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ORIGINAL ARTICLE

How Sustainability from Fiber Content in Wood-Polymer Composites Outweighs Lower Material Performance: An Industry Perspective

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Abstract
There is increasing demand in the industry to make plastic-intensive products more sustainable. Wood-Plastic Composites (WPC) represent a plastic-substitution technology. They consist of up to 80% wood fibers by volume embedded in a petrochemical plastic matrix. The fiber content makes them ecological, but then also more expensive and susceptible to color change and water absorption. This study uses a choice-based survey of 167 German industry experts to clarify whether WPC could be used across sectors to increase the sustainability of their products and applications, up to what maximum wood content they would give up the advantages of pure plastic in favor of sustainability, and on which company factors and plastic-relevant attitudinal characteristics the choice depends. 85% of respondents agreed with WPC, regardless of their branch. Only 18.6% would accept cost increases for sustainability, and the majority (48.5%) preferred to renounce color stability rather than moisture resistance (18.0%). However, if higher moisture absorption was tolerated, the experts tended towards lower maximum wood contents ($p=0.001$, r = -0.30). To fully exploit WPC`s eco-potential, future developments should optimize its hydrophobic properties rather than color stability. Due to low dependencies of the results on company factors, the marketing of WPC can be carried out under high standardization levels.

Keywords Wood-plastic Composites · Compolytics · Expert Survey · Sustainability · Decision tree

1 Introduction

The global production volume of petrochemical plastics reaches 400 million tons (Statista 2022a, b). As a result, oil reservoirs are irreversibly exploited and CO_2 is emitted (Scherer et al. 2018). The consequences are global warming, acidification, and often energy waste (Steenis et al. 2017). In the discussion of abatement efforts, according to a study by Magnier and Schoormans (Magnier and Schoormans 2015), 96% of Europeans believe industrial companies have a duty to act now. Besides avoidance, Khoshnava et al. (Khoshnava et al. 2018) consider resource efficiency to be the second most important measure, which includes the use of renewable resources. Biomass can be embedded in petrochemical plastics, making them more sustainable and saving oil resources (van den Oever et al. 2017). Such biocomposites not only lead to greener, but also much healthier goods and may increase quality (Roig 2018). If they contain enough plant fibers, products from them even become carbon neutral over their life cycle, even if they are incinerated at the end (Martins et al. 2017). Expectations for these novel biobased materials are high, as they represent a welcome alternative to conventional applications in industry (Scherer et al. 2018).

One representative of natural fiber-reinforced plastics is Wood-Plastic Composites (WPC). They consist of up to 80 vol.-% wood fibers in thermoplastics (Carus et al. 2016). The annual global production of WPC is expected to reach 8 million tons by 2022 (Statista 2022a, b). The main applications are in furniture, automotive, everyday products and construction applications such as decking or cladding (Carus and Partanen 2018). The great sustainability potential of WPC also lies in the fact that the bio-fibers can originate as a waste product from the agricultural, forestry and wood-processing industries (Osburg et al. 2016). Nevertheless, the literature warns against too high expectations, because applications must fulfill a wide range of requirements and legal criteria (Franzoni 2011). For example,

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such composites are subject to particularly high durability constraints in construction applications (Roig 2018). To counteract the disadvantage of hydrophilic wood fibers, the remaining plastic matrix must then be better than before (Ratanawilai and Taneerat 2018). Biobased plastic composites thus have limitations, which makes industry experts skeptical and uncertain in selecting such alternatives for their products (Brockhaus et al. 2016). Qi et al. (Qi et al. 2010) made an early point that openness to such materials will grow once the pressure on industry to use more sustainable alternatives increases. But whether biobased plastics can be developed into new products, simply because they are sustainable, is also a cost issue (Brockhaus et al. 2016). The variable costs could increase if the material is weaker and more of it has to be used in the products to compensate, and the fixed costs also rise if the production machines have to be adapted to the biomaterial (Markström et al. 2018). In order to balance cost increases through higher prices, sustainability must represent an additional benefit for the industry and consumers while maintaining the same level of performance.

The transformation of previous plastic-intensive products into Wood-Plastic Composites is thus an optimization task between the best achievable material properties, the lowest possible cost and the greatest willingness to buy in the market. How the application potential of WPC as a plastic substitute is analyzed in such a holistic way is reported in the literature as compolytics research approach (Friedrich 2023). As an acronym for composite polymer and policy analytics, compolytics studies derive guidelines for the transformation of plastics by WPC for various industries. Under this philosophy, the potential of WPC is assessed from an expert's point of view under technical performance aspects and under ecological, and at the same time, under economics criteria. Such an approach then follows the Triple Bottom Line (TBL) Principle according to Elkington (Henriques and Richardson 2004). Therefore, the aim of this study is to find out how industries evaluate the sustainability aspect from wood fiber relative to material performance. Specifically, the following research questions (RQ) are to be clarified, (RQ1) whether industries are differently in favor of WPC-use in their business, (RQ2) whether and how the previous role of plastic in their own business influences the consent to WPC in principle, (RQ3) whether cost efficiency or performance would rather be sacrificed for the sake of sustainability, (RQ4) how high the wood fiber content would be chosen in order to still trust the material sufficiently, and (RQ5) on which company-specific and latent factors it depends, whether the change from purely petrochemical to biobased may rather be at the expense of color stability or moisture resistance, and what the highest biobasedness is then.

Findings initially have practical relevance, as they inform the WPC and plastics industry about which material properties become relevant for decision-making and whether maximally provided sustainability is trusted at all. For further research, the study uncovers potential for addressing which specific performance parameters need to be further developed to increase industry trust and whether future research should focus more on their needs. The paper is organized as follows: Sect. 2 derives from the literature relevant material attributes that are most likely to influence the experts' decision and should therefore be considered in the study design. Section 3 presents the method of data generation and analysis. Section 4 presents the results of the expert survey and discusses them in the light of the literature, and the last section draws a conclusion, addresses the limitations and recommends further research.

2 Theoretical Framework and Hypotheses

In Lancaster's (Lancaster 1966) decision model, it is not the products themselves that influence the choice, but the bundle of utilities from the product. According to this model, products of the same kind achieve different prices in the market because they are equipped with varying properties in which decision-makers see diverse partial utilities (Klaiman et al. 2016). The Theory of Planned Behavior (TPB) according to Ajzen (Ajzen 1991) tries to explain why consumers and industry experts nevertheless react heterogeneously to products with the same characteristics. Obviously, the choice depends on the personal attitude toward the object, according to which WPC with a high wood content could evoke positive reactions, especially among environmentally conscious people. However, particularly companies must take their business environment into account. Such normative restrictions could lead to the rejection of WPCs, for example, if the performance is assessed as poorer despite sustainability, and the selection thus represents an operational risk. In the following, such hazard factors for WPCs are derived from the literature, and it is discussed how they could influence decision behavior in this expert survey.

2.1 How Sustainable is WPC?

Even if a material in products can be purely biobased, the CO_2-balance does not necessarily have to be positive. Accorsi et al. (Accorsi et al. 2014) illustrate this for packaging material, and cardboard then releases up to 1.18 kg CO_2eq, wood to 0.43 kg, but plastic is leading with 3.4 kg. Thus, WPC can help to make plastic products at least somewhat more climate neutral by adding wood fibers. The carbon footprint is then between pure wood and plastic (Teuber et al. 2016). Roos et al. (Roos et al. 2014) also see the CO_2 aspect of wood-based products as an opportunity to deliberately push environmentally harmful products out of the market while maintaining the same technical performance. Sijtsema et al. (Sijtsema et al. 2016) therefore refer to biobasedness as an additional benefit, which increases the utility bundle according to Lancaster's theory (Lancaster 1966), or for the same total utility, another product characteristic may decrease in return, e.g., products become more expensive.

2.2 What are the Costs of WPC?

Khoshnava et al. (Khoshnava et al. 2018) attribute a crucial role to the cost aspect in the product selection process. Regarding WPC ingredients, van den Oever et al. (van den Oever et al. 2017) asses the price of polyethylene plastic with 1.35 €/kg. For Keskisaari and Kärki (Keskisaari and Kärki 2018), wood fibers cost up to 0.40 €/kg, and Eder and Carus (Eder and Carus 2013) then arrive at 1.0 to 4.0 €/kg for produced WPC compound. Blending plastics with wood fibers not only conserves oil resources and the environment, but potentially also lowers material costs. But fix-costs increase for the time being, because investments in production factors are necessary. If the output volumes of WPC grow, the unit fixed costs decrease significantly, which can make WPC a cost-neutral alternative to conventional petro-plastics. Thus, products made in a WPC-variant will certainly be seen under strongly to moderately increasing costs in the short term, and even under the same costs in the long run. Friedrich (Friedrich 2020a, b) tested various packaging materials, including WPC, with consumers, and was able to derive significantly higher willingness-to-pay, both for everyday and shopping goods. At the same time, the author derived from another expert study that medium-sized companies in particular would only partially pass on additional costs to consumers (Friedrich 2020a, b). Higher costs therefore do not necessarily hold market players back. The taxation of conventional plastics in the European Union will also encourage companies with little environmental concern to consider WPC as a substitution technology just for cost reasons. Therefore, the question of the highest achievable wood content is all the more important for the industry.

2.3 How Well Performs WPC?

In order for deciders to opt for a new material, such as WPC, they need to be able to objectively assess its performance, also for business risk minimization. For Kuzman et al. (Kuzman et al. 2018), the provision of information to the industry is therefore crucial, especially for novel wood-based products. In this context, Franzoni (Franzoni 2011) mentions mechanical properties as the main criterion. For WPC, Soccalingame et al. (Soccalingame et al. 2015) detected a 20% growth in ultimate load after adding 30% wood fibers compared to pure polypropylene, which Sommerhuber et al. (Sommerhuber et al. 2017) also derived when using recycled plastic. Seldén et al. (Seldén et al. 2004) came up with only 8.5% rise under 50% wood content, suggesting that fiber addition for load increase is not endless. Nevertheless, even from a strength-related point of view, wood incorporation would initially maximize product utility.

However, Brockhaus et al. (Brockhaus et al. 2016) are more critical about the durability of biobased plastic composites, because wood fibers absorb moisture from the environment. Friedrich (Friedrich 2019) actually demonstrated 30% higher water absorption for WPC under 70% fiber content than with 50% share. Tamrakar and Lopez-Anido (Tamrakar and Lopez-Anido 2011) found that water absorption actually accelerates with higher temperatures. Even though the main applications of WPC are in decking and cladding panels, withstanding rough weather conditions, the range of applications seems to be limited.

Research on WPC material properties investigates not only mechanical characteristics, but also durability which becomes quantifiable by measuring color change behavior. Badji et al. (Badji et al. 2017) demonstrated significant bleaching effects from UV irradiation for WPC with 30% wood fibers, and Peng et al. (Peng et al. 2014) also reported an increase in surface roughness after artificial weathering of samples. The effect of fading is largely due to the degradation of lignin in the wood (Beg and Pickering 2008). Again, this may limit WPC applications, particularly where their aesthetics are intended to provide an additional benefit, e.g. in long-lasting prestige shopping goods. The literature also reports changes in other WPC characteristics, such as polymer-related thermal elongation or creeping under permanent load. However, the present study is concerned with possible utility reductions due to the change from pure plastic to WPC as a substitute material, which is why moisture resistance and color stability can be considered to be maximally disadvantageous due to the wood fiber. Therefore, in addition to cost and sustainability, these should be two further critical variables in an expert survey.

2.4 What Influences Decisions toward WPC?

Previous findings from the literature suggest that depending on the industry and normative business environment, the same utility bundle of sustainability, cost, color stability, and moisture resistance might be viewed differently for WPC products in one's own business segment. Reinders et al. (Reinders et al. 2017) revealed that product brands, that are only partially biobased, can actually underperform

Table 1 Test variables in the study design

Manifest Variables			
Wood Content [Vol.-%]		Costs	same
	0%		increase
	20%		intensive
	40%	Moisture Resistance	hydrophobic
	60%		hydrophilic
	80%	Colour Stability	resistant
			bleaching
Organisation-relevant Variables		**Latent Variables**	
Branch	Technics….Tourism	WPC Experience	low….high
Company Size	1….>250	Plastics in Use	0%….> 50%
Business Focus	Service…Production	Importance Plastic	low….high

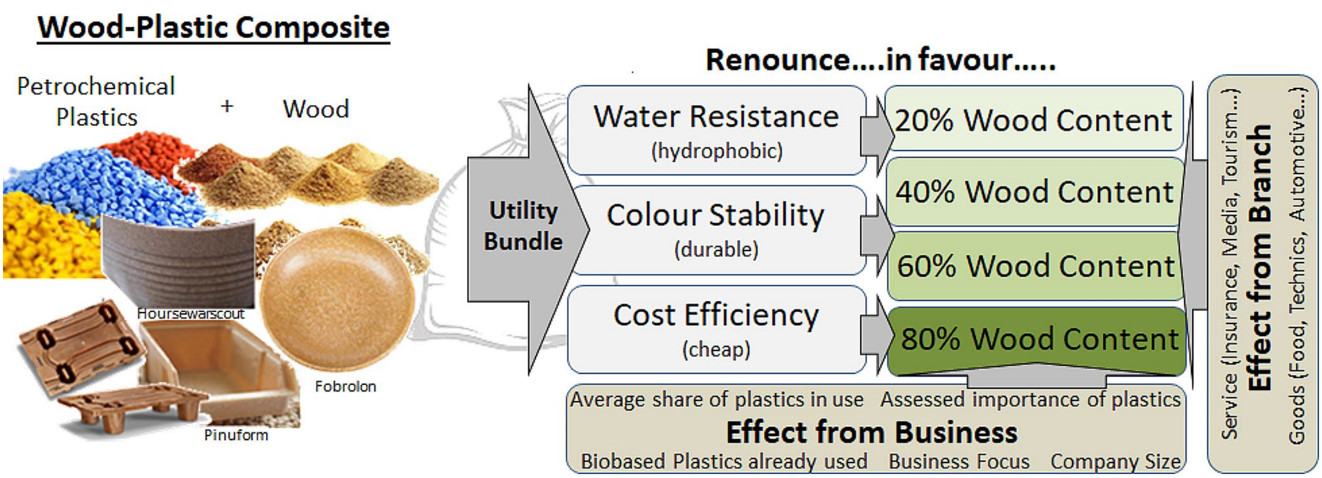

Fig. 1 Overview of hypotheses to demonstrate effects on expert attitudes toward WPC as a plastic-substitution technology

purely non-biobased products. Onwezen et al. (Onwezen et al. 2017) even argue that any slight negative aspects found in products can disproportionately weaken the major positive ones. This could also apply to the remaining plastic content in WPC, or a decrease in performance must be outweighed by many times greater increases in sustainability. Markström et al. (Markström et al. 2018) assume that a lack of knowledge and experience can also lead to rejection. Finally, Friedrich (Friedrich 2021a, b, c, d) demonstrated for WPC as a building product, that construction experts and private homeowners made their decision against WPC façade elements for different reasons. For the former, Qi et al. (Qi et al. 2010) saw the company size as an influencing factor. Thus, in addition to the material criteria already mentioned, organizational variables should also be taken into account in an expert study. These include the company size and the business focus, i.e. whether services or goods production is in the foreground. Latent variables could include previous experience with biobased plastics, the proportion of plastics in the company's own business and the estimated importance of plastics for business success. Table 1 summarizes the test variables derived from the literature.

Figure 1 illustrates the study design. It follows the Lancaster Theory (Lancaster 1966) derived from the literature that WPC products offer a bundle of partial utilities that can be described according to manifest variables as shown in Table 1. How high the utility is estimated for sustainable products can be determined according to the Theory of Planned Behavior (Liobikienė et al. 2016). In addition to costs, marketing also plays a role for companies (Lettner et al. 2017). Usually, then, for consumers, personality traits are the deciding factor for purchase (Vecchio and Annunziata 2015). For industrial experts, on the other hand, it is more the organizational and latent business-relevant variables that are crucial (Qi et al. 2010). Assuming that, as already described, the utility from material performance and cost efficiency are increasingly estimated to be lower under wood fiber addition, but could be compensated by more benefits from sustainability, the total utility would remain constant up to a certain degree of biobasedness. The central study question is then at which wood fiber content the compensation effect is no longer effective and whether this depends on the sampled variables.

3 Method

3.1 Data Generation via Survey

3.1.1 Questionnaire Preparation

The responses of the industry experts to WPC as a potential substitute material, applied to their own products, were gathered by a survey. According to Table 1, the four manifest variables with "Wood Content" 5-fold, "Costs" 3-fold, "Color Stability" and "Moisture Resistant" 2-fold each, entered the setting. This resulted in $5 \times 3 \times 2 \times 2 = 60$ choices, where the ordinal or cardinal scaling of the variables allowed a clear ranking. For this, 32 combinations had to be blocked, e.g. when the minimum wood content was combined with a maximum performance loss. The remaining 28 choice sets were divided into 16 choice containers. They each offered two to three utility bundles for selection, under two wood contents of plausible rank order, e.g., 20% and 40%. The utility bundles then described whether the wood-increase was at the expense of either costs, color stability, or moisture resistance. Depending on which choice was made, the questionnaire forwarded the test person to a next exactly defined choice container. This included a higher fiber content, again at the expense of another property. If none of the offered combinations was considered equally useful, the respondent could then "opt-out", keeping the latter choice with the lower wood content, and was then directed to the query of the organizational and latent variables. For the respondents, the 16 containers were visibly arranged in order of increasing sustainability aspects according to the five possible wood proportions. This is consistent with the Boundary Value Principle (Rao and Patel 2010). The selection process resembles multi-criteria choice-making (Pohekar and Ramachandran 2004). Similar to a multi-stage decision problem, the respondent must repeatedly choose a new utility bundle under pairwise comparison (Wong and Lee 2008). Since they did this until the perceived total utility decreased for the first time, this resembled the principle of an auction, where continuously increasing prices are always judged relative to the utility from the purchase.

3.1.2 Survey Execution

In October/November 2022, 35 students from the IU International University of Applied Sciences in Mainz, Germany, conducted the expert survey in their parent companies from various industries. Since the study combines lecture with working in a weekly rotation manner, each student was able to ask a minimum of five experts within a short time. The respondents were informed about the objective and their consent to participate was expressed by their willingness to volunteer information. The survey only gathers feedback on the operational status quo and bears no ethically relevant psychoanalytical aspects. The front of the questionnaire (see Supplement) contained general information about WPC, and the students were also taught essential material specifications in order to answer questions. This was intended to sensitize the experts to the main question of whether plastic-intensive products could be replaced by this material in their companies. On the back followed the 16 choice containers and finally the inquiry of the corporate and latent data. The questionnaire was previously tested in the "Marketing" lecture. A high reliability of the study design could be estimated in advance, as exactly this design was already applied under the compolytics-approach in four previous consumer and expert surveys for similar research questions on biobased plastics (Friedrich 2021a; b; c; 2022a). On the basis of the primary data obtained in this way, the research questions (RQ1) to (RQ5), described at the introduction, can be answered.

3.2 Data Analytics and Clarifying RQs

3.2.1 Representativeness and Robustness

The questionnaire attempts to find out which partial utilities from plastic-based products, namely cost efficiency, moisture and color stability, industry experts would give up for the benefit of higher sustainability in the form of wood fiber content. Of interest here is the percentage of wood, the order of sacrificed utility and the dependence of the decision on corporate characteristics. Statistically, the grouped data sets are subjected to a correlation analysis to find out, for example, whether and to what extent the highest possible level of sacrifice in favor of sustainability depends on the company size. Alternatively, difference statistics were performed if the test variable had few attributes, i.e. for "yes/no" answers. For example, the responses on industry affiliation were grouped according to material experience and checked for differences. This shows which sector is the most or least familiar with WPC. Finally, a significance check provided both approaches with a high degree of validity.

The more heterogeneous the answers are, the stronger is significance between agreement on the utility bundles and organizational and latent variables. For this reason, all entries for the variables were first tabulated and, in particular, the industry distribution was depicted as a pie chart. In order to exclude multicollinearity between the variables prior to the effect analyses, the variance inflation factor (VIF), derived from the correlation matrix, was tested for keeping the upper limit of 10.

3.2.2 Analysis of WPC Acceptance (RQ1) and Current Role of Plastic (RQ2)

To clarify the single research questions, the data from the 16 choice containers first had to be read out. Here, it was counted how often respondents generally chose a wood fiber content > 0%, which represents an item for "WPC-yes/no". This dichotomized data set (0% = 0; >0% = 1) was subjected to correlation analysis with selected variables, and effects were classified as weak for $0.10 \leq r < 0.20$, medium for $0.20 \leq r < 0.50$, and strong above, according to Cohen (Cohen 1988). In addition, an ANOVA using F- and Levene-statistics was executed to test the data sets for differences, with the significance level set at 5%. Thus, if the data sets for item "WPC yes/no" and the variable "Branch" were different and at least weakly associated, this answered the research question RQ1. In the same way, RQ2 was used to clarify whether agreement with WPC actually depends on the estimated importance, the proportion of plastics in one's own business and previous experience with biobased plastics. Finally, there had to be a significant effect and group difference between the item "WPC yes/no" and the variables "Importance Plastic", "Plastics in Use" and "WPC Experience" according to Table 1.

3.2.3 Analysis of Willingness to Renounce (RQ3) and Acceptable wood Content (RQ4)

RQ3 answers how far industry experts see a decrease in performance and cost efficiency in an increasing wood fiber proportion as material sustainability. For this, it is clarified at which maximum wood content a decline of the total utility is perceived for the first time. The growing number of entered choice containers indicates continuously accepted fiber amounts, despite shrinking material efficiency. First, the paths of all responses were graphically displayed as a decision tree with the main paths according to the variables "Costs", "Color Stability" and "Moisture Resistance". Then for each response, the wood share, at which the "opt-out" solution was selected, was read out, resulting in a data set for item "max.Wood". The distribution of the maximum wood proportion selected across all entries is again shown as a pie chart and the maximum is displayed. With item "FirstChoice", RQ4 clarifies whether experts would first renounce cost efficiency from the change to 20% wood share, or whether they would give up color stability or moisture resistance. In the latter case, a utility bundle from choice container 1 was agreed to, acceptance of higher costs results from container 2. Or, "opt-out" was chosen in both containers, which means rejecting WPC of such wood content. The counted responses were again presented as a pie chart.

3.2.4 Impact of Company Characteristics on the Decision (RQ5)

Whether the WPC product is allowed to lose color or become wetter in the long term when switching from purely petrochemical to biobased, and what triggered this decision, clarifies the first part of research question RQ5. For this purpose, only entries for "hydrophobic/hydrophilic" and "color stable/bleaching" were taken from the data set of item "FirstChoice" and condensed to the item "First Weakness". In order to uncover dependencies on corporate specific and latent variables, the data set was finally crossed with the variables "Company Size" and "Business Focus" and again with the variables "Importance Plastic", "Plastics in Use" and "WPC Experience" from Table 1, and the correlation analysis and difference statistics were carried out. The same was done with the data set for item "max.Wood", as the second part of RQ5. Finally, it was additionally examined whether there is also a general relationship between item "max.Wood" and item "First Weakness", which points to a universal character of WPC-related decision-making.

4 Results and Discussions

4.1 Characterization of Respondents

The survey gave a total of n = 167 participants, and since the interviews took place in the presence of the students, all responses could be declared valid. The VIF-value ranged from 1.01 to 1.47, which is far below the maximum of 10, and therefore multicollinearity between the variables could be excluded. Figure 2 shows that the sectors "Media/Leisure/Tourism" and "Medicine/Pharma/Health" are the most strongly represented, followed by "Technology/…", "Food/…" and finally Distribution/Logistics/…".

Table 2 summarizes the results on the test variables. As can be seen, most respondents were from small (57.5%) or medium-sized companies (38.9%) and are service-oriented (89.8%). Also, most of them had not yet used WPC as a bioplastic option (84.3%), and most use products with a medium content of petrochemical plastic (62.3%). Plastic generally seems to play a medium (35.3%) to important (37.1%) role, which is in line with the study question.

4.2 Consent to WPC as Plastic-Substitution Technology

Of the 167 respondents, 15.0% rejected wood-fiber addition in plastic. The related item "WPC-yes/no" did not show any significant result in the difference statistics with the variable

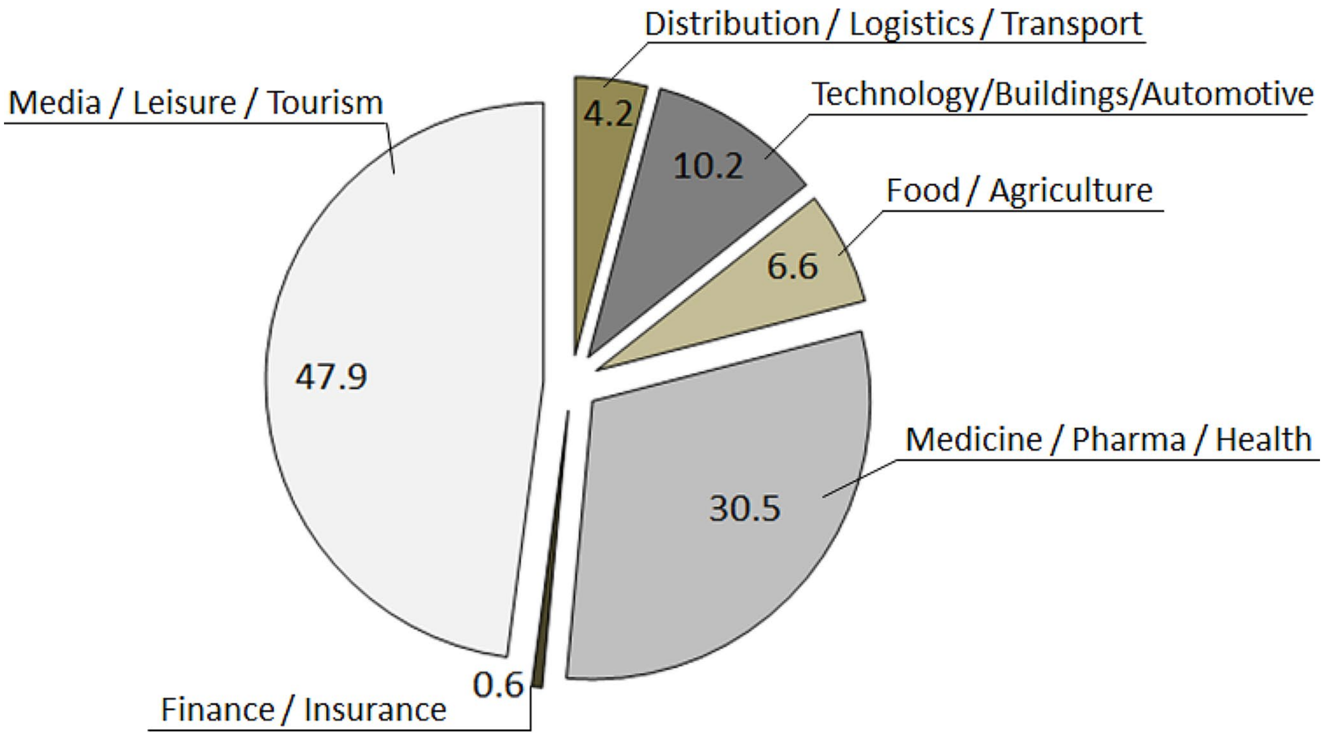

Fig. 2 Branch distribution of expert opinions (in %)

Table 2 Characterization of the experts surveyed and their companies (values in %)

Branch:		Company Size:	
Distribution / Logistics / Transport	4.2	< 50	57.5
Technology / Buildings/Automotive	10.2	51…0.250	38.9
Food / Agriculture	6.6	> 250	3.6
Medicine / Pharmaceuticals / Health	30.5	**Business Focus**:	
Finance / Insurance	0.6	Service	89.8
		Production	10.2
Biobased Plastics already used?			
no	84.3		
yes	20.8		
Average share of plastics in use:		**Assessed importance of plastics**:	
0	18.6	low	27.5
0…0.50	62.3	middle	35.3
> 50	19.2	high	37.1

Table 3 Association between item "WPC-yes/no" and selected variables

Correlation between Item….	…and Variable
"WPC-yes/no" (0 Vol.-% Wood Content)	**„Branch“**
	F(1, 165) = 1.83; p = 0.177; r = -0.10
	"Importance Plastics"
	F(1, 165) = 0.84; p = 0.359; r = 0.07
	"Plastics in Use"
	F(1, 166) = 2.15; p = 0.145; r = 0.11
	"WPC Experience"
	F(1, 166) = 2.57; p = 0.111; r = -0.12

"Branch" (Table 3). So, the agreement with WPC is sector-independent which answers RQ1.

The results first constrain the statements of Florez and Castro-Lacouture (Florez and Castro-Lacouture 2013) that sustainable materials are generally seen as beneficial by users, because after all WPC was rejected by 15%. Also that, as mentioned by Heidbreder et al. (Heidbreder et al. 2019), biobased materials are generally preferred over pure petroplastics cannot be confirmed for industrial deciders. Rather, the finding gives credit to Onwezen et al. (Onwezen et al. 2017) that risk assessment can negatively override the decision in favor of sustainability. This also underscores the concerns of Brockhaus et al. (Brockhaus et al. 2016) that skepticism about the performance and cost situation makes it hard for novel biomaterials to convince. As for the inexistent dependence of WPC approval on the industry branch, this result concretizes Friedrich's (Friedrich 2022a, b) statements on WPC packaging, which was assessed differently by industry representatives. Obviously, it is difficult to transfer findings from one product group to another, and studies must investigate specifically selected WPC test objects than only the material itself.

As can be seen in Table 3, all latent variables that could trigger the attitude toward biobased plastics are also unspecifically associated with the approval of WPC, which now answers RQ2. Overall, WPC seems to be equally well known in each industry as a plastic-substitution technology because, after all, 20.8% had already dealt with it, the decision in favor of WPC is industry-unspecific, and the importance of plastic and the applied proportion is medium to high. WPC is therefore a topic for all surveyed branches and the 15% rejection is most likely not due to inexperience.

The fact that consent to WPC is independent of material experience weakens the statement of Markström et al. (Markström et al. 2018) who saw a lack of material knowledge as a cause for rejection. The results complement the literature in that, from a branding perspective, not only do plastic-intensive companies represent the best possible target group for novel WPC products, but the material can be an interesting option for the industry in general. It can therefore be promoted via a high degree of standardization.

4.3 Assessments of WPC as Plastic-Substitution Technology

4.3.1 Willingness to Renounce on Performance

The decision tree with the path "cost increase", as a first selection in choice container 2, is shown in Fig. 3. In addition, Fig. 4 illustrates the results of the two paths "bleaching" and "hydrophilic", as an accepted decrease in performance for the benefit of sustainability. First, for the "20% Wood" sustainability option, it can be seen that 48.5% (Fig. 4) of the WPC supporters selected decreasing color stability (bleaching) in favor of moderate bio-content, and this is obviously seen as being identical to pure and color-stable petroplastics. For them, cost efficiency and moisture resistance must have been more important. At the 40%-wood level, it appears that cost increase was the better alternative to a threatened decrease in moisture resistance. This also remains the case in the further course, although hardly anyone still expressed agreement.

A similar amount of 15% was in favor of cost increase (Fig. 3 at 20% Wood level) and 18% for hydrophilic (Fig. 4 at 20% Wood level). At the next sustainability level (40% Wood) it is again evident that a decrease in moisture

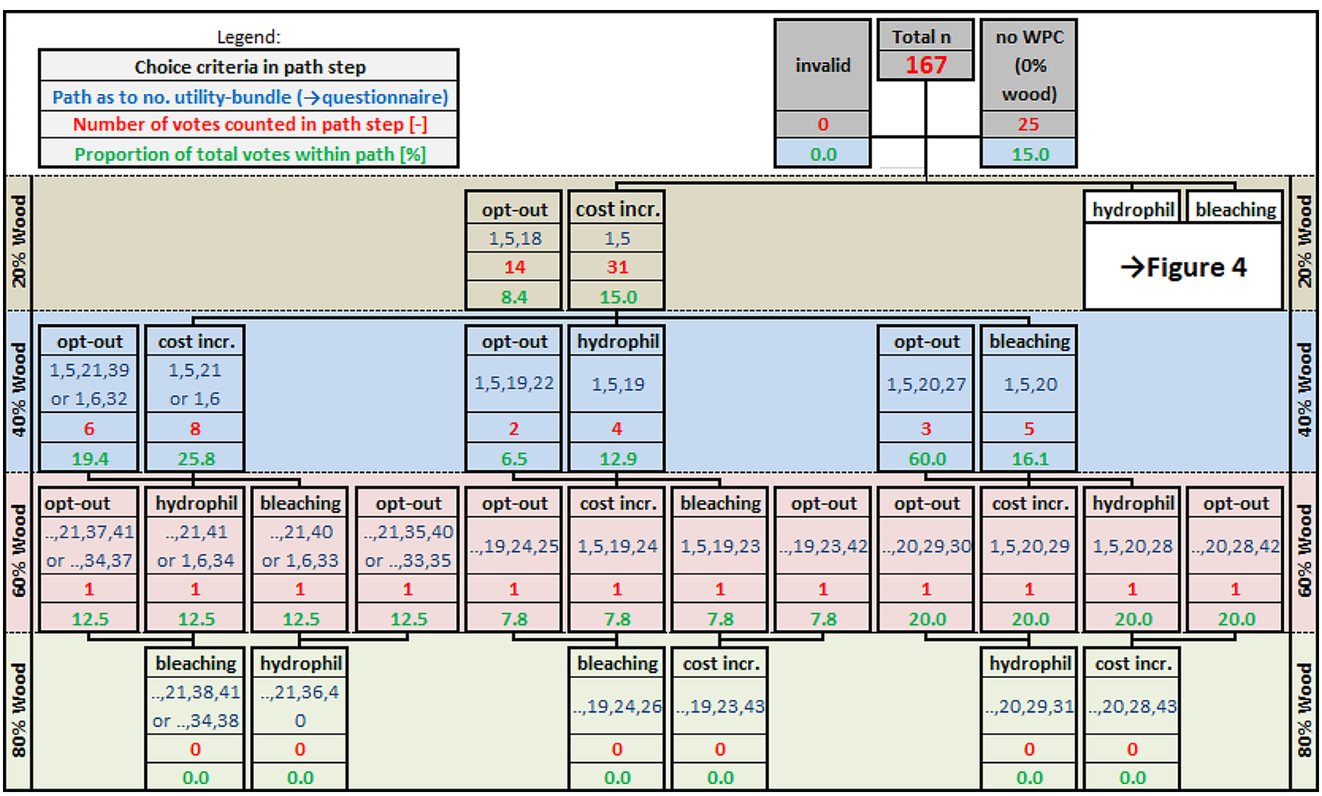

Fig. 3 Decision tree for main path "cost increase" to compensate for higher sustainability

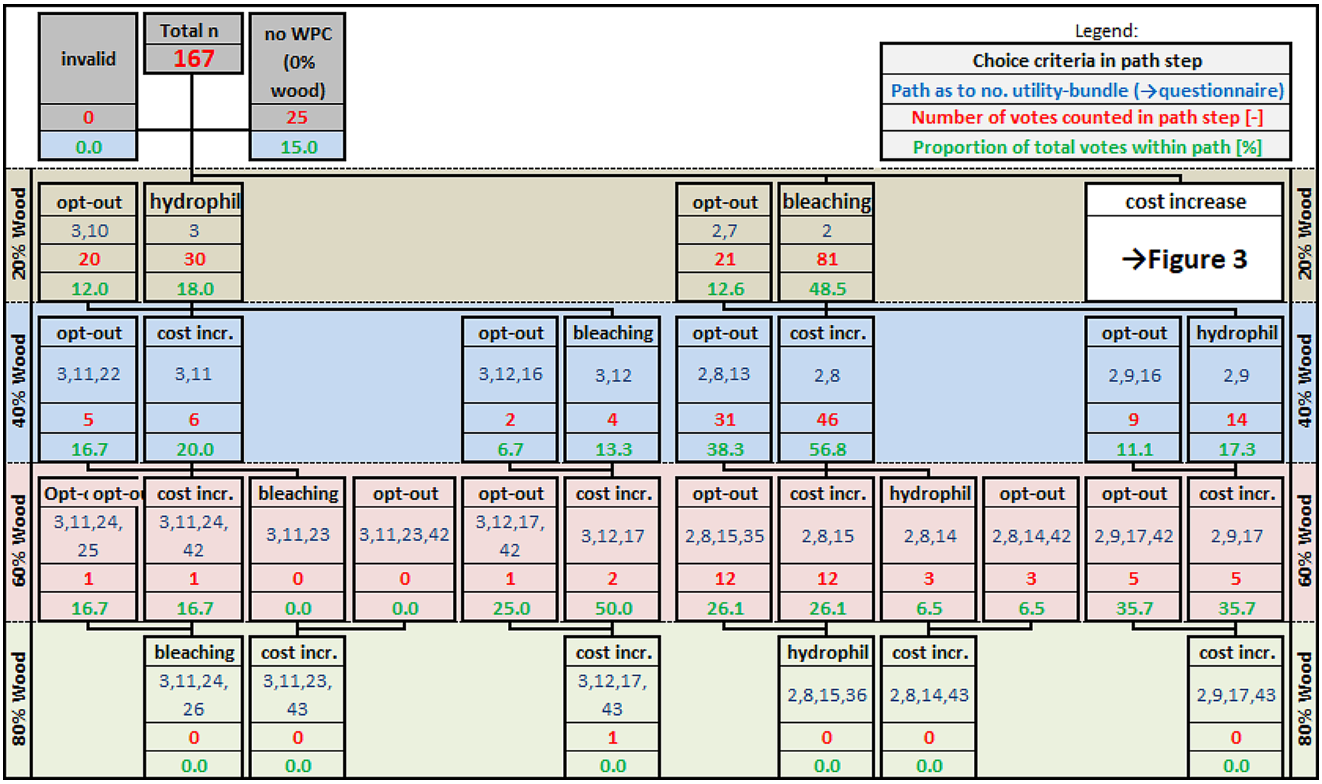

Fig. 4 Decision tree for main paths "bleaching" and "hydrophilic", which decrease to compensate for higher sustainability

resistance as alternative is always avoided (e.g. Figure 3; path 1,5,19 with 12.9% agreement instead of 25.8% for cost increase or 16.1% for bleaching). As before, moisture resistance has more priority than cost increase. In conclusion, most respondents give absolute priority to the moisture resistance of WPC, and costs may then also be higher, which answers RQ3.

The findings initially weaken Brockhaus et al. (Brockhaus et al. 2016) that industrial developers view the cost increase for such novel biomaterials critically, because 15% accepted this to the benefit of sustainability. Akadiri et al. (Akadiri et al. 2013) found that, in addition to cost, performance is also a decisive criterion, which the study likewise demonstrated. That, as claimed by Roig (Roig 2018), the durability of the biomaterial triggers the approval is also confirmed by the results because, after all, 18% did not want to give it up in favor of the same costs. The results complement the literature by showing that, in the choice between color stability and moisture resistance, as two of the most important WPC material properties, the latter is seen as even more significant by all industry experts. Optimization developments in the direction of even more water-resistant WPCs are obviously very effective here.

4.3.2 Maximal Wood Content Accepted

Item "max.Wood" now reads out the highest selected wood proportions from the decision tree. This distribution is shown in Fig. 5 (left). As can be seen, 40% fibers achieved maximum agreement (34.7%) with losses in cost or performance included in the utility bundle. In the same range is the choice for WPC with 20% share. It can be seen very well that a maximum amount of 60% or even 80% is no longer regarded as justified for the associated decrease in cost or performance utility. This now answers RQ4.

The results underline two facts that are crucial for biomaterials. First, as claimed by Scherer et al. (Scherer et al. 2018), there is a general interest in the highest possible bio content, because the maximum is 40% wood share and not 20%. On the other hand, it agrees with Roos et al. (Roos et al. 2014) that, if all other parameters considered important are perceived to be optimal, sustainability is the deciding factor. This is the only way to explain why the maximum is not 20%. But it also underlines the statement of Sijtsema et al. (Sijtsema et al. 2016) that this is just true as long as other aspects, such as performance, do not decrease more than sustainability increases. This is known in economics as the efficiency principle, and it ensures that scarce resources, in this case the total utility from a bundle of properties, are not used sub-optimally.

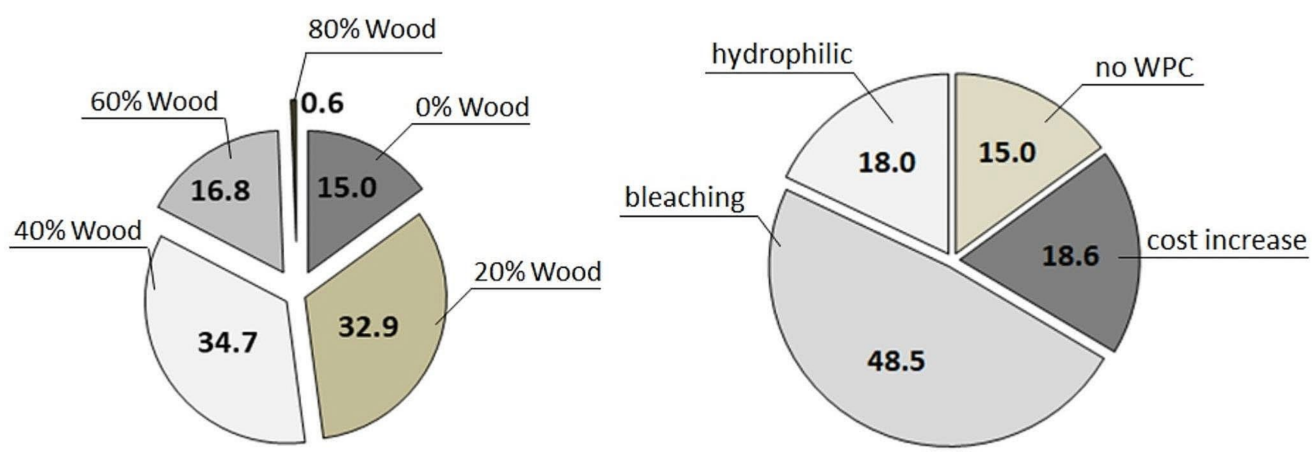

Fig. 5 Distribution of preferred maximum wood shares (left); distribution of first choices (right)

Table 4 Association between Items "First Weakness" or "max.Wood" and company-related or latent variables

Correlation between Item….	…and Variable
"max.Wood"	**"Company Size"**
	F(2, 110) = 5.00; $p = 0.08$; $r = -0.27$
	"Business Focus"
	F(2, 105) = 4.27; $p = 0.041$; $r = -0.20$
	"Importance Plastics"
	F(2, 110) = 1.89; $p = 0.248$; $r = -0.11$
	"Plastics in Use"
	F(2, 108) = 0.05; $p = 0.949$; $r = -0.03$
	"WPC Experience"
	F(2, 110) = 1.44; $p = 0.234$; $r = 0.11$
"First Weakness" (bleaching/hydrophilic)	**"Company Size"**
	F(2, 110) = 1.01; $p = 0.368$; $r = 0.05$
	"Business Focus"
	F(2, 105) = 2.06; $p = 0.154$; $r = 0.14$
	"Importance Plastics"
	F(2, 110) = 1.38; $p = 0.104$; $r = -0.15$
	"Plastics in Use"
	F(2, 108) = 0.05; $p = 0.948$; $r = 0.01$
	"WPC Experience"
	F(2, 110) = 0.02; $p = 0.884$; $r = -0.01$
Correlation between Item….	… and Item
"max.Wood"	**"First Weakness" (bleaching/ hydrophilic)**
	F(1, 111) = 11.08; $p = 0.001$; $r = -0.30$

4.4 Reasons for the Assessments on WPC

4.4.1 Dependence on Company Characteristics

To find out which variables triggered the item "max.Wood" (Fig. 5, left) and the item "First Weakness" with the entries for "hydrophilic" and "bleaching" from Fig. 5 (right), Table 4 now summarizes the results of the corresponding correlation and difference statistics. As can be seen, the choice of which material performance may decrease in favor of the first 20% wood fibers (item "First Weakness") is not significantly associated with any variable or makes any difference between them. Only the variable "Importance Plastics" with $p = 0.104$ just missed the significance threshold and suggests a weak trend that experts prefer moisture resistance to color stability, if plastics are considered essential for their own product. However, since almost all respondents use a relatively large amount of plastic in their own business (Table 2) and attach a fairly high priority to this material, no fundamental significant differences could be identified. In other words, plastic is a common material in products, so that a majority of all companies would initially give up color resistance, as can be seen in Fig. 5 (right). After all, moisture resistance is an unbeatable advantage of petroplastics, which even very sustainable WPC under high wood content hardly outweighs. The few existing associations underline the conclusion reached in Sect. 4.2 that WPC products must be tested individually in order to be able to identify specific differences between branches. Contrary to the statement of Markström et al. (Markström et al. 2018), the material itself is already sufficiently well assessed by industry representatives.

As far as the maximum wood content of 40%, preferred by most respondents, is concerned, service providers tended to favor this amount ($p = 0.041$). Manufacturing companies may have feared the additional effort involved in production under high wood fiber content in the plastic and thus went for lower proportions. It is also possible that service providers could better differentiate themselves with more sustainability and would then use this more effectively as a marketing tool. After all, they would only have to purchase WPC with a high wood content as a buy-in product. It should be remembered, however, that the data set included almost 90% service providers. In addition, the variable "Company Size" just missed the significance threshold with $p = 0.08$, but this tends to indicate that small companies are more interested in much wood-containing WPC, which would give them a differentiation advantage in the market. Since decisions for WPC wood shares show little relationship to the test variables, this also answers the last research question RQ5.

The identified dependence of the expert opinion on their business environment underlines the statement of Qi et al. (Qi et al. 2010) that a sustainability commitment of the industry is triggered by the company size, and this had also been proven by Friedrich (Friedrich 2021d) specifically for WPC facades and among building experts. Again, the results are encouraging that marketing of WPC can be standardized rather than personalized because the industry has little differentiated response to it.

4.4.2 Influence on Preferred Wood Fiber Content

It might still be interesting to know whether a personal preference for material performance somehow triggers expectations for maximum sustainability through wood fiber. As can be seen from Table 4 (below), the relationship between the two items is indeed highly significant ($p = 0.001$) and middle strong (r = -0.30). From the point of view of the industry experts, WPC products, which have lower visual requirements, can also contain more wood fibers, which may then naturally turn grey over time. If high demands are placed on the products in terms of moisture resistance, a rather lower fiber content is expected. This result is also a realistic assessment of the new WPC material. This finding is relevant for future WPC product developments, which should equip subordinate plastic-intensive and low moisture-stressed products with maximum wood content, because hardly any visual expectations are towards them. Otherwise, it could be sufficient to embed only 20% wood fibers, which already offers real ecological advantages. The average biobasedness, then prevailing in the market, can still be high and relieve the environment to a maximum.

5 Conclusions

This study investigated the attitudes of industry experts regarding the plastic substitute material WPC and the potential of the wood fibers it contains. The following findings were derived from an auction-like survey:

(1) WPC is not generally considered to be more advantageous than pure petroplastics. Approximately 15% of applications were rated as non-substitutable. The exact reasons for this could not be found out in the study, since the decision was unspecifically associated with the test variables.

(2) The industry has comparable knowledge across sectors to assess WPC. Information campaigns can therefore be conducted under a high degree of standardization. In order to find out branch differences in the perception, WPCs must be tested in a more differentiated way on the basis of real objects.

(3) WPC may well cause higher substitution costs if material performance is maintained in relation to pure petrochemical plastic. Since the literature reports that most consumers are willing to pay more for biobased products, additional costs from the transition to WPC can be passed on to the market.

(4) For wood content above 40–60%, experts see a greater decrease in performance and cost advantage than an increase in sustainability benefits. An average wood proportion of 50% can therefore be regarded as optimum for efficiency.

(5) For the industry, moisture resistance of WPC is a major criterion. As a consequence, the wood content, considered to be optimal, is also rated lower than if color resistance was seen more important. Future product developments with WPC should therefore focus on optimizing moisture resistance, which will then also increase the acceptance of higher wood shares.

(6) WPC substitution technology can make subordinate plastic products, without any moisture requirements, comparatively more sustainable than prestige goods or functional tech products. Nevertheless, the ecological potential is assumed to be high, as for most cases the embedding of wood fibers is viewed as feasible.

However, this study also has limitations. For example, the respondents were only placed in a hypothetical decision-making situation without any consequences. Nevertheless, since the survey took place in a real company environment, the results are comparatively more reliable than in consumer surveys. The survey also focused on Germany, which limits the results regionally. Due to the cultural and economic closeness of the Central European countries, there is a certain transfer potential to other economies, and the approach can ultimately also serve as a template for additional studies in further countries.

At the same time, the investigations also provided insights into the need for further research. For example, it was not possible to uncover why WPC was specifically rejected in 15% of cases. A follow-up study should find out the exact reasons. Practical substitution ideas should also be demonstrated with a specific WPC product and the degree of approval measured on this. In this way, more information can be obtained about sector-specific differences instead of general questions about WPC as a substitution technology.

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Data Availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Informed Consent Respondents were informed through statements in the questionnaire and through verbal information by the students that they were taking part in a survey. In this way, informed consent was obtained.

Competing of Interests The author declares that there are no competing interests.

References

Accorsi R, Cascini A, Cholette S, Manzini R, Mora C (2014) Economic and environmental assessment of reusable plastic containers: a food catering supply chain case study. Int J Prod Econ 152:88–101. https://doi.org/10.1016/j.ijpe.2013.12.014

Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50:179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Akadiri PO, Olomolaiye PO, Chinyio EA (2013) Multi-criteria evaluation model for the selection of sustainable materials for building projects. Autom Constr 30:113–125. https://doi.org/10.1016/j.autcon.2012.10.004

Badji C, Soccalingame L, Gara H, Bergeret A, Benezet JC (2017) Influence of weathering on visual and surface aspect of wood plastic composites: correlation approach with mechanical properties and microstructure. Polym Degrad Stab 137:162–172. https://doi.org/10.1016/j.polymdegradstab.2017.01.010

Beg MDH, Pickering KL (2008) Accelerated weathering of unbleached and bleached Kraft wood fibre rein-forced polypropylene composites. Polym Degrad Stab 93(10):1939–1946. https://doi.org/10.1016/j.polymdegradstab.2008.06.012

Brockhaus S, Petersen M, Kersten W (2016) A crossroads for bioplastics: exploring product developers’ challenges to move beyond petroleum-based plastics. J Leaner Prod 127:84–95. https://doi.org/10.1016/j.jclepro.2016.04.003

Carus M, Partanen A (2018) Natural fibre-reinforced plastics: establishment and growth in niche markets. nova-Institut, Germany. https://renewable-carbon.eu/news/natural-fibre-reinforced-plastics-establishment-and-growth-in-niche-markets/. (Accessed December, 5th. 2022)

Carus M, Partanen A, Dammer L (2016) Are there Green Premium prices for bio-based plastics? Hürth 2016. http://bio-based.eu/downloads/are-there-greenpremium-prices-for-bio-based-plastics/. (Accessed December, 5th. 2022)

Cohen J (1988) Statistical Power Analysis for the Behavioral Sciences. Hilsdale, N.J.: L. Erlbaum Associates. https://doi.org/10.1016/C2013-0-10517-X

Eder A, Carus M (2013) Global trends in wood-plastic composites (WPC). BioplasticsMagazin 8:16–17. https://renewable-carbon.eu/news/media/news-images/20130905-01/WPC_bioplastics-MAGAZINE_1304.pdf (Accessed December, 5th. 2022)

Florez L, Castro-Lacouture D (2013) Optimization model for sustainable materials selection using objective and subjective factors. Mater Des 46:310–321. https://doi.org/10.1016/j.matdes.2012.10.013

Franzoni E (2011) Materials selection for green buildings: which tools for engineers and architects? Procedia Eng 21:883–890. https://doi.org/10.1016/j.proeng.2011.11.2090

Friedrich D (2019) Natural fiber-reinforced plastics composites: long-term physico-structural performance in façades. Acad J Civil Eng 37(2):412–419. https://doi.org/10.26168/icbbm2019.59

Friedrich D (2020a) Consumer behaviour towards Wood-Polymer packaging in convenience and shopping goods: a comparative analysis to conventional materials. Resour Conserv Recycl 163:105097. https://doi.org/10.1016/j.resconrec.2020.105097

Friedrich D (2020b) How regulatory measures towards biobased packaging influence the strategic behaviour of the retail industry: a microempirical study. J Clean Prod 260:121128. https://doi.org/10.1016/j.jclepro.2020.121128

Friedrich D (2021a) Attitude of building experts towards novel bio-based wood-polymer façades under various properties: a choice-based experiment and impact analysis. J Building Eng 35:102079. https://doi.org/10.1016/j.jobe.2020.102079

Friedrich D (2021b) Comparative analysis of sustainability technologies in the apparel industry: an empirical consumer and market study. J Environ Manage 289:112536. https://doi.org/10.1016/j.jenvman.2021.112536

Friedrich D (2021c) How environmental goals influence consumer willingness-to-pay for a plastic tax: a discrete-choice analytical study. Environ Dev Sustain 24(2021):8218–8245. https://doi.org/10.1007/s10668-021-01781-7

Friedrich D (2021d) Consumer and expert behaviour towards biobased wood-polymer building products: a comparative multi-factorial study according to theory of planned behaviour. Architectural Eng Des Manage 18(2021):73–92. https://doi.org/10.1080/17452007.2020.1865867

Friedrich D (2022a) How building experts evaluate the sustainability and performance of novel bioplastic-based textile façades: an analysis of decision making. Build Environ 207:108485. https://doi.org/10.1016/j.buildenv.2021.108485

Friedrich D (2022b) Success factors of Wood-Plastic composites (WPC) as sustainable packaging material: a cross-sector expert study. Sustainable Prod Consum 30:506–517. https://doi.org/10.1016/j.spc.2021.12.030

Friedrich D (2023) Thermoforming of wood-plastic composites: a compolytics-approach translating combined polymer and policy analyses into industrial design principles. Int J Adv Manuf Technol 124(5–6). https://doi.org/10.1007/s00170-022-10760-9

Heidbreder M, Bablok I, Drewsd S, Menzel C (2019) Tackling the plastic problem: a review on perceptions, behaviors, and interventions. Sci Total Environ 668:1077–1093. https://doi.org/10.1016/j.scitotenv.2019.02.437

Henriques A, Richardson J (2004) The Triple Bottom Line. Does It All Add Up? Routledge. ISBN 9781844070152

Keskisaari A, Kärki T (2018) The use of waste materials in wood-plastic composites and their impact on the profitability of the product. Resour Conserv Recycl 134:257–261. https://doi.org/10.1016/j.resconrec.2018.03.023

Khoshnava SM, Rostami R, Valipour A, Ismail M, Rahmat AR (2018) Rank of green building material criteria based on the three pillars of sustainability using the hybrid multi criteria decision making method. J Clean Prod 173:82–99. https://doi.org/10.1016/j.jclepro.2016.10.066

Klaiman K, Ortega DL, Garnache C (2016) Consumer preferences and demand for packaging material and recyclability. Resour Conserv Recycl 115:1–8. https://doi.org/10.1016/j.resconrec.2016.08.021

Kuzman MK, Klaric S, Baršic AP, Vlosky RP, Janakieska MM, Grošelj P (2018) Architect perceptions of engineered wood products: an exploratory study of selected countries in Central and Southeast Europe. Constr Build Mater 179:360–370. https://doi.org/10.1016/j.conbuildmat.2018.05.164

Lancaster JK (1966) A new approach to consumer theory. J Polit Econ 74(2):132–157. https://doi.org/10.1086/259131

Lettner M, Schöggl JP, Stern T (2017) Factors influencing the market diffusion of bio-based plastics: results of four comparative scenario analyses. J Clean Prod 157:289–298. https://doi.org/10.1016/j.jclepro.2017.04.077

Liobikienė G, Mandravickaitė J, Bernatonienė J (2016) Theory of planned behavior approach to understand the green purchasing behavior in the EU: a cross-cultural study. Ecol Econ 125:38–46. https://doi.org/10.1016/j.ecolecon.2016.02.008

Magnier L, Schoormans J (2015) Consumer reactions to sustainable packaging: the interplay of visual appearance, verbal claim and environmental concern. J Environ Psychol 44:53–62. https://doi.org/10.1016/j.jenvp.2015.09.005

Markström E, Kuzman MK, Bystedt A, Sandberg D, Fredriksson M (2018) Swedish architects view of engineered wood products in buildings. J Clean Prod 181:33–41. https://doi.org/10.1016/j.jclepro.2018.01.216

Martins G, Antunes F, Mateus A, Malça C (2017) Optimization of a wood plastic composite for architectural applications. Procedia Manuf 12:203–220. https://doi.org/10.1016/j.promfg.2017.08.025

Onwezen MC, Reinders MJ, Sijtsema SJ (2017) Understanding intentions to purchase bio-based products: the role of subjective ambivalence. J Environ Psychol 52:26–36. https://doi.org/10.1016/j.jenvp.2017.05.001

Osburg VS, Strack M, Toporowski W (2016) Consumer acceptance of Wood-Polymer composites: a conjoint analytical approach with a focus on innovative and environmentally concerned consumers. J Clean Prod 110:180–190. https://doi.org/10.1016/j.jclepro.2015.04.086

Peng Y, Liu R, Cao J, Chen Y (2014) Effects of UV weathering on surface properties of polypropylene composites reinforced with wood flour, lignin, and cellulose. Appl Surf Sci 317:385–392. https://doi.org/10.1016/j.apsusc.2014.08.140

Pohekar SD, Ramachandran M (2004) Application of multi-criteria decision making to sustainable energy planning - A review. Renew Sustain Energy Rev 8:365–381. https://doi.org/10.1016/j.rser.2003.12.007

Qi GY, Shen LY, Zeng SX, Jorge OJ (2010) The drivers for contractors' green innovation: an industry perspective. J Clean Prod 18(14):1358–1365. https://doi.org/10.1016/j.jclepro.2010.04.017

Rao RV, Patel BK (2010) A subjective and objective integrated multiple attribute decision making method for material selection. Mater Des 31:4738–4747. https://doi.org/10.1016/j.matdes.2010.05.014

Ratanawilai T, Taneerat K (2018) Alternative polymeric matrices for wood-plastic composites: effects on mechanical properties and resistance to natural weathering. Constr Build Mater 172:349–357. https://doi.org/10.1016/j.conbuildmat.2018.03.266

Reinders MJ, Onwezen MC, Meeusen M (2017) Can bio-based attributes upgrade a brand? How partial and full use of bio-based materials affects the purchase intention of brands. J Clean Prod 162:1169–1179. https://doi.org/10.1016/j.jclepro.2017.06.126

Roig I (2018) Biocomposites for interior façades and partitions to improve air quality in new buildings and restorations. Reinf Plast 62:270–274. https://doi.org/10.1016/j.repl.2017.07.003

Roos A, Lindström M, Heuts L, Hylander N, Lind E, Nielsen C (2014) Innovation diffusion of new wood-based materials - reducing the time to market. Scand J for Res 29:394–401. https://doi.org/10.1080/02827581.2014.931454

Scherer C, Emberger-Klein A, Menrad K (2018) Consumer preferences for outdoor sporting equipment made of biobased plastics: results of a choice-based-conjoint experiment in Germany. J Clean Prod 203:1085–1094. https://doi.org/10.1016/j.jclepro.2018.08.298

Seldén R, Nyström B, Långström R (2004) UV aging of poly(propylene)/wood-fiber composites. Polym Compos 25(5):543–553. https://doi.org/10.1002/pc.20048

Sijtsema SJ, Onwezen MC, Reinders MJ, Dagevos H, Partanen A, Meeusen M (2016) Consumer perception of bio-based products - an exploratory study in 5 European countries. NJAS - Wageningen J Life Sci 77:61–69. https://doi.org/10.1016/j.njas.2016.03.007

Soccalingame L, Perrin D, Benezet JC, Mani S, Coiffier F, Richaud E, Bergeret A (2015) Reprocessing of artificial UV-weathered wood flour reinforced polypropylene composites. Polym Degrad Stab 120:313–327. https://doi.org/10.1016/j.polymdegradstab.2015.07.013

Sommerhuber PF, Wenker JL, Rüter S, Krause A (2017) Life cycle assessment of wood-plastic composites: Analysing alternative materials and identifying an environmental sound end-of-life option. Resour Conserv Recycl 117:235–248. https://doi.org/10.1016/j.resconrec.2016.10.012

Statista (2022a) Kunststoff: Produktion vs. Verbrauch. https://de.statista.com. (Accessed December, 5th. 2022)

Statista (2022b) Wood-Plastic-Composites - Prognose zum weltweiten Marktvolumen bis 2022. https://de.statista.com/statistik/daten/studie/668616/umfrage/prognose-zum-globalen-marktvolumen-fuer-wpc/. (Accessed December, 5th. 2022)

Steenis ND, van Herpen E, van der Lans IA, Ligthart TN, van Trijp H (2017) Consumer response to packaging design: the role of packaging materials and graphics in sustainability perceptions and product evaluations. J Clean Prod 162:286–298. https://doi.org/10.1016/j.jclepro.2017.06.036

Tamrakar T, Lopez-Anido RA (2011) Water absorption of wood polypropylene composite sheet piles and its influence on mechanical properties. Constr Build Mater 25(10):3977–3988. https://doi.org/10.1016/j.conbuildmat.2011.04.031

Teuber L, Osburg VS, Toporowski W, Militz H, Krause A (2016) Wood Polymer composites and their contribution to cascading utilisation. J Clean Prod 110:9–15. https://doi.org/10.1016/j.jclepro.2015.04.009

van den Oever M, Molenveld K, van der Zee M, Bos H (2017) Bio-based and biodegradable plastics – facts and figures focus on food packaging in the Netherlands. Rapport Nr 1722. https://doi.org/10.18174/408350

Vecchio R, Annunziata A (2015) Willingness-to-pay for sustainability-labelled chocolate: an experimental auction approach. J Clean Prod 86:335–342. https://doi.org/10.1016/j.jclepro.2014.08.006

Wong J, Lee H (2008) Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. Build Environ 43:108–125. https://doi.org/10.1016/j.buildenv.2006.11.019