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Value added and employment effects in Finland when wood fibre is substituted for plastic in food packaging–A case study

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ABSTRACT

In the food and beverage industry, the development of new bio-based packaging materials and films is lively nowadays, and in the future, these materials will increasingly replace the current plastic-based packaging solutions. This demand, however, will inevitably have an impact on wood raw material availability. Using cold cuts and chocolate bars as pilot food package product cases and input-output analysis, this study evaluates projected roundwood need, value added, and employment in Finland when certain volumes of packaging materials are converted from traditional plastic to wood fibre-based. The results indicated that the substitution effects both for value added and employment remained rather small. In the cases studied, the substitution effect on consumption of softwood pulpwood was only a few thousand cubic meters over bark, whereas the reduction of plastics was up to 3,000 tonnes. Economic effects, however, would be highly significant if production were scaled to several different food packages, especially from the viewpoint of value added. More research is clearly needed to analyse economic, environmental, and social aspects on a larger scale, as well as pros and cons when plastic is replaced by alternative fibre-based materials in food packaging.

1. Introduction

In the packaging industry, especially food and beverage packaging, the use of plastic has increased manyfold during recent decades (Geyer et al., 2017). In addition, the food packaging market is projected to grow worldwide at an annual rate of up to 5 per cent (Kan and Miller, 2022) in the coming decades. The growth of the market is supported by many global megatrends, such as the increase of total population and the number of people living alone, as well as the growing middle class. At the same time, consumption habits are changing with the growing popularity of remote work, online food shopping, and fast food (Barone et al., 2021). Growth has been further accelerated during the past several years by the COVID-19 pandemic, which increased takeaway food consumption remarkably (Mallick et al., 2021), and the popularity of semi-finished products. In addition, the lifecycle of a food package is typically extremely short; in most cases, it is used only once.

Increasing use of plastics has substantial resource and environmental impact effects. For example, OECD estimates that raw material usage will double by 2060, causing severe consequences for the environment (OECD, 2018). The pressure for change on food packaging started with increased global awareness of non-biodegradable plastic littering the oceans. A significant part of plastic waste in the oceans comes from food packaging materials (Wiefek et al., 2021), creating pressure for the packaging material industry to find bio-based replacements for traditional plastic packaging materials (Verde et al., 2022). On top of that, consumers are putting pressure on the packaging industry to create and offer new food packaging solutions (Bor and O'Shea, 2022). In addition to usability features, environmentally conscious consumers are demanding changes, such as easy sorting and recycling of packaging materials, avoidance of overpacking, and reducing plastic in package design and packaging materials (Sonck-Rautio et al., 2024).

To meet simultaneous requirements for more environmentally friendly and non-fossil packaging raw materials, consumers' even more ecological preferences, climate change mitigation, littering prevention, changing political goals, and estimated increase of packaging volumes in markets (Sundqvist-Andberg and Åkerman, 2021), the packaging

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industry is rapidly developing new food packaging solutions made from renewable and more environment-friendly materials. In particular, Nordic forest industry companies are actively developing new packaging materials to meet the growing demand for fibre-based materials in food packaging. Wood and agricultural side streams offer the most interesting source of raw materials for food packages to either partially or completely replace fossil-based plastics, glass, and metals. However, on one hand, using forest resources means allocating limited forest resources as well as having an impact on other closely related ecosystems, such as water and soil (Aro et al., 2022; Asada et al., 2020). On the other hand, restricted availability of certain agricultural side streams could cause a shift to consuming other resources that are more easily available, thus possibly even impacting feed or food crops (Gerassimidou et al., 2021). Besides, the growth of environmental and climate awareness has been strongly reflected in the policies enacted in different parts of the world (Herrmann et al., 2022; Nielsen et al., 2020; Sundqvist-Andberg and Åkerman, 2021). In the 2010s, the European Union (EU) promoted the use of wood products for climate change mitigation (Gustavsson et al., 2017). Recently, discussion concerning the new EU Forest Strategy has been lively around certain topics, such as meeting the EU's biodiversity targets as well as restoration and protection of forests. The European Commission is currently working on several initiatives related to these topics (European Commission, 2023; Finnish Government, 2021). The outcome of multiple initiatives remains to be seen in EU member countries, but certainly these initiatives will also influence the volume of wood-based materials available in the market in the future.

While a myriad of analyses focuses on the effects of the technical transition from plastic to fibre-based packaging in the food sector, or sustainability, using, e.g., life-cycle analysis (LCA) and substitution coefficients between renewable and non-renewable raw materials (Guillard et al., 2018; Korhonen et al., 2020; Molina-Besch and Keszleri, 2023; Schenker et al., 2021; Stark and Matuana, 2021), studies concentrating on the economic effects have been rare (cf. Hurmekoski et al., 2018; Li et al., 2021). Although there have been studies with respect to the circular economy and more efficient recycling of plastic (see, e.g., Andreasi Bassi et al., 2022; Cimpan et al., 2023; Wiebe et al., 2023) and although these studies consider the economic aspects to some extent, they do not specifically discuss plastic replacement with fibre-based solutions. While many studies highlight the environmental benefits of shifting from fossil-based plastic to bio-based materials (cf. Cordier et al., 2024; Filiciotto and Rothenberg, 2021; Hurmekoski et al., 2023; Leejarkpai et al., 2016) or consumer perceptions (Ciano et al., 2023; Fletcher et al., 2024; Nuojua et al., 2024; Sokolova et al., 2023), studies dealing with real economic effects can be more nuanced (e.g., Beltran et al., 2021; Lau et al., 2020; Ogutu et al., 2023). Biodegradable materials often come with higher initial costs due to limited production capacity and material sourcing challenges (Nesic et al., 2020, Hassegawa et al., 2022, Mori, 2023). The complete replacement of fossil-based goods by biopolymer-based ones can be costly and most likely is not even realistic (Friedrich, 2021), even though production costs could decrease over time with increased adoption and technological advancements and promote the transition to a circular economy together with financial benefits (Roy et al., 2021, Di Bartolo et al., 2021). As an exception, however, Stoica et al. (2020) used an econometric efficiency model to show that in the case of bio-based biodegradable synthetic biopolymers, the impact on the cost of the finished product is about 6–10 times higher than the petroleum-based polymers' impact on food packaging. Lekavičius et al. (2023) claim that based on their socioeconomic impact analysis, the influence on the domestic economy is beneficial if traditional plastic carrier bags are replaced either by bio-based carrier bags (+ €47 million) or paper bags (+ €8 million). The highest impact on employment effects was found to be in the biobased plastic scenario, resulting in 892 additional posts.

To overcome the gap in knowledge and to give precise calculations, this study is novel in trying to evaluate the economic effects simply through the material replacement point of view, when wood fibre-based materials are substituted for fossil-based plastic in food packaging. Using input-output analysis and two separate case studies (that is, cold cut and chocolate bar packages), this study evaluates the changes in value added, employment, and roundwood need when certain volumes of packaging materials are converted from traditional plastic to wood fibre-based. In this study we aim to reply to the following research questions:

i) How much roundwood is needed to substitute for a certain amount of plastic?
ii) How much fossil-based plastic could be replaced? and
iii) What would be the value-added and employment effects on the Finnish economy in the chosen case examples?

Although the harmful environmental effects of plastic on the oceans, for example, are global, Finland is used as the case country of the study. The research and development work of food packaging, such as the chosen case studies, is carried out in Finland, and the necessary statistical information is available: the amount of pulpwood fellings, technical production coefficients, and the input-output coefficients needed in economic analysis. In Finland, the guiding economic principle of the new Finnish bioeconomy strategy is 'Doing More from Less'. That is, natural resources should be more efficiently used through principles of circular economy, and the consumption of natural resources should not be increased, but rather decreased. The same amount of wood should yield more wood-based products, thereby to increase value added through higher processing degree of the forest products manufactured in Finland for local and global markets (Ministry of Economic Affairs and Employment, 2022). In addition, efficient recycling of existing raw materials enhances resource efficiency; therefore, it is seen as one of the fundamental aspects in the new bioeconomy strategy. The adaption and penetration of fibre-based food packages mean either the establishment of new packaging lines or the conversion of old lines, such as printing paper lines, for packaging. These changes evidently mean economic effects on employment, value added, and tax accrual, among others. Furthermore, the availability, use, and sustainability of raw materials induce many other direct and indirect economic, social, and environmental consequences. The results of this study help to understand the possibilities to replace fossil-based plastic with wood-based raw materials in packaging and the magnitude of need for raw materials and to establish, for example, climate policy frameworks as well as support decision making for both policymakers and companies, especially in the long term (see also Hagemann et al., 2016). This study also tries to respond to the research needs indicated by Hetemäki and Hurmekoski (2016) on the market for new forest products, raw material needs and their regional economic effects.

2. Materials and methods

The analysis examines two different types of food packages, in which fossil-based plastic is partially replaced by novel wood fibre-based solutions. The first case considers meat-based *Cold cuts* because of their high technical requirements for food packaging, especially for the barrier properties. The second case, *Chocolate bars*, was chosen because chocolate and snack bar packages are the fourth-most frequently found single-use plastic products (SUPPs) on the seashores of the EU (European Parliament, 2021). In both cases, the mainly wood fibre-based replacement packaging materials are considered renewable raw materials, and they are biodegradable (i.e., the material breaks down into water, carbon dioxide, methane, and biomass through biological activity (Gerassimidou et al., 2021)) both in soil and marine environments (Luoma et al., unpublished results; see also King et al., 2024; Luoma et al., 2022; Vikman et al., 2015). Recycling the packages is easy for consumers because the packages can be sorted into the cardboard recycling stream, similarly to the sorting instructions of current Finnish food packages which are made of cardboard and might include plastic coating and/or parts. The new materials of demo packages have been studied in a research project; thus, the technological feasibility and the upscaling potential of the new materials have been evaluated (Luoma et al., unpublished results; see also, e.g., Jaiswal et al., 2021; King et al., 2024; Kumar, 2022; Leppänen et al., 2022; Luoma et al., 2022). For the chocolate bar packages, shelf life and biodegradability tests have been carried out, but for the cold cut packages (both for materials and the design of package) additional research is still needed to verify the suitability of the new material for cold cuts. Moreover, the new packaging materials have been thoroughly evaluated from the environmental point of view by using life-cycle assessment (LCA) methods (Silvenius et al., unpublished results).

2.1. Current and replacement packaging materials

Currently, both the cold cuts and chocolate bars are mostly packed in plastic packages. For cold cuts, the current packaging materials are mainly some specific polymers (McMillin, 2017), such as polypropylene (PP), polyethylene terephthalate (PET), and low-density polyethylene (PE-LD) combinations. The receptacle is usually made of some rigid polymer type, such as PET, PP, or high-density polyethylene (PE-HD), and the peelable lid of the package is made from a polymer type that is especially suitable for heat sealing, such as PE-LD. Reclosable cold cut packages that can be opened and closed multiple times are typically made entirely of rigid polymer types.

For chocolate bars, the variety of polymers is greater, such as PE-LD or biaxially oriented polypropylene (BOPP) with a thin layer of aluminium foil (Robertson, 2013). The packaging solutions are already partly fibre-based (Bianchi et al., 2021); however, they often require some use of polymers or aluminium foil to improve their barrier properties (Hult et al., 2010) and increase the shelf life of the product itself. Currently, chocolate bar wrappers might include only a polymer coating for paper, or the wrapping might be made completely of plastic. Therefore, the amount of plastic used in chocolate bar packages varies.

Extrusion coating, as depicted in Fig. 1, is a commonly used processing method to create high-performance materials for food packaging (Toriseva et al., 2023). Lamination, as well as extrusion or lamination coatings, is used to improve the barrier (e.g., oxygen or water vapor) properties of the packaging material, especially in food applications. The barrier properties are crucial to maintain the good quality of the food and, hence, extend the shelf life of food (Robertson, 2009). Extrusion coating is in most cases suitable for various food products, but it has been challenged by dispersion coatings, which have better repulping properties at the end of the lifecycle (Kuusipalo, 2003). There might, however, be slight differences in the barrier properties.

Fibrillated cellulose dispersion coating, as a single layer for a paper-based structure, is made of cellulose fibres that are broken down into smaller fibres, such as cellulose nanofibers (CNF) and cellulose nanocrystals (CNC) (Li et al., 2022). These smaller, nanoscale fibre fractions have favourable characteristics, such as high strength and strong mechanical properties, required barrier properties, biocompatibility, and renewability (Li et al., 2022; Stark and Matuana, 2021). Cellulose nanomaterials are therefore used, e.g., for coatings to improve packaging material properties, especially when porous materials, such as paper, are used (Stark and Matuana, 2021).

Luoma et al. (unpublished results; see also King et al., 2024; Kumar, 2022; Leppänen et al., 2022; Luoma et al., 2022) have pilot tested two alternative fibre-based solutions—that is, paper-based and film-based solutions—to replace the traditional plastic in food packaging. The structures of these novel materials in both case packages are depicted in Fig. 1. In a paper-based structure, for example, the outer layer is paper while the inner layer consists of BioPBSA (Poly(butylene succinate-co-butylene adipate)) coating and fibrillated cellulose dispersion coating.

The replacement materials are biobased, in that paper and fibrillated cellulose are wood fibre-based and BioPBSA is made of agricultural waste streams. Because these materials are also heat-sealable, which is often a requirement by the food industry for an easy production process, they can totally replace the traditional plastic-based materials. The different material options are briefly introduced in Table 1.

In these two novel packaging structures, the share of wood fibre-based material varies between 6 and 70 per cent. The sleeve is expected to be 100 per cent wood fibre-based. Moreover, bio-based polybutylene succinate (PBS), a soft and flexible semi-crystalline polyester with food contact approval (Luoma et al., 2022; PTT MCC Biochem Company Limited, 2018), is used in the case structures (Fig. 1). The renewable resources used are partially made of biomass, mainly from agricultural side streams, such as sugarcane, cassava, and corn (Mitsubishi Chemical Corporation, 2023). Thus, given that these kinds of film materials are imported into Finland and not manufactured from wood fibres, the raw material need of the BioPBSA layer and the corresponding economic consequences are not included in the forthcoming economic calculations; in this study we concentrate on the possible impacts on the Finnish market only.

It is also noteworthy that these novel materials are still in the piloting

Table 1
Description of the current and replacement materials of the case examples.

	Traditional packaging materials (plastic)	Replacement materials (incl. in the following calculations)*
Chocolate bars	Various polymers, often BOPP	Paper with coating (BioPBSA + fibrillated cellulose)
Cold cuts	Various polymers, often PET/PE	*Lid:* Film (BioPBSA + fibrillated cellulose) *Receptacle:* Paper with coating (BioPBSA + fibrillated cellulose) *Belt (opt.):* Paper or cardboard

[*] To see the whole structure of the new materials, see Figure 1.

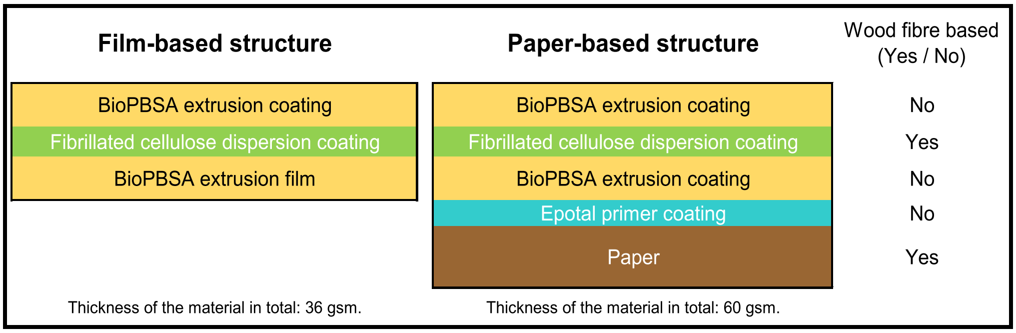

Fig. 1. The technical features of multilayer film-based and paper-based packaging structures. Note: the figure is illustrative and does not depict the scale of the layers nor the structure. The thickness is measured as grams per square meter (gsm). Source: Modified from Luoma et al. (unpublished results) and Kumar, 2022.

phase; thus, the streamlining of the material combination is only intended to be done in the industrial scale production phase. Additionally, the cold cut package design, as depicted in Fig. 2, has not yet been tested. Thus, more lab scale testing is needed in regards of the packaging materials used in the cold cut demo packages.

2.2. *Process description*

Since the studied package structures are still in the pilot phase, the actual amount of fibre needed for industrial production remains uncertain. Therefore, we use different alternatives, based on changes in the package design, thickness of materials used, or production volumes in number of pieces, to visualize how much wood fibre is needed to substitute for fossil-based plastic, either totally or partially, in both food package cases. This is then further broken down into needs for pulp and corresponding roundwood volumes, and finally supported with a more profound qualitative analysis of the possible economic impacts on the Finnish economy. The details of the thicknesses of materials in grams per square meter (gsm) for wood fibre-based materials in different alternatives are given in Table 2. The estimates for chocolate bars are calculated for various production volumes. For the cold cuts, there are four different scenarios (Table 2): S0: Structure without any belt (see Fig. 2); S1: Structure with belt but without any functionality; S2: Structure with belt and with functionality, option I; S3: Structure with belt and with functionality, option II. The difference between S2 and S3 is the belt structure, which in S3 is sturdier, i.e., it better withstands the closing and opening of the package multiple times.

Table 2
Details of the wood fibre-based material thicknesses used in alternative calculations, grams per square meter (gsm).

	Chocolate bars	**Cold cuts**			
		Scenario 0 (S0)	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Paper thickness, receptable only	40	40	40	80	80
Fibrillated cellulose dispersion coating thickness, receptable and lid	2	2	2	2	2
Paper thickness, belt structure	N/A	N/A	40	120	180

N/A = Not applicable

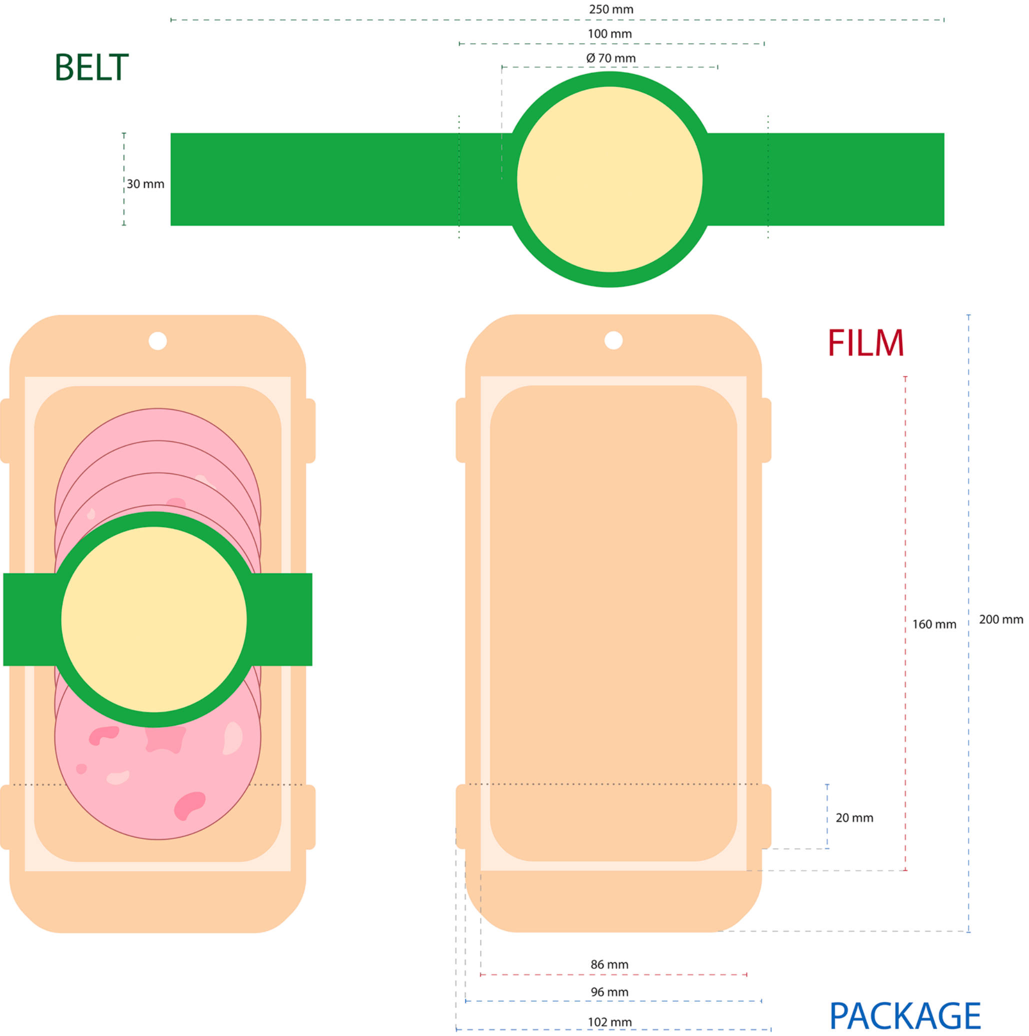

Fig. 2. Illustrative example of a possible design of cold cut package when using novel biobased and biodegradable packaging materials. Source: VTT Technical Research Centre of Finland.

When estimating the fibre need, we have also included a comparison for alternative package design of cold cuts stemming from consumer requirements. As found by Sonck-Rautio et al. (2024), consumers frequently expect a reclosability function, e.g., such as a belt depicted in Fig. 2, in cold cut packages to preserve the food better.

Wood fibre use in food packaging barrier materials or films is typically reported as grams per square meters, whereas the consumption of fibre (pulp) is given in cubic meters, and the units of measurement must be unified. To evaluate the square meter production of paper from 1 tonne of fibre, i.e., kraft pulp which is nearly all pure cellulose fibres (Klemm et al., 2011), the calculation method presented by Starkey et al. (2021) is utilized. The outcome is then converted into square meters (m^2) by using a multiplier (Metric Conversions, 2022)

(1) $\mathrm{msf} = 92.90304\ \mathrm{m}^2$.

The fibre need in tonnes was calculated for two alternative fibre-based materials which would substitute the current packaging material in chosen case examples (Table 2). As depicted in Fig. 1, in the film-based structure the package contains only fibrillated cellulose dispersion coating, which is made of bleached softwood pulp. In the paper-based structure, the base of the package, i.e., the paper part, is made totally of unbleached softwood pulp. It is generally used for unbleached paper and cardboard for packaging purposes, especially to improve the strength properties of the packaging material but also to improve the paper and cardboard machines' runnability during the production phase (Rantala et al., 2018).

The pulp need of the dispersion coating in both structures was evaluated by using a multiplier generated from the estimated yield (around 80 per cent, or even higher (Khakalo et al., 2021; Lehmonen et al., 2017; Pere et al., 2020)) of the enzymatic production process of nanocellulose. Therefore, when further evaluating the roundwood need for the fibre-based package cases, we used the multipliers 5.75 (bleached) and 5.56 (unbleached) to convert 1 tonne of softwood kraft pulp to the softwood pulpwood consumption in cubic meters (m^3, over bark) (Kulju et al., 2023).

No data of total annual use of cold cut and chocolate bar packages exist in Finland, but we used computational way to estimate the volumes of these packages. While there are available data for annual consumption of cold cuts in kilograms per person in 2016 in Finland (Aalto, 2018), the total annual consumption figure in kilograms was calculated first by multiplying the annual consumption of cold cuts in kilograms per person by Finland's population in 2016 (population above 10 years old; infants and small children are excluded) (Statistics Finland, 2023a). Then, the obtained figure of total annual consumption in kilograms was divided by the median weight of a single cold cut package (gross weight of 180 grams), obtained from GS1 data (GS1 Finland, 2022), resulting in an estimate of total annual consumption of cold cut packages in number of packages.

Similarly, first, the annual consumption of chocolate bars with a typical gross weight of about 40 grams was estimated. For this, an estimate of one large Finnish chocolate bar manufacturer's annual chocolate bar consumption in 2018 in Finland was used (Kalsta, 2020). Combining this information with the manufacturer's annual market share, we developed an estimate of total annual production of chocolate bar packages in Finland in 2018.

2.3. *Input-output analysis*

The economic analysis was done using the input-output method, the principles of which have been well described in the literature (e.g., Jackson, 2020; ten Raa, 2017). The method considers the direct and indirect value added and workforce effects on the national economy when plastic is replaced by wood fibre in the production of case products. The direct effects refer to the internal effects on the forest sector's industries, and the indirect effects are the result of the fact that a change in production in the forest sector also leads to a change in the production of industries outside the forest sector.

The production of new fibre-based packages needs wood, and the processing is done in the pulp and paper industry. Hence, the economic effects are assessed in the input-output model by applying harvest output values to the forestry industry and production value to the pulp and paper industry. In these case examples, changes in production volumes in the forest sector (direct effects) require, for example, an increase in services, production of intermediate products, retail trade and maintenance volumes in other industries as well (indirect effects) affecting value added and employment. The starting point in the input-output method is the connection between output (vector x) and final product demand (vector y)

(2) $x = Ly$, where $L = (I\text{-}A)^{-1}$ is the inverse Leontief matrix consisting of the identity matrix I and the input-output coefficient matrix A. The calculations were performed with the so-called output model derived from the basic model described above, where the analysis is based on Szyrmer's (1992) 'total flow' matrix

(3) $T = L\hat{L}^{-1}$, where $\hat{L}^{-1}$ is a diagonal matrix consisting of the diagonal elements of the inverse Leontief matrix. In the output model, the analysis is based exclusively on the output levels of the considered industries and the connections between industries, which in the model are described by the input coefficient matrix A. The details of this sophisticated calculation method are presented in Vatanen (2001, 2011).

Statistics Finland publishes input-output tables for 64 industries. The industries describe the product flows in the national economy and dependencies between the industries, as well as the use of products both as intermediate products for the manufacture of other products and as final goods for consumption, capital formation, and export (Statistics Finland, 2023b). The industries are aggregated and do not separately consist of, for example, a recycling sector. The most recent input-output data of the Finnish national economy from 2021 and the statistical data of national accounts from 2021 were used in the analysis (Statistics Finland, 2023c).

Since the input-output method is based on changes in monetary values, the production values were obtained by multiplying the production volumes by the product's market prices. In forestry, the production value was obtained by multiplying the amount of roundwood needed by the average stumpage price of pine pulpwood in 2022 in Finland (€19.79 /m^3). Although market values for chocolate bar and cold cut packages in Finland are not available, the calculated values for these products were obtained by multiplying the amount of softwood pulp needed in production by the unit price of export of Finnish unbleached softwood sulphate pulp in 2022 (€592/t). In the model, changes in the value of production spill over into income and employment effects for both these and other industries. Since there are no export nor import data on the case products and since the production quantities have been adjusted according to domestic consumption, foreign trade has been left out of the analysis for the sake of simplicity. Similarly, due to the lack of data the effects of reducing plastic in production have not been considered.

Although the input-output method is widely used in the analysis of economic effects and fits well with this case study, the limitations of the method should also be considered when interpreting the results. First, the method is static and does not consider the development of technology, changes in production processes, changes in interactions between the industries, or economies of scale in production. Second, it generally does not consider price elasticities or the market's reaction to price changes during business cycles, which can lead to misleading results, especially in situations where prices and demand fluctuate significantly. Finally, the model usually examines only certain aspects of the economy, such as production or consumption, and ignores many other economic variables, such as lump sum investments or public finances. Therefore, the results obtained with the method must be interpreted as indicative and they cannot be used for dynamic long-term forecasting.

3. Results

Using the calculation method by Starkey et al. (2021), the information on the substitution materials in Fig. 1 and Table 2, and the computational estimate of annual package usage, the total needs of fibre in tonnes and packaging material in square meters for both case examples were calculated first. These, in turn, were converted into softwood roundwood consumption in cubic meters (m^3) over bark, which were then used as inputs in the input-output model to analyse income and employment effects.

Table 3 depicts the results when current polymer-based packaging materials are replaced by two alternative wood fibre-based layer structures, as shown in Fig. 1, for both the cold cuts and chocolate bar packages, including weight details of each material type and an estimation of total packaging material weight for the estimated number of units. According to the computational estimate, the production of 220 million cold cut packages in 2016 in Finland, whose unit weight is 14 grams, required approximately 3,080 tonnes of plastic using current technology. When substituting fibre-based materials, the packaging material need for the same number of units is estimated to be around 370 tonnes when a basic structure (no belt) is used. Thus, in the substitution structure, the unit weight of the package is significantly lower with respect to plastic use, promoting other economic efficiencies—for example, in logistics.

In the case of chocolate bars, the total consumption was estimated to be 193 million units in 2018 in Finland. However, the true value is difficult to estimate because it would require sales data from each chocolate bar brand, which is not publicly available. While the current chocolate bar packages also contain materials other than plastic, the 100 per cent substitution is only hypothetical. The current amount of paper-based packaging materials varies, depending on the calculation method, but approximately 25 to 45 per cent of chocolate bar wrappers can be estimated to be paper-aluminium combinations instead of pure plastic wrappers, according to GS1 data (GS1 Finland 2022). Therefore, the maximum substitution potential in practice cannot be higher than 75 per cent, as chocolate bars are already partially packed in fibre-based materials. Often these packages include polymers as barrier material, but the amount of plastic is minor. Yet, this thin polymer layer affects the biodegradability of the packaging material; in most cases, the polymer is not biodegradable at all, and therefore especially causes problems if it ends up in nature, either intentionally or unintentionally. Given this assumption, the current packaging technology consumed approximately 120 tonnes of plastic in the production of 145 million units of chocolate bars, the unit weight of which was 0.83 grams. Thus, in this case, the unit weight of the paper-based substitution material, that is, 1.02 grams, is somewhat higher with respect to plastic packaging.

Table 3
Summary of the packaging materials used in case examples including weight details. Basic structure only.

Cold cuts	
Traditional packaging material (plastic)	
Material to replace	Various polymers, often PET/ PE
Weight of one package (g)	14.00
Maximum substitution potential[1)] of plastics for 220 million units (t)	3,080
Replacement material	
Film-based structure (lid)	BioPBSA + fibrillated cellulose
Paper-based structure (receptacle)	BioPBSA + fibrillated cellulose + paper
Belt (optional)	Paper / cardboard
Weight of one package (g)	1.68
Film-based structure (lid)	0.50
Paper-based structure (receptacle)	1.18
Package weight of 220 million units (t)	370
Film-based structure (lid)	110
Paper-based structure (receptacle)	260
Packaging material weight (gsm)	
Film-based structure (lid)	36
Paper-based structure (receptacle)	60
Belt (optional)	40, 120 or 180 (with functionality)[2]
Chocolate bars	
Traditional packaging material (plastic)	
Material to replace	Various polymers, often BOPP
Weight of one package (g)	0.83
Maximum substitution potential[1] of plastics for 145 million units (t)[3]	120
Replacement material in paper-based structure	BioPBSA + fibrillated cellulose + paper
Weight of one package (g)	1.02
Package weight for 145 million units (t)[3]	148
Packaging material weight (gsm)	60

Note: Figures include all material layers. The design for chocolate bars has been preliminary tested. The design for cold cuts has not been tested. Material losses are excluded.

[1] Constructive value only.

[2] Values for calculations only; design not tested in practice.

[3] Total annual consumption was estimated to be around 193 million units. As the packages are partly fibre-based already, the annual consumption figure is lower in the calculations.

3.1. Pulp need

When using different percentage shares of wood fibre in the substitution process, the consumption and need of fibre (that is, softwood pulp) evidently varies along with the thickness of the layers, as was depicted in Fig. 1 and Table 2. Fig. 3 summarizes the results in alternative production volumes when plastic is partially replaced with wood fibre-based materials for chocolate bar packages.

When material losses are excluded, the estimated substitution potential of 145 million units of chocolate bars results in a need for pulp close to 140 tonnes. A moderate increase in the number of pieces to 200 million units would mean a pulp need of nearly 190 tonnes; a more ambitious increase to 350 million units would mean a pulp need of close to 330 tonnes. For 1 billion units of snack bars, the need would rise to 935 tonnes of pulp. The material loss naturally increases along with the production volumes, and, in the highest volume case, the loss is 94 tonnes of pulp.

Fig. 4 presents the corresponding results when plastic is only partially replaced with wood fibre-based materials in cold cut packages, i.e., the paper used in the receptacle part and a thin layer of fibrillated cellulose used in the receptacle and lid. When also considering functionality and reclosability features of cold cut packages in their design, it requires, among other things, thicker material in the belt. This again increases the need for pulp significantly.

Generally, by using the substitution material in cold cut packages, the summed-up weight of the required material is 96 gsm for the receptacle and lid. As the majority of cold cut packages are still made of various fossil-based polymers, the realistic substitution potential with biobased materials is close to 100 per cent. Out of this, the share of wood fibre-based layer materials constitutes a bit more than 50 per cent of the total packaging material weight when a belt is also applied to the design. With a basic structure without belt, and excluding the possible material losses, the need for pulp is 270 tonnes for 220 million cold cut packages. If the belt structure is included, the consumption of pulp increases along with the increase of material thickness close to 970 tonnes. In the calculations, however, the material loss in production can be suspected to be 5 to 10 per cent of total material consumption for basic design. It is noteworthy, though, that in this specific cold cut package design (Fig. 2), the material losses in tonnes are fairly high, over 20 per cent when the belt structure is included. Hence, if marketing or functionality features are added, the material losses can be expected to be higher, and for instance, the material losses caused by the belt structure in this specific structure is as much as 35 per cent when calculated from the material in square meters.

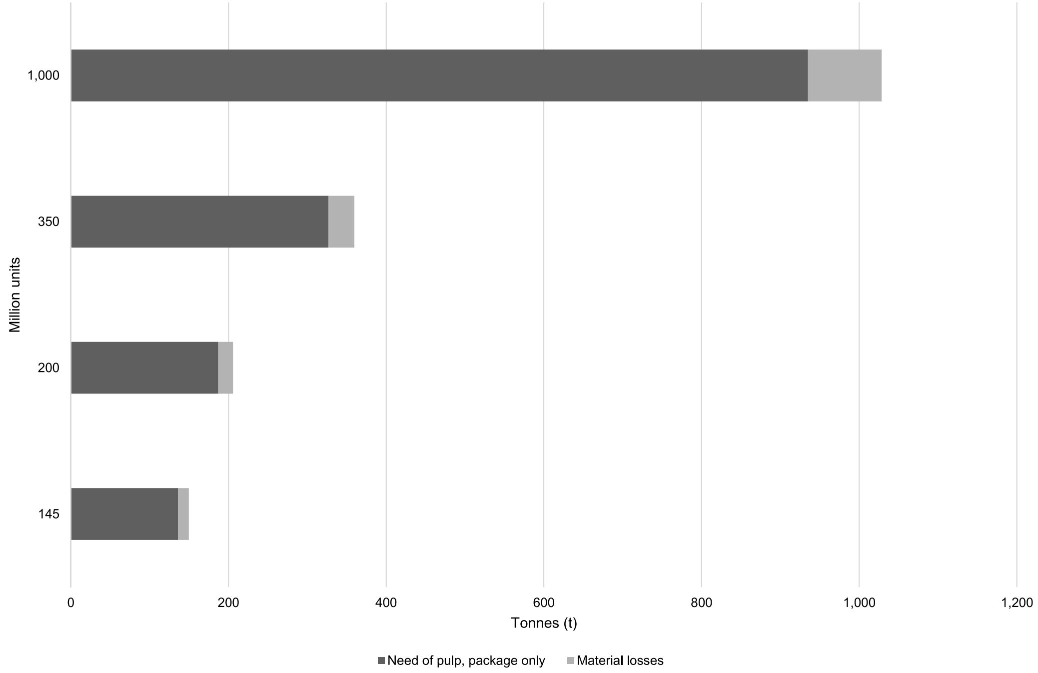

Fig. 3. Need of pulp (t) in chocolate bar packages estimated for various annual sales volumes.

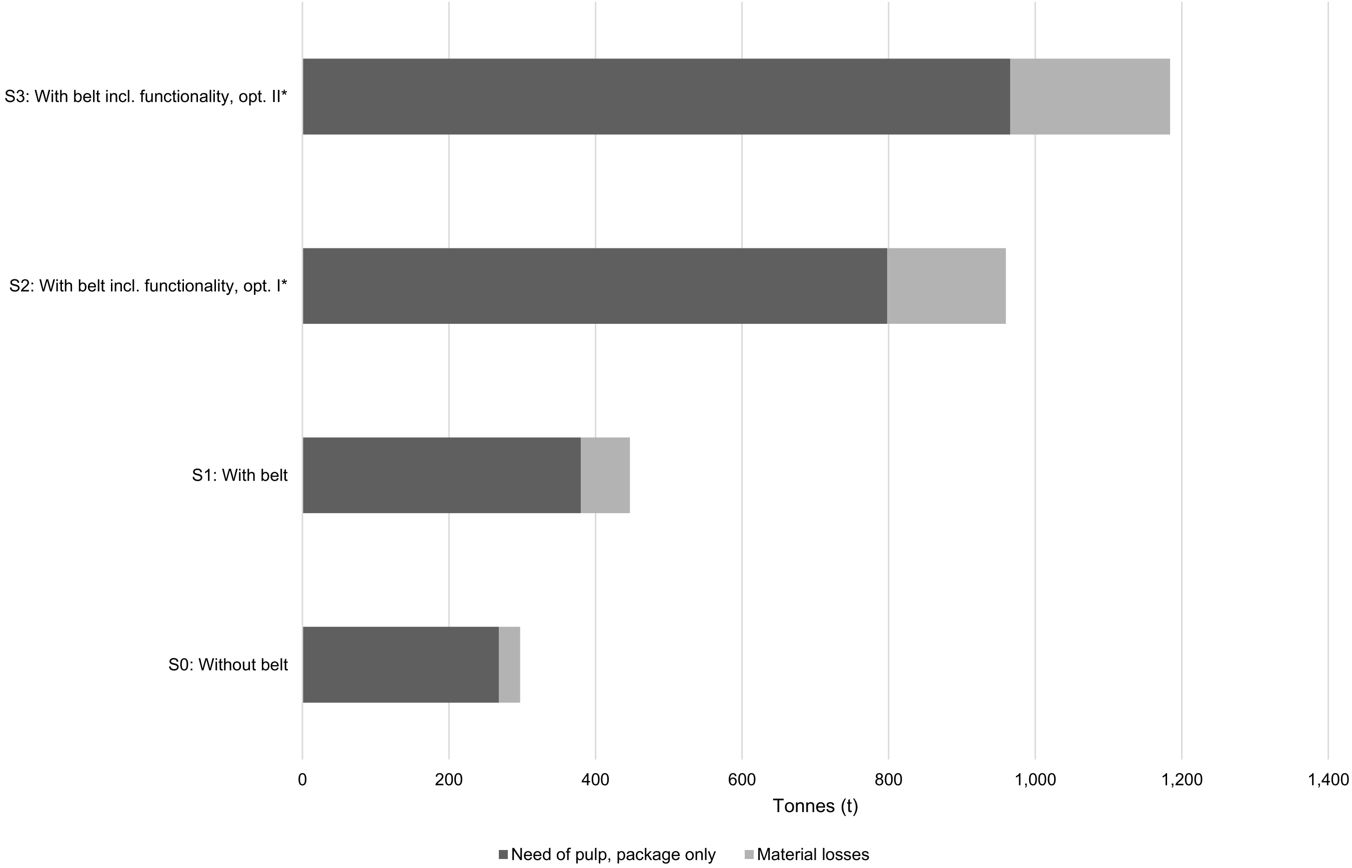

Fig. 4. Need of pulp (t) in alternative structures of cold cut packages for 220 million units, estimated by the variation of a package design.

3.2. *Roundwood need*

If plastic is partly substituted by wood fibre-based solutions in cold cut packages, using the pre-determined multipliers, the actual consumption of softwood pulpwood is approximately 1,665 to 6,600 cubic meters over bark, including material losses and depending on the design of the package (Fig. 5). While the average softwood pulpwood fellings during 2018–2022 in Finland were 27.1 million cubic meters,

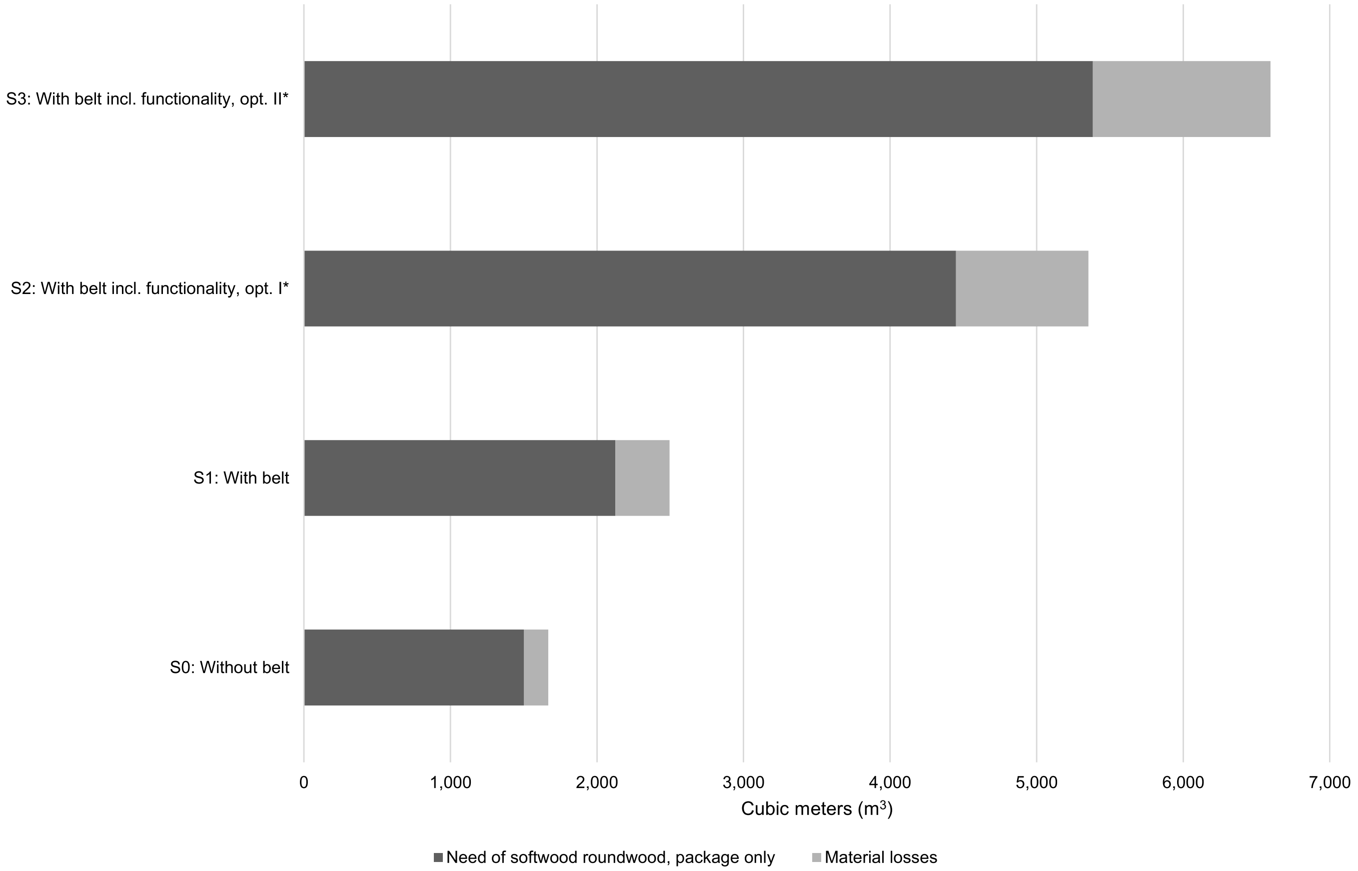

Fig. 5. Need of softwood roundwood (m^3) when substituting cold cut packages with novel, fibre-based packaging materials. Estimates by the various package design for an annual consumption of 220 million units.

the effect of the replacement of the current plastic cold cut packaging on the roundwood markets remains only marginal, even if the design enables reclosing the package. For the chocolate bar packages, the softwood pulpwood need is approximately 835 to 5,775 cubic meters (incl. material losses), depending on the production volumes (Fig. 6).

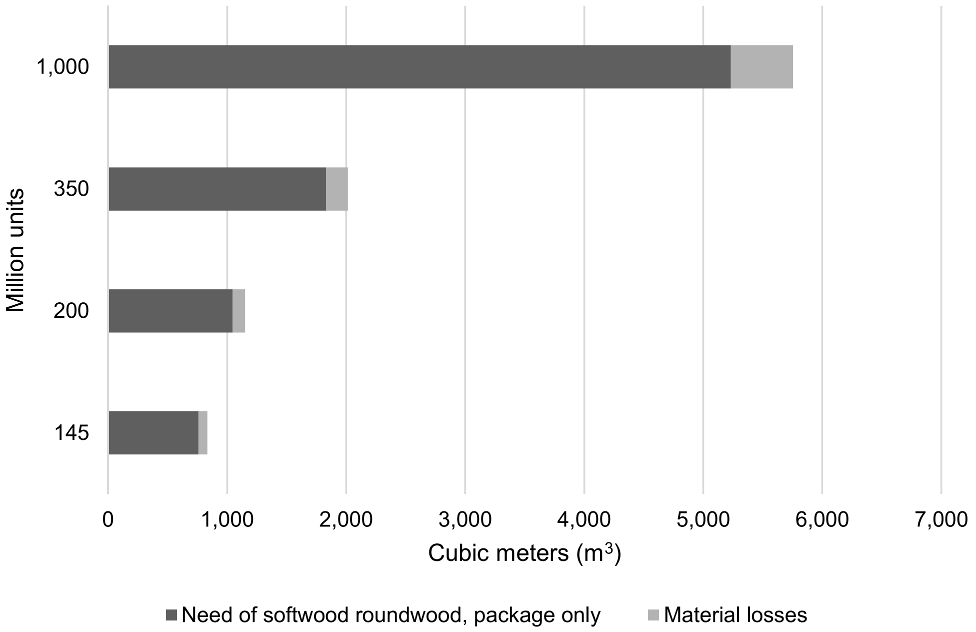

Fig. 6. Need of softwood roundwood (m^3) when substituting chocolate bar packages with novel, fibre-based packaging materials. Estimates for various annual sales volumes.

3.3. Value added and employment effects

Table 4 summarizes the results of input-output analysis for alternative production scenarios and softwood pulp need. In all cases, the effects remain quite small. In the forest sector, the direct economic effects due to the increasing need of roundwood are mainly targeting forestry, that is, harvesting, and the pulp and paper industry (Industries A02 and C17 in Standard Industrial Classification SIC 2008). The indirect effects are focused mainly on transport, maintenance, and services (Industries C33, H49 and H52). In the cases of alternative cold cut packages, the increase in value added is in the range of €100,000–440,000. The corresponding increase in employment is only 1–4 person-years.

The corresponding economic effects when replacing plastic with wood fibres are smaller in chocolate wrappers than in cold cut packages. This is naturally due to the lower need of procurement and processing of cellulose. According to the results, e.g., to produce 145 million fibre-based chocolate bar wrappers, it would increase value added only about €50,000 and employment only by 0.5 person-years. Along with the increase in pulpwood use and processing, the production of 1 billion units of chocolate bars creates value added up to nearly €400,000 and roughly 3 person-years of employment.

It is noteworthy that along with the calculated economic impacts above, there can be many other one-time short run costs and impacts which the input-output method cannot take into account. For example, changing packaging production lines from plastics to wood-based and acquiring machines require services, administrative work, and logistics, which temporarily increases added value.

4. Discussion

The results of this study showed that the impacts on the Finnish national economy when plastic is replaced by renewable wood-based raw materials were minor when considering the chosen case examples of cold cut packages and chocolate bar wrappers on their consumption in Finland only. The production process does not necessarily take many days or weeks to manufacture the number of example packages for consumption in domestic markets, and hence, the calculated increase in value added and the need for labour remain small. In forestry, for example, where the greatest need for labour is targeted, it takes about five months of personal work to harvest and transport 6,000 cubic meters of softwood, which was needed in conjunction with production of 1 billion chocolate bars.

In this study we used the input-output method, which is well established and widely used in economic analyses. One of its advantages is its suitability to explore the possible indirect economic effects on a fixed economic area. The model suits studies of natural resources and their possible use by utilizing observed data (Miller and Blair, 2009). Another clear benefit of input-output analysis is its low complexity compared to other statistical methods and data availability (Munksgaard et al., 2005). The results are provided in an easy-to-understand format. The limitations of input-output analysis, however, include the possible timeliness of data, or lack of it, various aggregation problems, and a quite static overview of the economy at a certain point in time (Ardent et al., 2009; Munksgaard et al., 2005; Rose, 1995). Other possible methods to evaluate similar types of economic effects through material substitution could be computable general equilibrium (CGE) models, for instance (Rose, 1995; Wiebe et al., 2023).

Due to the static nature of the input-output method and available data, the results are indicative. In addition, the results must be viewed and interpreted from a broader global perspective. When operating, the lines or factories that replace plastic in food packages would typically produce numerous other similar product groups during the year. For example, the substitution can be easily expanded and scaled to biscuit, snack, and protein bars, to mention a few. The global market for protein bars alone was valued at $4.7 billion in 2021, and it is projected to grow up to $7.1 billion by 2029 (Fortune Business Insights, 2022). If the new packaging materials gained further market share, the production volumes and resource needs would also multiply the economic effects. The value added can easily reach as much as several hundred million euros in Finland alone, and much more globally. At the same time, the amount of plastic waste can be significantly reduced. In 2018, the amount of food and beverage packaging consumed in the European Union was estimated at 1,130 billion packages in total. Since 2010, the amount of packaging waste has grown at an annual rate of about 4 per cent (Ketelsen et al., 2020). If development continues in the same direction, it is estimated that almost 107 million tonnes of packaging waste will be produced in the EU region in 2040 (European Parliamentary Research Service, 2023). Even if only some of the existing plastic-based packaging was replaced with wood fibre-based materials, it would significantly reduce the amount of plastic waste.

As production increases, the employment effects, on the other hand, do not necessarily increase to the same extent as the value added, because the production processes are largely automated. In Finland, roughly half of the pulp produced is processed domestically and half is exported abroad as market pulp. In 2023, the total export volume of bleached and unbleached pulp from Finland was as much as 4.04 million tonnes. In novel packaging solutions, replacing plastic with wood fibre might practically mean that the necessary cellulose would be further processed in Finland, and it would be removed from the exported market pulp. In calculations, only the total value chain from forest to processing industry was considered while the possible economic effects of reducing oil processing for plastic were omitted. In the case of utilising only market pulp in the substitution process, the value added, and employment effects would be smaller than those calculated above and would be directed to the processing industry and not to forestry. Anyway, the higher processing degree of pulp would be in accordance with the new Finnish bioeconomy strategy, 'Doing More with Less' (Ministry of Economic Affairs and Employment, 2022), and promote value added.

Li et al. (2015) have estimated that the new value-added products can be a significant driver for the Finnish economy in terms of GDP

Table 4

Value added (million €) and employment (number of employees) effects in different production scenarios.

	Cold cuts				Chocolate bars			
					Production volume (mill. units)			
	S0	S1	S2	S3	145	200	350	1,000
Value added effects								
Direct	0.06	0.09	0.21	0.26	0.03	0.04	0.08	0.22
Indirect	0.04	0.07	0.14	0.18	0.02	0.03	0.05	0.15
Total	0.10	0.16	0.35	0.44	0.05	0.07	0.13	0.37
Employment effects								
Direct	0.39	0.58	1.24	1.54	0.20	0.27	0.47	1.34
Indirect	0.55	0.83	1.79	2.21	0.28	0.38	0.67	1.92
Total	0.94	1.41	3.03	3.75	0.48	0.65	1.14	3.26

Note: Scenarios S0-S3 denote structures without belt, with belt and with belt including functionality (options I and II), respectively.

growth and could increase the total export value over 30 per cent by 2050. These estimates are based on the total production value of forest-based products in the Finnish bioeconomy. Packaging and bioplastics are indicated as near-term applications, and fibrillated cellulose solutions especially are seen as those with the most potential to drive the growth (Li et al., 2015), and packaging and plastics are among the most promising areas (Hurmekoski et al., 2018). The fibrillated cellulose solutions are indeed a significant part of novel food packaging solutions, especially when the required barrier properties for the paper-based packaging materials are improved.

As Hurmekoski et al. (2018) discuss, the most potential market growth of wood-based products could be expected, in addition to packaging and plastics, in biochemicals and biofuels, textile and construction industries. Simultaneously, the new markets create even more competition for roundwood resources (Hurmekoski et al., 2018). It is also worth remembering that in softwood pulp production, several other useful substances, such as lignin and tall oil, are being separated (Hassegawa et al., 2022; Hurmekoski et al., 2018), which are further processed for other purposes. In general, alternative utilization of forest resources as well as other closely related (water, soil) ecosystems means trade-offs between various actors and allocation of limited forest resources (Aro et al., 2022; Asada et al., 2020). If replacing plastic in packaging means ever-increasing fellings, it may also have a negative impact on the environment, forest biodiversity, recreational use of forests, and consumer welfare, as well as on climate aspects and carbon sequestration. All these aspects, however, would require separate studies to reveal pros and cons of increasing wood production on alternative utilisation of forests.

Along with the increasing awareness of environmental issues, changes in consumer preferences are an important aspect that might increase the raw material need significantly, as demonstrated in the cold cut package case. Functionalities, such as a reclosing feature, might be a crucial factor for a consumer to purchase a specific package, as well as the packaging's appearance, nature-friendliness, and good image (cf. Ketelsen et al., 2020; Sonck-Rautio et al., 2024). However, one key factor influencing the entry of new wood-based packages into the market would be the price of the product. The new product must not cost the consumer more than the old plastic-based product. The price competitiveness of the package, in turn, depends on the production technology and the price of the raw material. The latter depends on increasing alternative uses of forests, such as carbon sequestration; maintaining biodiversity and protection in the future; and the demand and use of wood for different products.

In addition to virgin raw material, recycled wood fibres are needed to ensure the adequacy of raw material. Traditionally it has been estimated that the wood fibre can be recycled three to seven times, after which it can be used only for energy production (Villanueva and Wenzel, 2007). For fibre-based packaging with current consumer recycling behaviour, the estimate is four to six times (Korhonen et al., 2020). Therefore, virgin wood fibres are always needed to improve the quality of the recycled fibres (Villanueva and Wenzel, 2007). Recent studies (e.g., Putz and Schabel 2018) claim that even after 25 recycling cycles, the properties of the fibre, such as fibre length and stability, remained somewhat unchanged. It is also noteworthy that the use of recycled material is often not allowed in direct contact with food for food safety reasons (Finnish Food Authority, 2022; Jamnicki Hanzer et al., 2021); when using a food-approved layer material between the food and the recycled material, the recycled material can be used in primary food packaging.

The possible packaging material losses during the production and packaging process increases the need for raw materials. A general estimation of the material loss during the production phase is a few per cent only, but if any specific features, such as marketing or a functionality feature, are added, the material losses can become significant. The packaging material wastage (scrap), however, can be recycled as well to minimise loss. The same applies to the paper manufacturing; the virgin paper scrap, particularly, can be recycled in the paper factory process (es), hence, reducing the losses of the raw material (Li et al., 2015). Trade-offs are always a result of various decisions made by individuals on how to use the current, often limited, resources (see also Aro et al., 2022). Thus, reliable data are essential to support and validate decision-making.

5. Conclusions and recommendations

In the food and beverage industry, the development of new bio-based materials and films is lively nowadays, and in the future, these materials will increasingly replace, at least to some extent, the current plastic-based packaging solutions. With two food pilot package products—-that is, cold cuts and chocolate bars—this study has determined how much fossil-based plastic can be replaced by renewable wood-based raw materials and evaluated the changes in value added, employment, and roundwood need, when certain volumes of packaging materials are converted from traditional plastic to wood fibre-based in Finland. Although the results based on the input-output method are only indicative, and in the case of individual products the value added and employment effects remained small, scaling production to a larger scale globally would bring significant economic effects, especially from the point of view of value addition. The employment effects may be smaller if only market pulp and not virgin raw material is used in the substitution process. In this case, the effects are mainly focused on production processes and not on forestry.

In the studied cases, the substitution effect on consumption of softwood pulpwood was only a few thousand cubic meters over bark, including material losses and depending on the design of the package. With respect to the total fellings of softwood pulpwood in Finland, this is only a marginal amount. Instead, along with the estimated increase in packaging volumes in the future, the reduction of plastic in food and beverage packaging will reduce littering and the possible harm caused by microplastics to the environment. In the cases studied, the reduction of plastics was up to 3,000 tonnes.

However, more research is clearly needed to analyse economic, environmental, and social aspects on a larger scale, as well as pros and cons when plastic is replaced by alternative fibre-based materials in food packaging. For example, the reduction of plastic is evidently a desirable thing from the point of view of the environment, but how much the substitution and the use of alternative fibre-based raw materials creates negative economic and social effects remains unknown. Also, the availability and sufficiency of raw materials to produce new fibre-based packaging, as well as the optimisation and scaling of materials to an industrial scale, require further research. The recycling of new packaging materials, for instance, the possible impacts on the purity of waste streams, and more efficient recycling of biobased plastics must also be carefully analysed.

CRediT authorship contribution statement

Taina Lahtinen: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jari Viitanen:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Antti Mutanen:** Writing – review & editing, Writing – original draft. **Jussi Lintunen:** Writing – review & editing, Writing – original draft, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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