use and increases the value added
10	Public Relations	WT	W2/T5	Setting up an intercompany and inter-organisational platform providing the public and specifiers (e.g., engineers, architects) with information about advantages of hardwood products
11	Process innovations	WT	W3/T5	Stimulating development of processing methods able to process different hardwoods, e.g., mixed hardwood pulp
12	Vertical cooperation	WT	W4/T4, W3/T5	Better connections between the forestry and wood industries would enable joint initiatives to pursue innovative paths (e.g., biorefineries)

descriptions and policy measures could be added by the participants.

Participants added strategy #13 Circular Economy in the 2nd Delphi round. This strategy aims at increasing the cascade of wood utilisation through greater use of waste

wood, in the sense of a closed loop economy, to raise the potential of biogenic resources.

3.4 Strategy evaluation

By analysing the extended strategy descriptions and comments of the participants, further aggregation of the strategies as a basis for the strategy evaluation within the 3rd Delphi round was possible (Table 7).

With reference to the four participating groups, four significant correlations were found in the evaluation of the five strategies (Table 8). Strategy #2 was rated by group (D) in the criterion "likelihood of implementation" significantly lower than the other three groups did. The other three significant correlations were identified for group (C) indicating that members of group (C) perceive their own core competence of lobbying for the interests of their members as very important and uprated appropriate strategies (e.g., support for targeted marketing of results, image campaigns).

Table 6 Evaluation results of the 2nd Delphi round for strategies to increase the material utilisation of hardwoods

Rank	#	Strategy	Mean value	Standard deviation	Aggregated to strategy
1	2	Development of innovative hardwood products	1.64	0.75	2*
2	8	Research transfer	1.72	0.58	
3	10	Public Relations	2.00	0.89	10*
4	6	Substitution of tropical woods imports	2.02	0.98	2*
5	12	Vertical cooperation	2.05	0.72	10*
6	4	National hardwood strategy	2.23	0.88	
7	9	Support for biorefineries	2.25	1.02	2*
8	5	Vocational education and training system	2.28	0.92	10*
9	7	Supportive legal framework	2.42	1.07	10*
10	1	Image campaign	2.46	0.97	10*
11	11	Process adaptations/optimisation	2.46	0.89	2*
12	3	Substitution of softwoods	2.64	1.09	2*

*Initial strategies were merged to a one aaggregated strategy

Table 7 3rd Delphi round evaluation of aggregated strategies to increase material utilisation of hardwoods

Rank	#	Strategy	Integrated strategies	Importance mean value	Importance standard deviation
1	2*	Innovative hardwood products including manufacturing processes	# 2, 3, 6, 9	1.8	0.99
2	8	Research transfer		3.0	1.11
3	10*	Lobbying	# 1, 5, 7, 10, 12	3.17	1.15
4	4	National hardwood strategy		3.51	1.48
5	13	Circular Economy		3.51	1.58

*Initial strategies were merged to a one aaggregated strategy

Table 8 Results of the statistical test on significant correlations in the evaluation of the five strategies

Strategy	Criterion	Group	Significance level ($p < 0.05$)	Mean value $\bar{x}$	Standard deviation s
#2*	Likelihood of implementation	(D)	0.03	3.18	0.75
		(A)–(C)		2.52	0.85
#8	Desirability (regarding efficiency/benefits)	(C)	0.02	1.18	0.4
		(A), (B), (D)		1.79	0.79
#10*	Desirability (regarding efficiency/benefits)	(C)	0.02	1.36	0.5
		(A), (B), (D)		2.11	0.96
#10*	Priority of implementation	(C)	0.02	1.45	0.69
		(A), (B), (D)		2.18	0.9

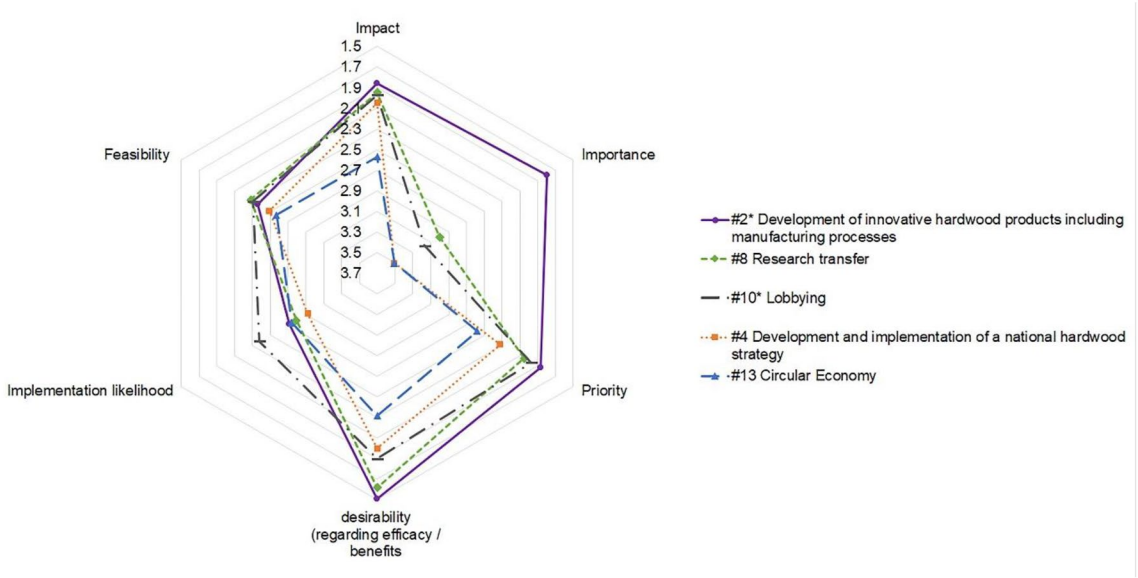

Fig. 3 Classification of strategies according to the criteria of desirability (regarding efficacy/benefit, importance, priority, feasibility, likelihood of implementation and impact on the increased material use of hardwoods

Figure 3 shows a comparative evaluation of the strategies according to the evaluation criteria.

3.5 Formulation of strategies and measures

In the following, a compilation of participants' comments and suggestions on the three best ranked strategies and their corresponding measures is provided for policy guidance to facilitate strategy implementation.

Strategy #2 innovative hardwood products including manufacturing processes* turned out to be the key strategy in increasing the material use of hardwood. Due to the wide range of product possibilities, intensive research and development of innovative, high value products (e.g., laminated veneer lumber, platform chemicals such as succinic acid or levulinic acid, composite materials, medical devices) is recommended by the experts. They also emphasis to develop new hardwood construction materials which are compatible with conventional manufacturing processes.

As was stated by an expert: "It is important to have a "whole tree utilisation concept"—i.e., the possibility of using as many assortments as possible—sawn/peeled wood—industrial wood—crown wood with a correspondingly good increase in value. Due to the enormous range of product possibilities the focus on a promising concept (with new products and applications) must not be lost."

One challenge identified by the experts was the high heterogeneity of hardwoods, and the currently low wood potential (e.g., maple, birch, ash,) compared to native softwood species has to be overcome to achieve economic product and process development and to create a critical demand quantity. Therefore, mixed hardwood pulp was suggested to be investigated more deeply. The experts described the following specific measures to implement strategy #2*:

- Providing information on the availability of hardwood species in the market to both the public and potential investors, an in-depth study of hardwoods' supply potential, classified by technology-specific assortments.
- Higher budgets for publicly funded research, development projects, promotion of young scientists in hardwood research and idea competitions are essential. The following research areas were identified as important by the experts
    - Solid wood production, material manufacturing sector up to biorefinery industry
    - Use of soft hardwoods (e.g., birch, poplar, alder)
    - Utilisation of the different properties of sapwood and heartwood
    - Material composites of softwoods and hardwoods
    - Development of technical processes for the utilisation of large logs
    - Modification processes to increase the natural durability of hardwoods
    - Development of hardwood applications within the building sector
- Overcome fragmentation of hardwood research by creating a freely accessible database incorporating publicly funded research projects on the use of hardwood in production.

Although *research transfer* (Strategy #8) is a standard requirement for publicly funded R&D projects, the experts believe that this transfer should be more effectively used in transferring research to companies. However, from a governmental perspective, experts suggested a reduction in the dependency of research on project-related third-party funding. The establishment of incentive systems based on, for example, the sustainability portfolio, full reusability business models, and regionally manufactured hardwood products (e.g., in public procurement) is recommended to promote the transfer of research results into industrial applications.

The experts described the following specific measures to implement strategy #8:

- Promoting knowledge transfer by integrating practitioners in research projects from an early stage on (e.g., as steering group) together with obligatory feasibility studies as a research funding criterion.
- Mandatory coupling of research and industry partners (team-up) in the case of public funding in applied and experimental research and promoting a practice-oriented research culture as well as a corporate culture with an affinity for research.
- Bridging the financing gap between the end of research projects and product market launch, offering support for micro-enterprises and start-ups to overcome the so-called "Valley of Death".
- Accelerating the marketing of results to specific interest groups, to lower the inhibition threshold for the purchase of hardwood products and creating market incentives.

Strategy #10 lobbying* aims at joint initiatives by the forestry and the timber industry to pursue innovative utilisation paths (e.g., biorefineries). Therefore, the experts identified three main fields of lobbying activities:

1. A carbon tax on products based on product life cycle assessments to promote short distances and regional production. An accredited certification scheme for the implementation of measures has to be developed in cooperation with all relevant institutions based on standardised data and compensatory measures.
2. Promotion of the use of wood in construction to overcome discrimination of wood as a building material compared to other building materials, particularly in legal standards. Timber construction acts as a long-term carbon-store. New taxation schemes must be accompanied by its legal adoption of (federal states) building regulations as well as model building codes and standards to promote the use of high-quality hardwood, especially for load-bearing purposes.
3. Marketing of results to specific interest groups to lower the inhibition threshold for the purchase of hardwood products and to create market incentives.

The experts described the following specific measures to implement strategy #10*:

- Establishment of coordination offices (e.g., support for the implementation of hardwood in construction projects, recommendation by experts, and support of forest owners).
- Funding of a platform to build up a hardwood supportive network.
- Target group-specific networking, for example promotion of hardwood to architects in education and training, trade fairs, the public; promotion of wood-based (platform) chemicals.
- Campaign for the use of wood as a material in general, pointing out the advantages compared to for example steel and plastics and for wood use and forest management as sustainable measures against climate change.
- Promotion of business models aiming at full reusability through appropriate pricing/subsidy incentives.
- Regulations to increase the use of regionally produced and manufactured hardwood products in public procurement (construction, interior design, office furniture, equipment, uniforms, etc.) as a model and positive example for society.

3.6 Discussion

3.6.1 Discussion of developed strategies and measures

Study results point out that to increase hardwood material use, new products have to be developed (strategy #2*) and for some already developed product prototypes, the innovation process of transferring research results into industry production is missing and has to be supported (strategy #8). Furthermore, both strategies need a coordinated and supportive network of research, industry and policies as recommended by the panel experts in strategy #10*.

Implementing strategy #2* the portfolio of wood-based products is anticipated to expand further in the future (Hurmekoski et al. 2019; Buehlmann et al. 2010; Temmes and Peck 2020) and higher value-added hardwood products research is seen as a promising pathway to convert higher proportions of wood into longer-life products (Temmes and Peck 2020).

For Switzerland, options for a higher utilisation of domestic hardwoods are accepted within the building industry where specific norms and approvals were, as with this study, recognised as barriers. Existing norms are also seen as major barrier in the panel and chemical industry (Krackler et al.

2010; NFP66 2017). Similarly, in the US, laminated veneer lumber (LVL), pulp and wood panels are seen as utilisation possibilities for low-quality hardwood (Luppold and Bumgardner 2003). The need to develop innovative hardwood products (cf. strategy #2*) has been noted in France, where the abundance of hardwood resources is not fully utilized (Lenglet et al. 2017). Wolfslehner et al. (2013) showed positive effects of a higher material utilisation rate for small-diameter hardwoods on both value added and sustainable regional development in Lower Austria. For Canada, it was shown that low-quality hardwood assortments offer a serious potential for adding further value to the wood value chain by the production of high value-added products, for example betulin (Hassegawa et al. 2018). Strategies such as widening the range of products or supplying certified products were identified as ways to transform the US hardwood mass market to a more diversified niche market (Buehlmann et al. 2010). This is mostly in line with the herein suggested future hardwood utilisations.

In line with findings for Italy, France and Austria (Falcone et al. 2020; Lenglet et al. 2017; Wolfslehner et al. 2013), reliable information regarding hardwood supply potential was seen as essential for the development of innovative hardwood products by the German experts involved in the Delphi study.

Confirming the study´s results, hybrid products using low-quality hardwood such as mixed hardwood LVL (McGavin et al. 2019; Nguyen et al. 2020, 2019), innovative mixed-hardwood pulp (Olsson et al. 2019), and mixed soft- and hardwood pulp (Fišerová et al. 2019) are actually under investigation.

New fields for the application of hardwoods are driven by the sustainability and climate mitigation debate. For example, the application of various hardwood-based materials in the automotive sector (e.g. Müller et al. 2019; FNR 2020) has the potential to become a mass volume market but is only currently considered as research topic. Therefore, research transfer strategies (strategy #8) are required in order to accelerate innovation.

Pushing research transfer (strategy #8) as recommended by the experts in the Delphi study requires mutually respected information policy between academic research and industry to avoid over-engineering by academics or an untimely early focus on techno-economic benefits by companies. Successful innovation requires the integration of different stakeholders and balanced information policies (Lettner et al. 2020).

As described in strategy #10* support for networks and cooperation is strongly recommended overcoming cross-sectoral cooperation barriers. It is essential to both strengthening wood-based bioeconomy projects (Hedeler et al. 2020; Lettner et al. 2020) and raise capital for large-scale cooperative efforts (Hedeler et al. 2020). Systems assessing environmental and social aspects have to be developed to initiate fiscal measures that adjust the market mechanisms supporting bioproducts and their production systems (Stafford et al. 2020). Therefore, carbon tax on products, is a measure recommended by the Delphi experts, as an appropriate policy instrument to ensure sustainable production on a global level (Aldieri et al. 2019; Aryapratama and Pauliuk 2019).

In line with the results of this study and the policy measures recommended, public procurement is seen as a motor for promoting multi-story wood-based constructions like Wildspitze in Hamburg (Germany), wooden high-rise (HoHo) of Vienna (Austria), Canada Earth Tower in Vancouver (Canada) (all three timber hybrid construction methods) or the highest wooden high-rise Mjøstårnet in Brumunddal (Norway).

The experts emphasised the requirement of research funds for product development and innovation transfer. Consequently, it may be worthwhile investigating the possibility of green finance for this purpose.

Strategies #2*, 8, 10* and 4 are in line with the recommendations on potential development for hardwoods by Knauf and Frühwald (2020) such as: building up industrial manufacturing capacities with optimized processes, a joint professional industry marketing for hardwood in both the forestry and wood industries and research funding for reducing barriers to the use of hardwood. This and the Knauf and Frühwald (2020) study reached similar conclusions but utilized slightly different methodical approaches. The policy measures identified herein contribute to the range of policies promoting bio-based products as considered in the European Green Deal (EC 2019) and as formulated by Ladu et al. (2020): climate mitigation combined with sustainable forest management (referred strategies #2*, 4, 10* and 13), and R&D policies (referred strategies #2* and 8), and awareness raising (referred strategy #10).

3.6.2 Reflections on the study design and future needs

A potential limitation of the study is the decreasing number of participants in the later Delphi rounds. Even though the panel was compiled very carefully, the bias of the participants cannot be fully excluded. However, we considered it important to form a relatively large panel composed of people with solid, relevant expertise (starting with > 50 people). The policy Delphi was conducted in three rounds, and new strategies were raised within the Delphi process (e.g., strategy #13). However, these did not get the same attention as the first-round topics. Although this is a well-known disadvantage for Delphi studies in general (Turoff 2002), it had negligible impact in this case.

Further well-known limitations of expert studies applying to this study are overrating the importance of one's own field of expertise and the fact that radical new ideas for a

sector are typically not developed by their existing stakeholders (Egfjord and Sund 2020). An example is the limited adoption of biorefinery technologies by pulp and paper incumbents, which seems to result from a lack of the competencies and partnerships required for this as well as a preference for improving the existing technologies. (Hansen and Coenen 2017). Even though wood-based biorefineries have the potential to use almost all wood components as a base material (textiles, nanocellulose, composites, lignin-based binders, chemical building blocks) (Stafford et al. 2020), such innovative products were only partly considered by the expert survey.

Another disadvantage of the passive Delphi method is that experts do not discuss directly with each other (Mendoza and Martins 2006) and tend to defer consideration of possible future scenarios, for example bioenergy market development and climate change impacts (Hurmekoski et al. 2019). Accordingly, in the first Delphi round, the utilisation of hardwood as fuel was strongly emphasised as a barrier to higher material utilisation, but in the final strategies, energy production based on hardwoods was disregarded.

Another limitation is that panellists were only from German speaking regions restricting the generalisation of findings to a global level. Opening up the focus for example, to the main hardwood countries in Europe (e.g., Slovenia, Romania, France, Poland) could be a topic of future research.

Furthermore, gaining a deeper understanding of causality and system dynamics within a hardwood-based circular economy (cf. path dependency of key factors, e.g., forest ownership, forest management, policy framework (Hurmekoski et al. 2019)) is highly recommended as a topic for future research.

4 Conclusion

This paper is focused on the strategies needed to stimulate the material use of hardwood in the whole sector of the forestry and wood industries. To sufficiently support product innovation as the most important strategy, a coordinated interaction of several other strategies is recommended. As an example, a national hardwood strategy would provide a supportive funding and policy environment as well as the need for changes at the highest level. With this, the hardwood sector would be eligible for attractive alternative financing schemes, such as Green Finance. Developing innovative products and associated production technologies are most important and so, research and innovation transfer must be continuously improved.

This study scrutinized shareholder perceptions to strategic analyses and development of effective strategies to stimulate the production of hardwood-based products. Results obtained and policy recommendations derived affirm the objectives of the Charter for Wood 2.0 regarding the necessity of promoting the production of hardwood products and increase its material use.

The three strategies developed herein and their associated policy recommendations were selected by expert ranking after three Delphi rounds. These were: innovative hardwood products including manufacturing processes, research and innovation transfer, and lobbying. This substantially extends the Charter of Wood 2.0's approaches regarding hardwood valorisation.

This study ends with a short and concise description of strategies and policy measures benchmarked against current literature and best practise examples. The applied hybrid policy Delphi-SWOT approach proved to be adequate for strategy development and evaluation at an industry sector level.

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Availability of data and material The anonymised data that support the findings of this study are available on request from the corresponding author Veronika Auer. The data are not publicly available since they contain information that could compromise research participant consent.

Declarations

Conflict of interest The author declares that there is no competing interest.

References

Aldieri L, Carlucci F, Vinci CP et al (2019) Environmental innovation, knowledge spillovers and policy implications: a systematic review of the economic effects literature. J Clean Prod 239:118051. https://doi.org/10.1016/j.jclepro.2019.118051

Aryapratama R, Pauliuk S (2019) Estimating in-use wood-based materials carbon stocks in Indonesia: towards a contribution to the national climate mitigation effort. Resour Conserv Recycl 149:301–311. https://doi.org/10.1016/j.resconrec.2019.06.010

BMEL (2017) Mitigating climate change. Creating value. Utilising resources efficiently. Charter for Wood 2.0. Federal Ministry of Food and Agriculture (BMEL) (ed), Bonn

Bolte A, Börner J, Bräsicke N et al (2016a) Holz in der Bioökonomie—Chancen und Grenzen [Wood in the bio-economy—opportunities and limits]. Bioökonomierat (ed). Accessed 8 Mar 2017

Bolte A, Börner J, Bräsike N et al (2016b) Perspektiven der Forst- und Holzwirtschaft in Deutschland [Prospects for the forestry and timber industry in Germany]. Bioökonomierat (ed)

Bösch M, Jochem D, Weimar H et al (2015) Physical input-output accounting of the wood and paper flow in Germany. Resour Conserv Recycl 94:99–109. https://doi.org/10.1016/j.resconrec.2014.11.014

Brunnhofer M, Gabriella N, Schöggl J-P et al (2019) The biorefinery transition in the European pulp and paper industry—a three-phase Delphi study including a SWOT-AHP analysis. Forest Policy Econ. https://doi.org/10.1016/j.forpol.2019.02.006

Buehlmann U, Espinoza O, Bumgardner M et al (2010) Trends in the US Hardwood Lumber distribution industry: changing products, customers, and services. For Prod J 60:547–553

Butterfield BG (2006) The structure of wood: overview. In: Walker JCF (ed) Primary wood processing. Principles and practice, 2nd edn. Springer, Dordrecht, pp 1–22

Cole ZD, Donohoe HM, Stellefson ML (2013) Internet-based Delphi research: case based discussion. J Environ Manage 51:511–523. https://doi.org/10.1007/s00267-012-0005-5

Da Silva FA, Simioni FJ, Hoff DN (2020) Diagnosis of circular economy in the forest sector in southern Brazil. Sci Total Environ 706:135973. https://doi.org/10.1016/j.scitotenv.2019.135973

de Loë RC, Melnychuk N, Murray D et al (2016) Advancing the state of policy Delphi practice: a systematic review evaluating methodological evolution, innovation, and opportunities. Technol Forecast Soc Change 104:78–88. https://doi.org/10.1016/j.techfore.2015.12.009

Delbecq AL, van de Ven AH, Gustafson DH (1975) Group techniques for program planning. A guide to nominal group and Delphi processes. Scott, Foresman and Company, Glenview

Di Lallo G, Maesano M, Masiero M et al (2016) Analyzing strategies to enhance small and low intensity managed forests certification in Europe using SWOT-ANP. Small-Scale for 15:393–411. https://doi.org/10.1007/s11842-016-9329-y

EC (2018) Guidance on cascading use of biomass with selected good practice examples on woody biomass. European Commission, Brussels

EC (2019) The European Green Deal. Communication from the commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the regions. European Commission, Brussels

Egfjord KF-H, Sund KJ (2020) Do you see what I see? How differing perceptions of the environment can hinder radical business model innovation. Technol Forecast Soc Change 150:119787. https://doi.org/10.1016/j.techfore.2019.119787

Etongo D, Kanninen M, Epule TE et al (2018) Assessing the effectiveness of joint forest management in Southern Burkina Faso: a SWOT-AHP analysis. Forest Policy Econ 90:31–38. https://doi.org/10.1016/j.forpol.2018.01.008

Falcone PM (2019) Tourism-based circular economy in Salento (South Italy): a SWOT-ANP analysis. Soc Sci 8:216. https://doi.org/10.3390/socsci8070216

Falcone PM, Tani A, Tartiu VE et al (2020) Towards a sustainable forest-based bioeconomy in Italy: findings from a SWOT analysis. Forest Policy Econ 110:101910. https://doi.org/10.1016/j.forpol.2019.04.014

FAO (2018) State of the world's forests. Forests pathways to sustainable development. FAO, Rome

Fišerová M, Gigac J, Stankovská M et al (2019) Influence of bleached softwood and hardwood kraft pulps on tissue paper properties. Cell Chem Technol 53:469–477. https://doi.org/10.35812/CelluloseChemTechnol.2019.53.47

FNR (2020) Verbundvorhaben: Holzbasierte Werkstoffe im Maschinenbau (HoMaba) [Joint research project: Wood-based materials in mechanical engineering (HoMaba)]. https://www.fnr.de/index.php?id=11148#trefferliste. Accessed 3 May 2020

Gerasimov Y, Karjalainen T (2008) Development program for improving wood procurement in Northwest Russia based on SWOT analysis. Balt for 14:87–92

Hansen T, Coenen L (2017) Unpacking resource mobilisation by incumbents for biorefineries: the role of micro-level factors for technological innovation system weaknesses. Technol Anal Strateg Manag 29:500–513. https://doi.org/10.1080/09537325.2016.1249838

Hassegawa M, Gélinas N, Beaudoin D et al (2018) Assessing the potential impact of a biorefinery product from sawmill residues on the profitability of a hardwood value chain. Can J for Res 48:857–868. https://doi.org/10.1139/cjfr-2017-0457

Haynes CA, Shelton K (2018) Delphi method in a digital age: practical considerations for online Delphi studies. In: Wang VCX, Reio TG (eds) Handbook of research on innovative techniques, trends, and analysis for optimized research methods. IGI Global, Hershey

Hedeler B, Lettner M, Stern T et al (2020) Strategic decisions on knowledge development and diffusion at pilot and demonstration projects: an empirical mapping of actors, projects and strategies in the case of circular forest bioeconomy. For Policy Econ. https://doi.org/10.1016/j.forpol.2019.102027

Hetemäki L, Hanewinkel M, Muys B et al (2017) Leading the way to a European circular bioeconomy strategy. From Science to Policy 5, European Forest Institute. https://doi.org/10.36333/fs05

Hurmekoski E, Hetemäki L (2013) Studying the future of the forest sector: review and implications for long-term outlook studies. For Policy Econ 34:17–29. https://doi.org/10.1016/j.forpol.2013.05.005

Hurmekoski E, Lovrić M, Lovrić N et al (2019) Frontiers of the forest-based bioeconomy—a European Delphi study. For Policy Econ 102:86–99. https://doi.org/10.1016/j.forpol.2019.03.008

Jochem D, Weimar H, Bösch M et al (2015) Estimation of wood removals and fellings in Germany. A calculation approach based on the amount of used roundwood. Eur J for Res 134:869–888. https://doi.org/10.1007/s10342-015-0896-9

Jungmeier G, Van Ree R, Jong Ed et al (2015) The »Biorefinery Fact Sheet« and its Application to Wood Based Biorefining. Case Studies of IEA Bioenergy Task 42 »Biorefining«, IEA Bioenergy—Task 42 Biorefinery. https://www.iea-bioenergy.task42-biorefineries.com/upload_mm/5/e/b/dc3a42c3-eea3-45b2-b3b7-0132dff16f6c_B5_Template_Proceedings_NWBC_2015_Jungmeier%20201507 31a.pdf

Kajanus M, Leskinen P, Kurttila M et al (2012) Making use of MCDS methods in SWOT analysis—lessons learnt in strategic natural resources management. For Policy Econ 20:1–9. https://doi.org/10.1016/j.forpol.2012.03.005

Knauf M, Frühwald A (2020) Broschüre Laubholz-Produktmärkte aus technisch-wirtschaftlicher und marktstruktureller Sicht [Brochure Hardwood Product Markets from a Technical-Economic and Market Structure Perspective]. FNR (ed). https://www.fnr.de/fileadmin/allgemein/pdf/broschueren/Brosch_LauholzProduktmaerkte_WEB.pdf. Accessed 21 May 2021

Krackler V, Keunecke D, Niemz P (2010) Verarbeitung und Verwendungsmöglichkeiten von Laubholz und Laubholzresten [Processing and uses of hardwood and hardwood residues]. Rep ETH Zürich. https://doi.org/10.3929/ethz-a-006113078

Kühle S, Teischinger A, Gronalt M (2019) Business approach for hardwood. Connecting product design, process, and technology decisions to strengthen the solid hardwood business with a multi-step Quality Function Deployment approach. BioResources 14:2229–2255. https://doi.org/10.15376/biores.14.1.2229-2255

Ladu L, Imbert E, Quitzow R et al (2020) The role of the policy mix in the transition toward a circular forest bioeconomy. For Policy Econ 110:101937. https://doi.org/10.1016/j.forpol.2019.05.023

Landeta J (2006) Current validity of the Delphi method in social sciences. Technol Forecast Soc Change 73:467–482. https://doi.org/10.1016/j.techfore.2005.09.002

Lenglet J, Courtonne J-Y, Caurla S (2017) Material flow analysis of the forest-wood supply chain: a consequential approach for log export policies in France. J Clean Prod 165:1296–1305. https://doi.org/10.1016/j.jclepro.2017.07.177

Lettner M, Hesser F, Hedeler B et al (2020) Barriers and incentives for the use of lignin-based resins: results of a comparative importance performance analysis. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.120520

Linstone HA, Turoff M (2002) The Delphi method: techniques and applications. Linstone, HA, Turoff, M (eds). Newmark, New Jersey

Lombriser R, Abplanalp PA (2018) Strategisches Management: Visionen entwickeln, Erfolgspotenziale aufbauen, Strategien umsetzen [Strategic management: developing visions, building up success potential, implementing strategies], 7th edn. Versus, Zürich

Lu HR, El Hanandeh A (2019) Energy conversion vs structural products: a novel multi-objective multi-period linear optimisation with application to the Australian hardwood plantation thinned logs. J Clean Prod 224:614–625. https://doi.org/10.1016/j.jclepro.2019.03.222

Luppold W, Bumgardner M (2003) What is low-value and/or low-grade hardwood? For Prod J 53:54–59

Mantau U (2012) Holzrohstoffbilanz Deutschland: Entwicklungen und Szenarien des Holzaufkommens und der Holzverwendung von 1987 bis 2015 [Wood balance Germany: developments and scenarios of wood supply and wood use from 1987 to 2015], Hamburg. Accessed 3 Feb 2016

McGavin RL, Nguyen HH, Gilbert BP et al (2019) A comparative study on the mechanical properties of Laminated Veneer Lumber (LVL) produced from blending various wood veneers. BioResources 14:9064–9081

Mendoza GA, Martins H (2006) Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. For Ecol Manag 230:1–22. https://doi.org/10.1016/j.foreco.2006.03.023

Müller U, Jost T, Kurzböck C et al (2019) Crash simulation of wood and composite wood for future automotive engineering. Wood Mater Sci Eng 15(5):312–324. https://doi.org/10.1080/17480272.2019.1665581

NFP66 (2017) Programmresümee des Nationalen Forschungsprogramms NFP66 «Ressource Holz» [Programme Summary of the National Research Programme NRP66 "Wood Resource"], Leitungsgruppe NFP66 Schweizerischer Nationalfonds, Bern

Nguyen HH, Gilbert BP, McGavin RL et al (2019) Optimisation of cross-banded laminated veneer lumbers manufactured from blending hardwood and softwood veneers. Eur J Wood Prod 77:783–797. https://doi.org/10.1007/s00107-019-01434-7

Nguyen HH, Gilbert BP, McGavin RL et al (2020) Embedment strength of mixed-species laminated veneer lumbers and cross-banded laminated veneer lumbers. Eur J Wood Prod 78:365–386. https://doi.org/10.1007/s00107-020-01504-1

Okoli C, Pawlowski SD (2004) The Delphi method as a research tool: an example, design considerations and applications. J Inf Manag 42:15–29. https://doi.org/10.1016/j.im.2003.11.002

Olsson J, Novy V, Nielsen F et al (2019) Sequential fractionation of the lignocellulosic components in hardwood based on steam explosion and hydrotropic extraction. Biotechnol Biofuels. https://doi.org/10.1186/s13068-018-1346-y

Pätäri S (2010) Industry- and company-level factors influencing the development of the forest energy business—insights from a Delphi Study. Technol Forecast Soc Change 77:94–109. https://doi.org/10.1016/j.techfore.2009.06.004

Pätäri S, Tuppura A, Toppinen A et al (2016) Global sustainability megaforces in shaping the future of the European pulp and paper industry towards a bioeconomy. For Policy Econ 66:38–46. https://doi.org/10.1016/j.forpol.2015.10.009

Patterson D, Titmuss FH (1988) Commercial timbers of the world, 5th edn. Gower Technical Pr, Aldershot

Pesonen M, Kurttila M, Kangas J et al (2001) Assessing the priorities using A'WOT among resource management strategies at the Finnish forest and park service. For Sci 47:534–541

Pickton DW, Wright S (1998) What's swot in strategic analysis? Strat. Change 7:101–109. https://doi.org/10.1002/(SICI)1099-1697(199803/04)7:2%3c101::AID-JSC332%3e3.0.CO;2-6

Polley H, Hennig P, Kroiher F et al (2014) Der Wald in Deutschland: Ausgewählte Ergebnisse der dritten Bundeswaldinventur [The Forest in Germany: Selected Results of the Third Federal Forest Inventory]. Bundesministerium für Ernährung und Landwirtschaft (BMEL)

Purkus A, Lüdtke J (2020) A systemic evaluation framework for a multi-actor, forest-based bioeconomy governance process: the German Charter for Wood 2.0 as a case study. Forest Policy Econ. https://doi.org/10.1016/j.forpol.2020.102113

Purkus A, Hagemann N, Bedtke N et al (2018) Towards a sustainable innovation system for the German wood-based bioeconomy: implications for policy design. J Clean Prod 172:3955–3968. https://doi.org/10.1016/j.jclepro.2017.04.146

Rauch P (2007) SWOT analyses and SWOT strategy formulation for forest owner cooperations in Austria. Eur J for Res 126:413–420. https://doi.org/10.1007/s10342-006-0162-2

Rauch P (2017) Developing and evaluating strategies to overcome biomass supply risks. Renew Energy 103:561–569. https://doi.org/10.1016/j.renene.2016.11.060

Rauch P, Wolfsmayr UJ, Borz SA et al (2015) SWOT analysis and strategy development for forest fuel supply chains in South East Europe. For Policy Econ 61:87–94. https://doi.org/10.1016/j.forpol.2015.09.003

Roos A (2016) Business—bioproducts in the bioeconomy. In: Kutnar A, Muthu SS (eds) Environmental impacts of traditional and innovative forest-based bioproducts. Springer, Singapore, pp 205–226

Rowe G, Wright G (1999) The Delphi technique as a forecasting tool: issues and analysis. Int J Forecast 15:353–375

Rowe G, Wright G (2001) Expert opinions in forecasting: the role of the Delphi technique. In: Armstrong JS (ed) Principles of forecasting: a handbook for researchers and practitioners (International series in operations research & management science). Springer, US, pp 125–144. https://doi.org/10.1007/978-0-306-47630-3

Schier F, Morland C, Janzen N et al (2018) Impacts of changing coniferous and non-coniferous wood supply on forest product markets. A German scenario case study. Eur J for Res 137:279–300. https://doi.org/10.1007/s10342-018-1111-6

Sillanpaä M, Ncibi C (2017) A sustainable bioeconomy: the green industrial revolution. Springer, Cham

Stafford W, de Lange W, Nahman A et al (2020) Forestry biorefineries. Renew Energy 154:461–475. https://doi.org/10.1016/j.renene.2020.02.002

Stängle SM, Brüchert F, Heikkila A et al (2015) Potentially increased sawmill yield from hardwoods using X-ray computed tomography for knot detection. Ann for Sci 72:57–65. https://doi.org/10.1007/s13595-014-0385-1

Štěrbová M, Loučanová E, Paluš H et al (2016) Innovation strategy in Slovak forest contractor firms—a SWOT analysis. Forests 7:118. https://doi.org/10.3390/f7060118

Teischinger A (2019a) Herausforderungen Laubholz - Laubholzinitiativen und Projekte in Europa [Hardwood challenges—Hardwood initiatives and projects in Europe]. In: Teischinger A (ed) Zur Laubholzfrage Österreich: Eine Zusammenstellung aktueller Entwicklungen und Aktivitäten in Österreich und im benachbarten Ausland [The Austrian hardwood issue: A summary of current developments and activities in Austria and neighbouring countries], LIGNOVISIONEN, 34, 74. Universität für Bodenkultur Wien, Wien. ISBN: 1681-2808

Teischinger A (2019b) World Café zum Thema Laubholz [World Café on the subject of hardwoods]. In: Teischinger A (ed) Zur Laubholzfrage Österreich: Eine Zusammenstellung aktueller Entwicklungen und Aktivitäten in Österreich und im benachbarten Ausland [The Austrian hardwood issue: A summary of current developments and activities in Austria and neighbouring countries], LIGNOVISIONEN, 34, 74. Universität für Bodenkultur Wien, Wien. ISBN:1681-2808

Teischinger A (2019c) Zukunftsforumholz 2018: Entwicklungen Laubholz—Was ist wrklich dran? [Zukunftsforumholz 2018: Hardwood developments—what is the real story]. In: Teischinger A (ed) Zur Laubholzfrage Österreich: Eine Zusammenstellung aktueller Entwicklungen und Aktivitäten in Österreich und im benachbarten Ausland [The Austrian hardwood issue: A summary of current developments and activities in Austria and neighbouring countries], LIGNOVISIONEN, 34, 74. Universität für Bodenkultur Wien, Wien. ISBN:1681-2808

Teischinger A (2019d) Zur Laubholzfrage Österreich: Eine Zusammenstellung aktueller Entwicklungen und Aktivitäten in Österreich und im benachbarten Ausland [The Austrian hardwood issue: a summary of current developments and activities in Austria and neighbouring countries]. Teischinger, A (ed), LIGNOVISIONEN, 34, 74. Universität für Bodenkultur Wien, Wien. ISBN: 1681-2808

Teischinger A, Ritter S, Huber C et al (2019) Laubholzaufkommen, Laubholzverarbeitung in Österreich und Ansätze für Konzepte von Innovationsstrategien [Hardwood supply, hardwood processing in Austria and approaches for concepts of innovation strategies]. In: Teischinger A (ed) Zur Laubholzfrage Österreich: Eine Zusammenstellung aktueller Entwicklungen und Aktivitäten in Österreich und im benachbarten Ausland [The Austrian hardwood issue: A summary of current developments and activities in Austria and neighbouring countries], LIGNOVISIONEN, 34, 74. Universität für Bodenkultur Wien, Wien. ISBN:1681-2808

Temmes A, Peck P (2020) Do forest biorefineries fit with working principles of a circular bioeconomy? A case of Finnish and Swedish initiatives. For Policy Econ. https://doi.org/10.1016/j.forpol.2019.03.013

Toppinen A, Pätäri S, Tuppura A et al (2017) The European pulp and paper industry in transition to a bio-economy: a Delphi study. Futures 88:1–14. https://doi.org/10.1016/j.futures.2017.02.002

Toppinen A, D'Amato D, Stern T (2020) Forest-based circular bioeconomy: matching sustainability challenges and novel business opportunities? For Policy Econ. https://doi.org/10.1016/j.forpol.2019.102041

Turnbull AE, Dinglas VD, Friedman LA et al (2018) A survey of Delphi panelists after core outcome set development revealed positive feedback and methods to facilitate panel member participation. J Clin Epidemiol 102:99–106. https://doi.org/10.1016/j.jclinepi.2018.06.007

Turoff M (2002) The policy Delphi. In: Linstone HA, Turoff M (eds) The Delphi method: techniques and applications. Newmark, New Jersey

UPM (2020) UPM invests in next generation biochemicals to drive a switch from fossil raw materials to sustainable solutions. UPM. https://www.upm.com/about-us/for-media/releases/2020/01/upm-invests-in-next-generation-biochemicals-to-drive-a-switch-from-fossil-raw-materials-to-sustainable-solutions/. Accessed 30 Jan 2020

Weimar H (2011) Der Holzfluss in der Bundesrepublik Deutschland 2009: Methode und Ergebnis der Modellierung des Stoffflusses von Holz [Wood flow in the Federal Republic of Germany 2009: Method and result of modelling the material flow of wood]. Johann Heinrich von Thünen-Institut (ed), Hamburg

Winkel G (2017) Towards a sustainable european forest-based bioeconomy. Assessment and the way forward. In: Winkel G (ed) What science can tell us 8. European Forest Institute. ISBN 978-952-5980-42-4

Wolfslehner B, Huber P, Lexer MJ (2013) Smart use of small-diameter hardwood—a forestry-wood chain sustainability impact assessment in Austria. Scand J for Res 28:184–192. https://doi.org/10.1080/02827581.2012.686626