Chapter 4
Outlook for the Forest-Based Bioeconomy

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Abstract The state of the world's managed forests is determined by the societal demands for wood resources and other ecosystem services. The forest-based sector is experiencing a number of structural changes, which makes the task of looking ahead important, but challenging. One of the main trends in the forest-based industries is diversification. On one hand, this refers to the emergence of new factors influencing the demand for forest-based products, which leads to substitution between forest-based products and alternative products. On the other hand, it refers to new market opportunities for forest-based industries in, for example, the construction, textiles, packaging, biochemicals and biofuels markets. As the importance of some of the traditional forest-based industries, such as communication papers, is declining, and new opportunities are simultaneously emerging, the sector will not necessarily be dominated by single sectors in the long term. However, research illuminating the possible impacts of the expected structural changes of the forest-based sector remains scarce. The uncertainties in the future outlook of the forest-based sector also imply great uncertainties in the demand for roundwood globally, and by extension, the extent of trade-offs between different ecosystem services and land uses.

Keywords Demand · Foresight · Forest-based-products markets · Forest-sector modelling · New forest-based products · Structural change

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4.1 Background: Forest-Based Sector Outlook Studies

The outlook for the forest-based sector has great importance through the impacts that the sector has on the state of forests and the amenities that forests provide, such as forest-based products,[1] energy, employment, biodiversity, the carbon cycle and water management. Without understanding the demand for forest-based products, and the ensuing demand for roundwood, it is very difficult to assess, for example, the impacts that strategies and policies may have on the forest-based sector or on society. Nor is it possible to assess the future state of the forests.

The forest-based sector has a long history in producing *outlook studies*, extending back to the 1950s (United Nations Economic Commission for Europe/Food and Agriculture Organization [UNECE/FAO] 2021). The purposes of forest- sector outlook studies have been to examine long-term economic, social, institutional and technological trends to support policy and strategy planning, depict the range of choices available, and describe the alternative scenarios that might arise as a result of these choices (UNECE/FAO 2011). The focus has traditionally been on trends in the forest-based-products markets and the availability of wood resources, concluding that the demand for forest-based products is expected to continue to steadily increase, which results in a steady increase in the level of harvesting (e.g. Mantau et al. 2010).

In recent UNECE/FAO outlook studies, the focus has been more on 'what if' analyses, describing the potential impact of, for example, changes in the wood supply of, or demand for, forest-based products (UNECE/FAO 2011, 2021). The most-recent outlook study took the perspective of structural changes and their impacts across the global forest sector, including climate-change mitigation and adaptation (UNECE/FAO 2021). This broadening perspective is necessary in order to meet the changing information needs of policy-makers and stakeholders in the increasingly complex forest-based sector.

Indeed, there are major structural changes associated with the stagnating or declining demand for some of the traditional forest-based products, such as graphic papers and sawnwood. However, a number of innovations are also expanding the product portfolios of the forest-based industries. These changes may be the largest structural changes in a century, comparable to the uptake of wood fibres to replace rags in paper-making in the late nineteenth century. However, the methodological approaches of long-term outlook studies were adopted in an era of constant growth, and are now facing difficulties in capturing the changes taking place in the forest-products markets of the twenty-first century. Due to the lack of research and the ongoing structural changes, the outlook for forest-based-products markets remains in many ways a great unknown.

[1] 'Forest-based product' refers to all products made from wood raw materials and can be used interchangeably with the concepts of 'forest product', 'wood-based product', 'forest-based bio-product', etc. As the term 'wood product' may sometimes refer to solid wood industries specifically, here we use the term 'forest-based product' for consistency.

The purpose of this section is to introduce and assess some of the prominent trends and recent changes in the forest- based sector, and to examine their implications in relation to the future outlook. This section does not provide a systematic outlook, but synthesises the current knowledge and raises questions to guide future endeavours.

Box 4.1 Why Do We Need Future-Oriented Market Research?

The forest-based-products markets of the twenty-first century differ significantly from their twentieth century counterparts. The forest-based sector, as well as the operating environment, has become more fragmented and unpredictable. The customary market structures are gradually evolving, due to, for example, the diversification of product portfolios and value chains, diminishing industry boundaries, changing consumption patterns, and strengthening environmental values in business and society. This creates a need to look ahead, but at the same time, it makes this task evermore challenging.

Obviously, there is no way to directly study the future, since hypotheses regarding the future cannot be validated in the present. This is why academic future-oriented research is mainly not about predicting what is going to happen, but rather evaluating what could happen, and what would be the consequences if it did (i.e. ‘what if’ analysis), as well as what should happen to reach certain outcomes. Together, these guiding questions refer to *probable*, *possible* and *preferable futures*, which are considered to be the foundations of futures studies (Bell 2003).

In one of the pioneering market foresight studies, an argument and accompanying evidence were presented for the case that the rise in electronic media would significantly impact the communication-paper market (i.e. newsprint) in particular (Hetemäki 1999). The newsprint markets in North America have plummeted further and more rapidly than the study anticipated, yet at the time of publishing, these early warning signals were commonly ignored. Moreover, the study drew attention to the inability of the prevailing long-term outlook studies to capture the structural change in the newsprint markets.

By 2020, these structural changes have become evident. This poses challenges for research, as the conventional models used for long-term projections no longer sufficiently capture the market drivers, such as the factors driving substitution or the demand for new forest-based products.

In future-oriented research, it makes sense to pursue multiple approaches to obtain as comprehensive a picture as possible. One increasingly popular approach has been normative in nature—defining the means to reach set targets (e.g. backcasting). As it is not the role of a researcher to set value-laden goals, such research has to be participative. Moreover, the targets are often largely accepted, such as implementing the Paris Agreement or the UN Sustainable Development Goals. This is why future-oriented market research should increasingly be coupled with environmental impact assessment as a

(continued)

Box 4.1 (continued)

means of grasping the role and potential of the expanding forest sector in the transition to a more sustainable society.

The purpose of academic market research is to critically examine established thought patterns, present new questions, indicate knowledge gaps, unveil broader contexts, and to evoke justified views on probable, possible and preferable futures and their implications. In academic research, the methods and data need to be transparent, and the studies need to be repeatable and able to pass the peer-review process. However, the major concern with regard to the academic research on forest-based-products markets is the lack of it (Hetemäki and Hurmekoski 2016). The subject area is dominated by consulting company studies, for which there is certainly a demand, but they are not a substitute for academic research. As shown in this chapter, there are many important open questions associated with future market developments and their impacts. Thus, there is a clear need for research related to the outlook for forest-based-products markets.

4.2 Forest-Based-Products Markets in the Bioeconomy Era

4.2.1 Forest-Based-Products Markets in the Twenty-First Century

Forest-based-products *markets* refer to all industrial activities around the use of wood. Of the global growing stock of 531 billion m^3 (FAO 2018), only around 4 billion m^3, or 0.75%, is annually harvested, around half of which goes to industrial uses and half to energy (Table 4.1). The production value of the industry and energy use of wood was estimated to be approximately US$950 billion in 2018, based on FAOSTAT data. This compares, for example, to the entire global turnover in the textile industry, or the sum of the revenues of the following companies in 2018: Apple, Amazon, General Motors, Microsoft, Bank of America, IBM and General Electric. Importantly, these figures only refer to the core industrial activities and do not include various downstream industries and related services. Clearly, the forest sector plays a significant role in the global economy and employment, besides heavily influencing the state of the world's forests.

Wood is used for various purposes, such as for buildings, furniture, packaging, communication, decoration, clothing, hygiene, vehicles, paints, glues, detergents, fuel, heat, medicine, feed and food. Forest-based industries are typically separated into the solid-wood industries, comprising sawnwood, wood-based panels, furniture and engineered wood products (EWPs), and the chemical forest industries, comprising pulp, paper and paperboard. There is little in common between the solid and chemical forest industries, save for the raw material supply.

Table 4.1 Global forest-products production in 2018

	Production quantity *(million tons)*	Production value *(billion US$)*
Industrial roundwood	1014*	–
Wood fuel	972*	146
Paper and paperboard	409	374
Wood pulp	188	137
Sawnwood	246*	135
Wood-based panels	204*	159
Total	–	950

* *Converted from m³*
Source: FAOSTAT

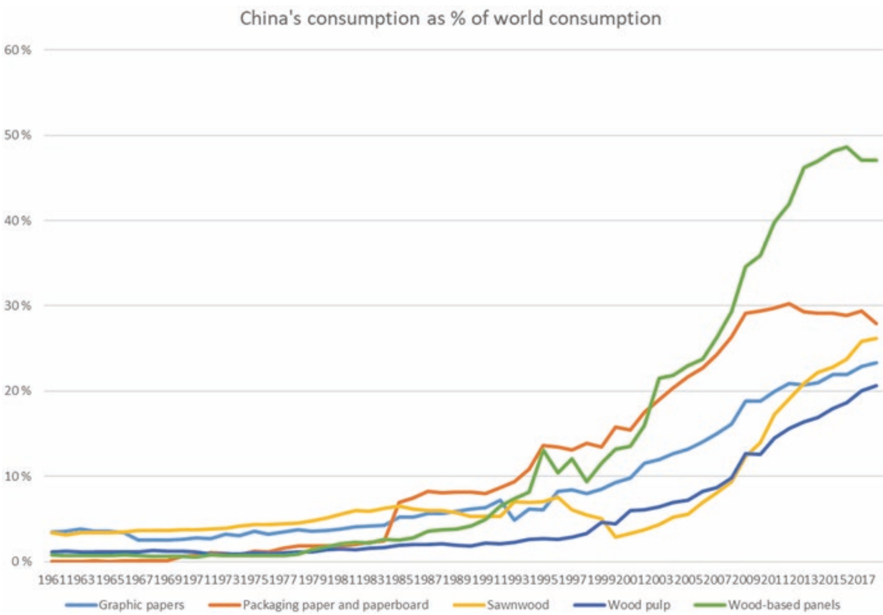

Fig. 4.1 China's share of the global consumption of major forest products. (Data: FAOSTAT)

There have been many visible changes in the global forest-products markets in the twenty-first century. For example, the global competitive advantages have experienced a clear shift, with a remarkable share of forest-industry investments going to fast-growing markets in Asia and low-cost-production regions, such as South America. The increase in demand for forest products in the 2000s originated almost entirely in Asia (FAOSTAT), with China's share of the global consumption having grown to more than 20% of all major forest products by 2018 (Fig. 4.1).

A more profound, yet less tangible, change is the *structural change* in the demand patterns of the forest-based industries. In the twentieth century, the global demand for forest products was steadily increasing, driven by increasing incomes, populations and urbanisation. However, in the twenty-first century, many of the forest-based products no longer seem to follow the pattern of stable and predictable growth of the last century. This is a consequence of various structural changes in demand, driven by the substitution of forest-based products for, or by, competing products. For example, global graphic- papers production (≈ consumption) declined between 2007 and 2018 by almost a quarter (24%), according to FAOSTAT data, due to its substitution by electronic media. On the other hand, in the same period, the production of dissolving pulp has grown by 2.5 times, driven by textile industry needs.

Important drivers of structural change also include the Sustainable Development Goals (UN 2015a) and the Paris Climate Agreement (UN 2015b). These set internationally agreed goals that encourage sustainable production and consumption. As forests constitute the most important, non-food, renewable land resource, increasing interest in utilising forests as a substitute for fossil-based and other non-renewable feedstock materials can be expected.

As a response to the maturing or declining traditional forest-products markets and the emerging opportunities, new forest-based products are being developed. Thus, it is conceivable that, within a few decades, there will be a larger number of forest-based-products categories, although none of these will dominate the sector to the extent that paper and solid- wood products did in the last century, particularly in terms of value added (Jonsson et al. 2017). Moreover, with the new products, industry boundaries may become increasingly indistinguishable, with the chemical, energy, textile and forest industries using the same feedstocks and developing products for the same markets (Jonsson et al. 2017).

Based on these trends, a keyword for characterising the market development of the forest-based products in the twenty-first century is *diversification*. Above all, the term refers to the widening scope of the forest-based-products markets in terms of product portfolios and value propositions. One can argue that the sawnwood industries are diversifying towards wood- based panels and EWPs, whilst the pulp and paper industries are diversifying from communication papers towards packaging paper grades and various biorefinery products.

Clearly, the outlook for the forest-based sector depends on whether we only consider the traditional large-volume products, such as sawnwood and graphic papers, or also the development of *new forest-based products*, such as textile fibres. Capturing the influence of the latter can be tricky, as sectoral statistics are lagging behind the restructuring of this industry. In particular, it is increasingly challenging to measure the employment, turnover and value added based on wood raw materials in the chemical, construction, textile and energy industries.

4.2.2 Characterising the Structural Change in Demand

Industrial evolution is a continuous process that serves to maintain the vitality of the market economy, as already noted in the 1940s by Joseph Schumpeter, who coined the term '*creative destruction*'. Here, we briefly introduce a few analytical concepts so as to characterise the structural changes occurring in the forest sector in the twenty-first century—evidence of ongoing creative destruction.

4.2.2.1 Demand Elasticity and Substitution

By the term '*demand*', we refer to the amount or value of a good consumed. A useful empirical approximation of demand is 'apparent consumption', defined as production + imports – exports. The terms 'demand' and 'consumption' are therefore regarded as synonyms.

As most forest-based products are intermediate goods, models quantify forest-based-products consumption as *derived demand*. Essentially, this means that the demand for forest-based products is a function of the same factors that affect the demand for the final uses of the products (Klemperer 2003). In empirical research, the demand determinants for wood- based products are typically reduced to price and income.

One way to demonstrate the existence of a structural change is to observe the relationship between available income and the demand for forest-based products. This leads us to the concept of demand *elasticity*. While elasticities can be attributed to any demand determinant, they are typically associated with price and income. The demand for a *normal good* increases when income increases and decreases when income decreases, whereas, for an *inferior good*, an increase in income results in a reduction in this consumption and vice versa (Varian 2010). Forest-based products are generally regarded as normal goods (Kangas and Baudin 2003), except for newsprint and printing and writing papers (Hetemäki 2005).

Indeed, the income and price elasticities remained remarkably stable throughout the twentieth century, when the markets enjoyed a period of relatively stable growth, and there were no major technical innovations making competing goods more desirable. Consequently, income and price have been able to explain and predict the level and rate of demand remarkably well at the global level. However, the power of these two predictors diminish, the more disaggregated markets and more recent data are analysed.

In the twenty-first century, the demand for forest-based products has no longer developed in line with the gross domestic product (GDP) for some of the most significant forest products. This suggests that income cannot be the only demand shifter. For example, the global production of sawnwood and wood-based panels has exhibited markedly different patterns in 2000–2018 compared to 1980–1999, relative to per-capita GDP growth (Fig. 4.2). In the EU, one can observe an apparent decoupling of demand from the GDP, or a structural break or discontinuity in the GDP elasticity, for many traditional forest-based-products markets (Fig. 4.3). The underlying causes have been studied only in the context of graphic papers, which are being substituted by electronic media (Hetemäki 1999; Hetemäki and Obersteiner 2001), and bioenergy, which has been substituting for fossil energy in the EU due to climate and energy policies (Moiseyev et al. 2013). Despite some of this apparent turbulence possibly being caused by the historically long economic downturn, therefore making it transitory, it may equally become more exaggerated in the future due to the introduction of new forest- based products and new end uses, as well as the impacts of the COVID-19 pandemic.

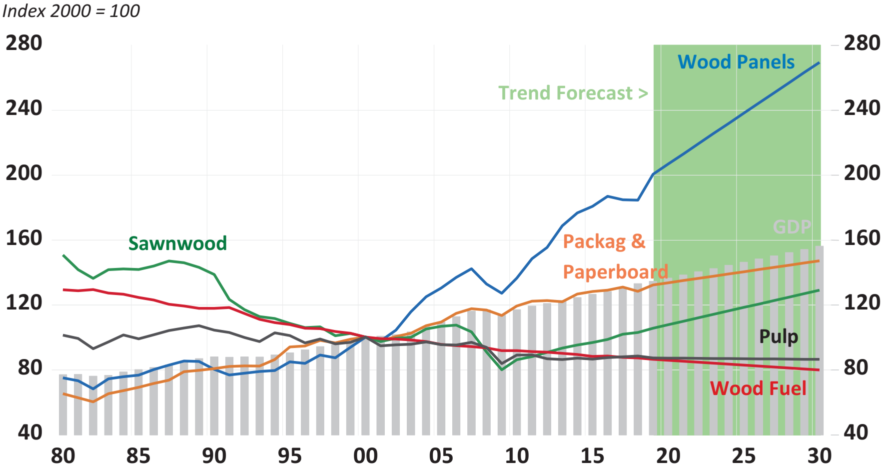

Fig. 4.2 Per-capita global consumption of forest products versus GDP in 1980–2018 and the trend forecasts (2010–2018 trend) to 2030. (Data: FAOSTAT and World Bank)

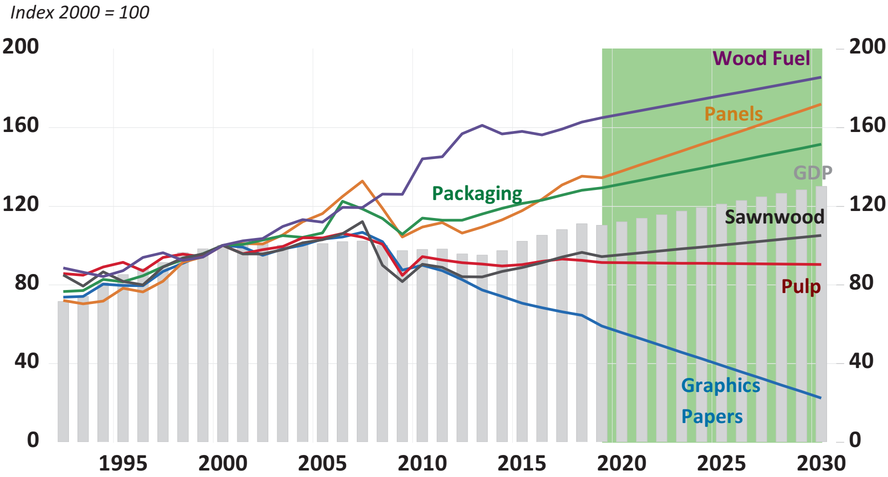

Fig. 4.3 Consumption of wood-based products and GDP in Europe (excluding Russia) in 1992–2018 and the trend forecasts (2010–2018 trend) to 2030. (Data: FAOSTAT and World Bank)

The lack of research literature on *substitution*, in the context of forest-products markets, is striking, given the structural changes that took place in the graphic papers markets in many Organisation for Economic Co-operation and Development (OECD) countries some decades ago (recent exceptions being described in Latta et al. 2016; Rougieux and Damette 2018). Moreover, the commonly stated goal of 'shifting towards bioeconomy' would implicitly require the large-scale substitution of feedstock materials, and yet the conventional demand equations cannot fully capture this substitution. The implications of this knowledge gap are further underscored in Chap. 7.

4.2.2.2 Product Life-Cycles

The diversification of the sector is closely related to the *product life-cycle*, comprising four to five stages— introduction, growth, maturity, decline and, in some cases, renewal (e.g. Routley et al. 2013). During the period of introduction and growth, the goods become increasingly competitive through decreasing production costs from learning- by-doing (Arrow 1962; Rosenberg 1982). At the maturity stage, productivity improvements are increasingly difficult to gain, and in the decline stage, the product starts to lose the markets to emerging products or technologies (Anderson and Tushman 1990). In some cases, the growth phase may be renewed after a period of stagnation or decline, as a result of changes in demand determinants or improvements in the established technology—this has been the case for dissolving pulp, for example.

The demand for most woodworking and pulp and paper industry products has become inelastic; that is, the market growth rate has fallen below the GDP growth rate (Rougieux and Damette 2018). Moreover, the prices of the end products have been trending downwards, while the production costs have been increasing, with the price differentials between suppliers being marginal, the switching costs being low, and the negotiating power lying with the customers (Uronen 2010; Hetemäki et al. 2013). These point to the conclusion that many of the forest-products markets have become commoditised. At the same time, in the big picture, fossil-based energy is likely to hit the maturity stage in the coming decades, due to environmental values and regulations, which will lead to substitution by alternative energy and material feedstocks, including forest biomass.

Indeed, one can name wood-based products for all phases of the typical product life-cycle, as demonstrated in Fig. 4.4. For example, cross-laminated timber (CLT) is clearly in the growth phase, as demonstrated by the double-digit growth rates, irrespective of periods of negative or stagnating GDP growth rate (Hetemäki and Hurmekoski 2016). In the next section, we focus particularly on the markets of emerging wood-based products.

4.2.3 Emerging Markets

4.2.3.1 Defining New Forest-Based Products

There is no clear or established definition for new forest-based products (Cai et al. 2013; Näyhä et al. 2014; Hetemäki and Hurmekoski 2016). The concept can refer to products in the introduction or growth phases of the product life-cycle, but also to products with renewed growth in demand, such as dissolving pulp. Thus, a new forest-based product does not necessarily have to be a novel product, or based on a novel technology—it can also be an old product with a new market environment, such as the constrained supply of competing feedstock materials, or with enough incremental improvements to drive growth, such as a lighter weight (Hurmekoski

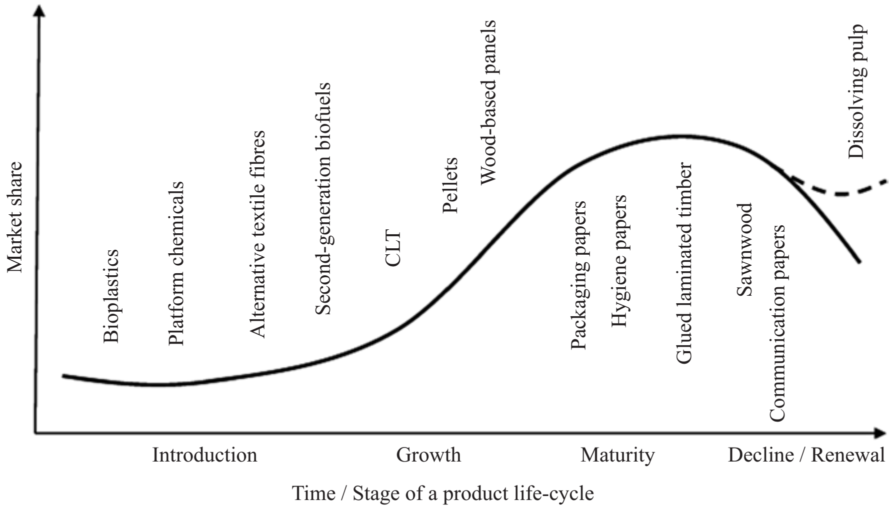

Fig. 4.4 Approximate market location of selected wood-based products based on product life-cycle in 2020

et al. 2018a). Thus, one could describe new wood-based products as products for which the demand is determined mainly by drivers other than economic activity (GDP), bar short-term economic cycles. Such a classification is naturally prone to interpretation in terms of where to draw the line. For example, compared to CLT and dissolving pulp, the growth of the fibre-based packaging sector, as a whole, is not necessarily fast enough to qualify as a new forest-based product, even if some of the emerging packaging applications are novel, such as cups containing no fossil plastics. These definition attempts may at least demonstrate the diversity of the forest-based- products markets in the twenty-first century.

Literature on the diversification of the sector and new forest-based products remains relatively scarce, particularly from the perspective of market potential (e.g. Guerrero and Hansen 2018). Based on the literature that is available, however, some of the most important emerging markets appear to be construction, textiles, chemicals, advanced biofuels, and plastics and packaging (Bio-based Industries Consortium 2013; Graichen et al. 2016; Antikainen et al. 2017; Kruus and Hakala 2017; Schipfer et al. 2017). In the following, we briefly review these markets, as summarised in Table 4.2.

4.2.3.2 Construction Markets

The outlook for wood construction is regarded as almost unanimously positive, which is partly due to the enormous and still-growing size of the market, and partly due to claims of the superior environmental performance of wood products (e.g. European Commission 2018). Wood construction, particularly on a small scale,

Table 4.2 Markets for new forest-based products

	Construction	Textiles	Chemicals	Fuels	Plastics and packaging
Market size in 2030 (*in 2015*)	28,000 Mt. (*21,500 Mt*); 3.16 billion m^2 (*2.24 billion m^2*)	130 Mt. (*90 Mt*)	600 Mt. (*330 Mt*)	2300 Mt. (*2100 Mt*)	130 Mt. (*72 Mt*)
Technologies / products	- EWPs (CLT, laminated- veneer lumber) - industrially prefabricated construction elements (including modular elements) - concrete admixtures (lignin)	- new solvents for dissolving pulp: e.g. IONCELL-F - new fibre-spinning technologies: e.g. Spinnova	- drop-in substitutes for petrochemicals: Ethylene - smart drop-in substitutes for petrochemicals: Succinic acid, butanediol - dedicated bio-based chemicals: Lactic acid, furfural	- renewable diesel: Based on distilling tall oil - ethanol: Based on fermenting sugars (hemicelluloses and celluloses)	- wood–plastic composites (WPCs): Extrusion and injection moulding - pulp-based, paper-resembling films for flexible packaging - other plastic-resembling wood or wood-fibre-based materials for rigid packaging
Target markets and substitutions	- residential and non-residential buildings - substituting for concrete, steel and established wood-construction technologies in the load-bearing frames of buildings	- garments - substituting cotton, polyester and viscose	- main downstream markets, including plastics, food and feed ingredients, and pharmaceutical industries - substituting first-generation (starch-based) biochemicals and petrochemicals	- energy carrier for transport, particularly long-haul truck transport, maritime transport and jet fuel - substituting first-generation biofuels and fossil fuels	- rigid and flexible plastic substitutes: Food, healthcare and cosmetics packaging, carrier bags - WPCs: Decking (mostly substituting for tropical wood), car interiors (mostly substituting for plastics)

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Table 4.2 (continued)

	Construction	Textiles	Chemicals	Fuels	Plastics and packaging
Main drivers	- efficiency gains in industrial prefabrication - favourable policies in certain regions	- ‘cellulose gap’—Constrained farming area for cotton due to land competition with food production, coupled with rapid growth in demand for textiles - large freshwater consumption in cotton irrigation in arid areas	- major firms targeting renewable feedstocks - co-production with biofuels	- climate and energy policies - crude oil and CO_2 price in the long run	- growth in population, GDP, e-commerce and take-away products - rising polymer prices - policies to restrict the use of plastics
Main barriers	- risk perceptions of key decision-makers (officers of main contractor and developer firms) - fragmented and path-dependent industry structure	- some of the technical attributes (product properties) of man-made cellulosic fibres (MMCFs)	- REACH[1] and other regulations - extensive validation required for dedicated compounds - investment costs - path dependency of petrochemical industries	- feedstock availability - for many processes, conversion efficiency - investment and running costs	- uncertain legislative environment
Competing innovations	- low-emissions cement - 3D printing of recycled concrete and similar	- cotton recycling technology - other bio-based fibres, e.g. based on spiders’ webs - functional textiles, e.g. antibacterial, anti-odour or electrical properties	- CO_2 as a feedstock for chemicals - first- and third-generation chemicals	- first- and third-generation fuels - electric engines - hydrogen engines	- first- and third-generation bioplastics - recycled or biodegradable plastics - natural fibre composites

Desirable product characteristics	- no need for major changes in construction practices - no technical or economic hazards	- technical properties: Avoiding wrinkles and electricity, good moisture absorption, etc. - environmental properties: Avoiding hazardous chemicals, less pollution, increased recycling, etc.	- low cost - non-hazardous and non-toxic	- drop-in fuel: Existing distribution infrastructure and existing car fleet without a need for major modification	WPC: - natural feel - easy maintenance packaging: - biodegradability or recyclability - lightness - product safety
Comparative advantages	- lightness of the material, allowing efficient industrial prefabrication and the resulting productivity benefits - renewable material	- feedstock availability (compared to virgin cotton) - ability to convert existing pulp mills to dissolving pulp - environmental footprint	- interest towards bio-based alternatives - in smart drop-in and dedicated chemicals, reduced costs and/or environmental footprint	- policy pull - does not directly compete with food production - can be biodegradable, free of aromatics and Sulphur, and non-toxic	- reduced costs compared to pure plastics - combination of biodegradability and thermoplasticity
Position of forest- based firms in the value chain	- admixture supplier - subcontractor (product or element supplier) - main contractor or developer (managing whole value chain)	- raw material supplier (dissolving pulp) - textile fibre producer (MMCFs) - yarn producer	- primary and secondary platform chemicals	- end-product producer	- packaging: Converter of shopping bags and solid packages - WPC: Converter of intermediate/end products

[a]*Note: REACH—Registration, evaluation, authorisation and restriction of chemicals—is an EU regulation covering the production and use of chemicals*
Adapted from Hurmekoski et al. (2018a)

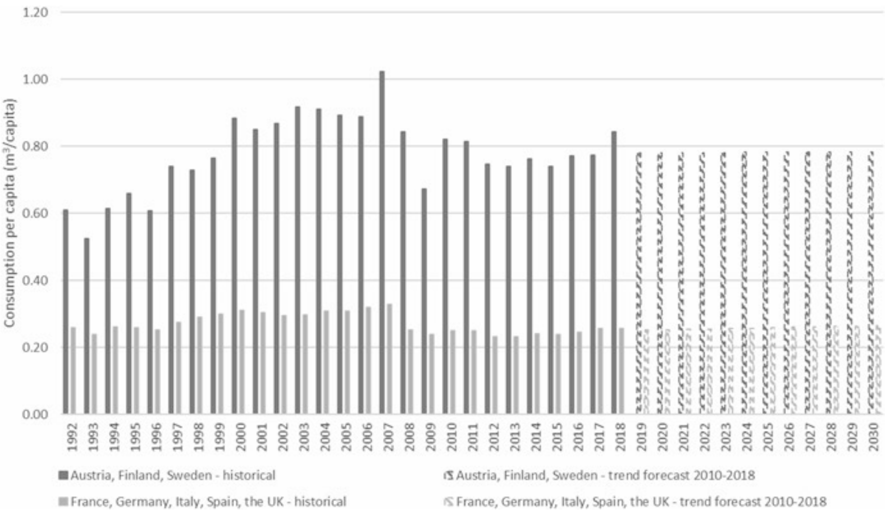

Fig. 4.5 Per-capita consumption of sawnwood and wood-based panels in two selected country groups in the EU in 1992–2018. (Data: FAOSTAT)

such as single-family homes, can hardly be regarded as a new market, per se, but new opportunities are emerging in the large-scale construction markets due to recent innovations, as well as growing interest among decision-makers and industries (e.g. FAO 2016). The market can also be approached from an entirely different perspective, such as using lignin to partly replace cement in concrete manufacturing (de Vet et al. 2018).

The average market share of wood in small-scale construction in Europe has remained below 10%, but it varies from above 80% in the Nordic countries to near zero in many Southern European countries (Alderman 2013). Figure 4.5 shows that, during the last couple of decades, the per-capita consumption of construction-related forest-based products in the large European economies has only been around one-third of the equivalent consumption in sparsely populated and densely forested countries. Furthermore, there is no convergence in the per-capita consumption between the high- and low-consumption regions, with a slight exception being modest growth in the UK. Figure 4.5 also indicates that the per- capita consumption of wood-based construction products in Austria, Finland and Sweden nearly doubled from 1993 to 2007, after which the markets were severely affected by the global economic downturn, and did not manage to reach the peak of 2007 in the decade that followed. Looking at the trend forecast based on the trend of the 2010s, no significant deviation would be expected.

Besides the long-lasting impact of the housing-market meltdown, the lack of significant progress in the countries with a smaller wood-construction market share arises from the various path dependencies of the construction sector (e.g. Mahapatra and Gustavsson 2008). Construction markets are very much influenced by tradition, culture and the availability of local resources. In this highly established market, major drivers include cost competitiveness and being able to guarantee a low-risk investment. That is, particularly in large-scale construction value chains, the actors are generally unwilling to accept new practices that could potentially cause extra work and associated costs in the short run (Arora et al. 2014). There is, however, significant variance in the market potential between market segments and regions, even from one city to the next.

The demand drivers are slightly different between the small-scale and large-scale housing markets. Some of the technological- and business-model-related innovations hold promise for changing the market prognosis in the large-scale construction markets. In particular, the expansion of *EWPs*, together with *industrial prefabrication*, has allowed wood to increasingly compete with steel and concrete in large-scale construction (Bühlmann and Schuler 2013; Hildebrandt et al. 2017), such as in multi-family dwellings, office and industrial buildings, sports complexes, additional-storey construction, and in infrastructure, such as bridges. Industrial prefabrication refers to the off-site manufacturing of elements and components, which allows the combination of several work phases in a single off-site location, potentially resulting in productivity and quality gains, for example (Malmgren 2014). However, even if wood-based industrial prefabrication could address many of the pressures faced by the construction sector, including productivity, quality, safety and environmental impact, the risks, as perceived by the construction project managers, might outweigh these in the short term (Hurmekoski et al. 2018b). These hindrances would need to be addressed, for example, by taking responsibility for a larger share of the construction value chain, if firms seek rapid market growth (Hurmekoski et al. 2018b). More-gradual change can happen through standardisation and winning trust through repeated positive experiences along the value chain (Hurmekoski et al. 2018b).

The market is also influenced by policy. In Finland, wood construction has been promoted by public targets, technology platforms and campaigns for several decades. While the small-scale construction markets have already been saturated by wood, the uptake of wood-frame, multi-storey construction remains modest, with only a few percent market share. In the 2020s, the possible uptake of environmentally stricter national regulations, driven by, for example, the national implementation of the voluntary EU framework for measuring the emissions of the construction sector or supportive measures favouring wood in public procurement in the building sector, may favour wood (Toppinen et al. 2018), besides spurring competition.

Changing consumer preferences may also influence the market uptake of modern wood-construction practices. For example, wooden surfaces may have beneficial impacts on human health through improved air quality and a stress- relieving atmosphere (Muilu-Mäkelä et al. 2014), which has been found to be attractive to certain types of consumers (Lähtinen et al. 2019). However, particularly in multi-storey buildings, consumers tend to emphasise the size, location and price of the apartments rather than the material of the structural frames. Here, consumer segmentation and business model innovations may be required.

4.2.3.3 Textile Markets

The global textile demand has been projected to grow from 90 Mt. in 2015 to more than 250 Mt. in 2050 (Alkhagen et al. 2015). In the absence of more-efficient recycling, polyester fibres are foreseen as having the strongest growth, followed by a more stable increase in cellulosic fibres, while cotton production is expected to remain at the current level (Antikainen et al. 2017), due to the increasing competition for land between cotton and food production (Hammerle 2011). Additionally, the large demand for fresh water for cotton farming in arid areas lends a competitive advantage to alternative cellulose supply sources (Shen et al. 2010), such as wood-based MMCFs.

The MMCF market is still dominated by viscose, with a 79% share in 2018 (Textile Exchange 2019)—a product that was introduced already in the late nineteenth century. Currently, new MMCF processes based on alternative solvents, such as IONCELL-F and Arbron, are being developed that aim to overcome the weaknesses of contemporary viscose (Kruus and Hakala 2017). Of these more advanced MMCFs, dissolving-pulp-based lyocell already had a 4% market share of the MMCF markets in 2018, and it is expected to grow faster than viscose (Textile Exchange 2019). If the development of new cellulosic fibres is successful, the general growth rate of MMCFs can be higher than so far perceived, and could expand into currently unattainable markets, such as sports textiles (Alkhagen et al. 2015).

The main intermediate product in manufacturing MMCF is dissolving pulp. Following a decline lasting the four decades since 1960, the global production of dissolving pulp has grown from 2.8 Mt. in 2000 to 8.4 Mt. in 2018, reaching 4.5% of the overall wood-pulp production volume (FAOSTAT). With a growing global textile demand, an increasing number of kraft pulp mills could be converted to produce dissolving pulp. Dissolving pulp is currently exported in large quantities to Asia, where most of the global textile production takes place. In principle, the value added of wood-based industries from the textile market could be multiplied by moving downstream in the value chain to garment manufacturing (Hurmekoski et al. 2018a).

According to Antikainen et al. (2017), the textile supply chains are typically long and complex, while the use time of textiles is relatively short due to low pricing and rapid fashion cycles. The industry is further characterised by a high share of labour costs (Antikainen et al. 2017). As a consequence, textile manufacturing has been off-shored from much of the global West to regions with lower wages—notably, the Far East countries. Even considering the possibility of highly automated textile production, Antikainen et al. (2017) did not foresee any substantial reshoring of garment manufacturing to the Western economies. Instead, the technology that is being developed could be licenced to areas where textiles are produced, and recycled cotton fibres could also be used as feedstock, along with wood pulp, for example (Kruus and Hakala 2017).

4.2.3.4 Biorefining—Biochemical and Biofuel Markets

There is a clear need to find alternative feedstock materials for fossil coal, oil and gas. Technically, almost all industrial materials made from fossil resources could be substituted by their bio-based counterparts (de Jong et al. 2012). However, so far, the most common uses of wood have been to exploit the solid wood or fibre structure, as some of the molecular structures have been too complex to be replicated by engineers, and there are cheaper sources for the development of chemicals. This setting could be slowly changing, due to constantly developing technologies, as well as changes in the *operating environment*.

Biorefinery feedstocks can be divided into three generations—the higher the generation, the less competition the feedstock poses for land use and food production, but, at the same time, the higher the techno-economic barriers for the market uptake (Sirajunnisa and Surendhiran 2016). First-generation biorefineries are mostly based on food crops or plants that reduce the land available for food production, which drives up the food price, particularly in developing countries (Naik et al. 2010). Typically, the first-generation biorefineries are also technologically less efficient and have higher carbon footprints than second-generation biorefineries (Naik et al. 2010). Second-generation biorefineries are based on lignocellulosic biomass, such as wood and agricultural residues or waste streams, and do not directly compete with food production. A third-generation biorefinery is yet to be established, but it would be based on various algae that do not require any land surface for cultivation.

So far, most market prognoses for biorefining concern the first-generation feedstocks (e.g. Aeschelmann and Carus 2015). Accordingly, the literature on lignocellulosic biorefineries tends to focus on the technical challenges related to its pretreatment phase, such as the insufficient separation of cellulose and lignin, the formation of byproducts that inhibit downstream fermentation, the high use of chemicals and/or energy, the cost of enzymes, and the high capital costs for pretreatment facilities (Taylor et al. 2015). Given that the technical-readiness level of most wood-based chemicals remains fairly low (Hurmekoski et al. 2018a), the market outlook, even up to 2030, remains uncertain, despite the obvious potential.

Advanced Biofuels

In terms of sheer volume, the substitution potential is several magnitudes higher for bioenergy than for biomaterials (Schipfer et al. 2017). According to Plastics Europe (2016), 42% of all oil and gas in Europe is used for electricity and heating, while 45% is used for transportation, 8% for chemistry (plastics 4–6%) and 5% for other uses.

The demand for biofuels has largely been created by national or regional climate and energy policies, such as the Renewable Energy Directive of the EU, which necessitated a 10% blend of biofuels in road traffic by 2020 (EU 2009). However, the first-generation biofuels have faced criticism due to the uncertainties associated with their ability to reduce emissions, their low conversion efficiency, and the low energy return on energy invested in some of the processes (de Jong et al. 2012). This has created interest in advanced biofuels based on second-generation feedstocks.

The investment requirements can be up to three times higher for lignocellulosic biofuels than for cornstarch- or sugarcane-based ethanol (Nguyen et al. 2017), due to there being more steps in the production process. Also, the C5 and C6 sugars produced in lignocellulosic biorefineries for fermentation are much more expensive than sugar from sugarbeet or sugarcane (Carus et al. 2016). The cost disadvantage of sugars derived from lignocellulosic feedstocks would need to be balanced by the utilisation of lignin, which seems to be feasible only in the very long term, in terms of its full potential (Carus et al. 2016). For this reason, the production of biofuels typically requires the complementary production of biochemicals (or selling the residues for such use) to make the business profitable. Indeed, the value of the chemical industry is comparable to that of the fuel industry, despite it requiring only a fraction of the biomass (FitzPatrick et al. 2010).

Chemicals

In Finland, more than a third of the chemical industry firms use bio-based feedstocks, and the number is expected to rapidly increase (Ministry of Employment and the Economy 2014). The chemical industry is therefore seen as playing a key role in the diversification of the forest-based sector.

Like biorefineries, chemicals can be classified in many ways. In terms of markets, an important distinction is for bulk chemicals (or basic chemicals), characterised by a high volume, low price and highly diverse end uses, and fine chemicals, characterised by a low volume, high price and few applications. The mixtures of the chemicals in these categories constitute specialty chemicals (or performance chemicals), including adhesives, agrichemicals, detergents, cosmetic additives, construction chemicals, elastomers, emulsifiers, flavourings, food additives, fragrances, industrial gases, lubricants, pigments, polymers and surfactants. A probable role for the forest-based industries would be to supply basic or fine chemicals to be sold to the chemical industries for a plethora of end uses (Hurmekoski et al. 2018a).

In terms of volume, the chemical sector is dominated by a small number of key bulk chemicals, such as ethylene. Producing bio-sourced, drop-in basic chemicals with an identical compound structure to their fossil-based counterparts appears to be a promising approach for the biochemical markets, due to a greater likelihood of acceptance by established chemical producers (FitzPatrick et al. 2010). That is, a functional replacement with a different molecular structure would require significant property testing to allow displacement of the chemical currently being used (Biddy et al. 2016). However, while drop-in, bio-based chemicals are seen to have an easier access to the markets compared to other types of chemicals (de Jong et al. 2012), they are not expected to be competitive by 2030 due to their low technology readiness, longer conversion pathways and comparably high running and investment costs (e.g. Kruus and Hakala 2017). As a consequence, Bazzanella and

Ausfelder (2017) recommend exploiting the more efficient synthesis of target products that maintain the functional units of the feedstock molecules, such as polylactic acid.

Let us consider the case of ethylene to highlight the complexity of the interplay of market drivers and barriers in the chemical market, and the resulting difficulty of assessing the market potential. According to Dornburg et al. (2008), ethylene (used mostly for polyethylene plastic) is the largest of the currently produced petrochemicals by volume. While bio-based ethylene has a technical readiness level of 8–9 out of 9, it is competing with natural gas and, particularly, shale oil and gas, which have higher relative yields of ethylene compared to conventional oil and gas sources (Biddy et al. 2016). Yet ethylene production could fit into the overall product portfolio of wood-based biorefineries, if certain parts of the feedstock would otherwise have no use. If there is a price premium for bio-sourced ethylene, even a minute share of the global market could have a large impact on the profitability of a single biorefinery.

Unlike for biofuels, the demand shifters of biochemicals are not only related to policy. There has been a shift from a technology push led by major chemical companies to a market pull created by leading consumer brands, such as P&G, IKEA, LEGO and the Coca Cola Company, which all have set specific targets for replacing fossil-based chemicals (polymers) with more sustainable alternatives (Aeschelmann and Carus 2015; Biddy et al. 2016). Naturally, policies could also create incentives or influence the relative costs of different feedstocks through, for example, CO_2 pricing to level off the differences between the operating and investment costs. Due to the myriad end uses of chemicals, the market drivers and consumer preferences may also vary significantly from one use to another.

According to Hurmekoski et al. (2018a), wood-based chemicals may primarily compete with first-generation biochemicals and chemicals produced from other second-generation feedstocks rather than petrochemicals, which would lower the expected production volume considerably. However, it is too early to state any such prognoses with certainty, and there seem to be ripe opportunities already available, based on the €550 million standalone wood-based chemical mill investment by UPM Kymmene in Germany in 2020, which will be producing dedicated biochemicals for the production of items such as textiles, bottles, medicines, cosmetics and detergents. Beyond 2030, the competition may change again with the introduction of, for example, CO_2 as a feedstock for the development of platform chemicals (Alper and Orhan 2017).

Besides cellulose and hemicellulose, wood also contains lignin and a number of heterogeneous extractives, derived, for example, from birch bark. There are highly varied opportunities for such niche markets, resulting in a large number of speculative uses in the long term (Box 4.2). Due to the numerous opportunities and the early stage of their life-cycle, we can only argue that they may eventually make a big difference in terms of value added, albeit the volume potential remains fairly low due to the restricted availability of byproducts, except for lignin.

Box 4.2 Opportunities Related to Byproducts and Niche Markets

The biofuels and biochemicals reviewed in this section are mostly based on fermenting or catalysing *C5 and C6 sugars* from cellulose and hemicellulose. Besides cellulose and hemicellulose, wood also contains lignin and a number of heterogeneous extractives (Fig. Box 4.1).

Around 70 Mt. of *lignin* are produced annually in the world, with 95% of the production being incinerated. Other uses include dispersants (e.g. in the construction industry), emulsifiers (asphalt emulsions), foams (plastics/polymers), aromatics (vanillin) and stiffness enhancers (corrugated board) (Bruijnincx et al. 2016), with most utilised, without chemical modification, as fillers or additives (Aro and Fatehi 2017). However, lignin is considered to be a main aromatic renewable resource for the development of chemicals and polymers in the long term (Laurichesse and Avérous 2014). The low rate of lignin exploitation to produce chemicals is mostly due to its complex, largely undefined structure and its versatility depending on the origin, as well as its tedious separation and fragmentation processes (Laurichesse and Avérous 2014). That is, while the limitations on the use of hemicellulose relate to markets rather than technology (Stern et al. 2015), the opposite holds true for lignin (Bruijnincx et al. 2016). Platform or fine chemicals based on the thermochemical conversion of lignin show a low technological-readiness level (Kruus and Hakala 2017). However, the possibilities are highly varied, resulting in a countless number of speculative uses in the long term.

Wood also contains several small and highly heterogeneous extractives, such as *terpenes*, *fatty and resin acids*, *sterols*, *phenolic compounds* and *hydrocarbons*, which hold considerable potential as renewable resource s and feedstocks for future biorefineries (Routa et al. 2017). For example, tree bark

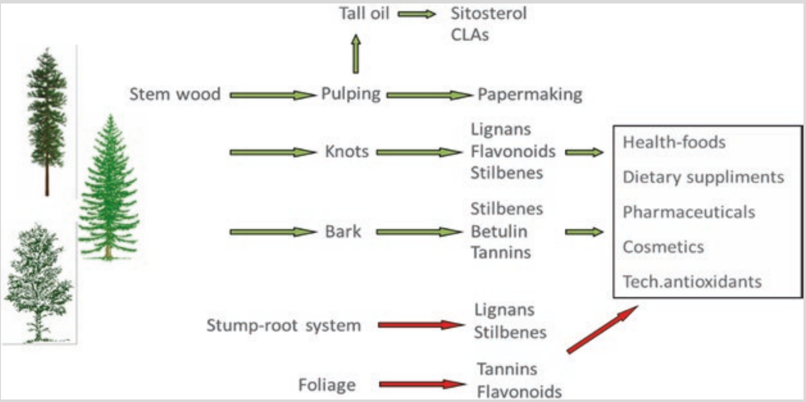

Fig. Box 4.1 Currently utilised and potential routes from wood extractives to valuable biochemicals. *Green arrows* commercialised routes, *red arrows* non-commercialised routes, *CLAs* conjugated linoleic acids. (After Routa et al. 2017)

(continued)

Box 4.2 (continued)

contains bioactive components, such as tannins—phenolic compounds that could be used in several technochemical applications and products, such as glues, wood preservatives, foams, functional coatings and adhesives. Tannins have widespread applications in many other industrial sectors, including the food, beverage, clothing and pharmaceutical industries (Shirmohammadli et al. 2018). Bark also contains non-cellulosic sugars, which can be utilised further, but also make direct tannin extraction difficult (Kemppainen et al. 2014).

A very interesting group of compounds are *the birch wood extractives*, which possess considerable potential utility. Natural birch bark extractives, such as triterpenoids (e.g. betulin and related derivatives), suberinic fatty acids and phenolic compounds, find potential use in pharmaceutical, technochemical and food/feed applications. Birch bark triterpenoids have shown a marked potential as precursors for HIV and cancer therapy, as well (Krasutsky 2006). For the recovery of wood extractives, thermochemical techniques, such as pyrolysis, hot-water extraction and hydrothermal liquefaction, seem to be the most promising technologies. Nevertheless, large-scale operations for the recovery and further refinement of wood extractives are still scarce.

The utilisation of *tall oil* is mainly focused on the production of renewable diesel. However, crude tall oil refining also produces side-products, such as tall oil rosin and tall oil pitch, which find use in many different applications, especially in the technochemical field (Routa et al. 2017).

Cellulose can also be broken down to the *nanoscale*, which alters the properties of the fibres, giving them superior strength, liquid-crystal behaviour, transparency, low thermal expansion, the capacity to absorb water, and piezoelectric and electrical behaviours (Cai et al. 2013). According to Cowie et al. (2014), the largest uses for nanocellulose are projected to be in packaging (2 Mt), paper (1.5 Mt) and plastic film (0.7 Mt) applications. Globally, the use of nanocellulose as a cement additive has a potential market size of over four million t. Other applications include functional paper, coatings, packaging, pharmaceuticals, cultivation media, biosensors, various membranes, catalysts, polymer composites, textiles and electronics (Thomas et al. 2018). So far, larger-scale applications are limited to increasing the strength and reducing the weight of conventional carton packaging, for example.

4.2.3.5 Plastics and Packaging Markets

Similar to the construction market, there is a long tradition of using wood in the packaging market s. Generally, the packaging markets are driven by global population and GDP growth, as well as increasing e-commerce and the demand for takeaway products. However, wood-based packaging solutions may have increasing potential due to an increasing resistance against plastics, originating particularly from marine and microplastic pollution (World Economic Forum 2016). For example, in the EU, certain short-lived plastic products have been banned, and the use of plastic bags is being disincentivised, creating market pull for alternative materials.

The packaging markets also represent one of the most important uses of bio-based chemicals (Hämäläinen et al. 2011; Näyhä and Pesonen 2012). The global production of plastics has increased 20-fold over the past 50 years, from 15 Mt. in 1964 to 311 Mt. in 2014 (World Economic Forum 2016). Over the next 20 years, the volume is expected to double, and by 2050 to quadruple (1.124 Bt) (World Economic Forum 2016). Of the total global plastic market in 2015 (322 Mt), 40% ended up in packaging, while up to 70% of bioplastics are used for packaging (Plastics Europe 2016). Plastics, and paper and paperboard each account for around 35% of the total value of the packaging markets (Neil-Boss and Brooks 2013). The bioplastics market is expected to gain a 5% share of the entire plastic-packaging market within 20 years (Byun and Kim 2014), but the share of wood-based polymers from the entire bio-based polymer market remains modest.

As noted by de Jong et al. (2012), a plastic with a technical function and complex supply chain could take between two and four decades to achieve production scales over 100,000 t. According to Aeschelmann and Carus (2015), novel, 100% bio-based, indirect-substitute polymers are not expected to grow as fast as the drop-in polymers until 2030. Moreover, the advantage of bioplastics in a circular economy is not clear, as they are not necessarily biodegradable, and rapid biodegradability is not necessarily beneficial for the environment either, if the material cannot be recycled (Soroudi and Jakubowicz 2013).

This leads us to argue that plastics, as such, are not necessarily a key business opportunity for the forest-based industries (Hurmekoski et al. 2018a). Combined with the technical and economic issues raised for the biochemical market, and the likely role of forest industries as a platform chemical provider, indirect-substitute products for the plastics market could have more potential by 2030. These indirect substitutes could be plastic-mimicking products that use existing industrial infrastructure, such as WPCs (Carus et al. 2015), paper-resembling films for flexible packaging (Kruus and Hakala 2017) and other plastic-resembling wood or fibre-mix materials for rigid packaging (e.g. Nägele et al. 2002). The demand for such indirect plastic substitutes could be promoted by policy, such as the EU directive that bans certain single- use-plastic products. Naturally, the demand for traditional wood-based packaging or 'second-generation' fibre-based packaging (free from fossil-based polymer coatings and adhesives) could increase their market share, vis-à-vis plastics, glass and aluminium, as long as they are compatible with the disposal and recycling behaviours in a circular production– consumption system, satisfy heterogeneous consumer needs, and support sustainable lifestyles by extending material life- cycles (Korhonen et al. 2020).

4.2.3.6 Impacts of New Forest-Based Products on the Forest-Based Sector

Despite the wide array of possibilities associated with new forest-based products, the core forest industry products— sawnwood and pulp and paper—are likely to still retain a significant role in 2030. This is due to the continuous demand for them, as well as the long process involved with introducing a new product to the markets and gaining large market volumes, and the long investment cycles of the forest-based industries. Another reason is that the research and development (R&D) and investment in new products is funded, to a significant degree, by turnover from the traditional businesses, albeit wood-based innovations, such as textiles, may arise from outside the traditional forest sector.

As local conditions and cultures vary, so do the shapes of the forest-based bioeconomy business models, as exemplified by the biorefineries of Borregaard in Sarpsborg, Norway and the Metsä Group in Äänekoski, Finland (Hetemäki and Hurmekoski 2020). Borregaard focuses on low-volume global niche markets rather than commodity products, and makes relatively large R&D investments to serve, for example, the agriculture, construction, pharmaceutical, cosmetics, food and electronics markets. In contrast, the bioproduct mill in Äänekoski—the largest forest-industry investment in the Nordic countries—is centred around large-volume-market pulp production, but it creates an ecosystem for smaller firms to utilise some of the sidestreams created in the material- and energy-efficient pulp production process.

What do the developments reviewed above imply for the forest-based sector? Consider a simple case, in which the forest-based industries in the USA, Canada, Sweden and Finland gained a 1–2% global market share in the construction, textiles, biofuels, platform chemicals and (plastic) packaging markets by 2030. This could result in an increase in revenue to the forest industries ranging from €18 to 75 billion per annum, corresponding to 10–43% of the production value of the forest industries in these four countries in 2016 (Hurmekoski et al. 2018a). Achieving the higher end of the range would require moving further downstream in the value chains; that is, to assume new roles rather than remain a producer of intermediate goods, which would highlight the role of services.

What would this mean for forests? The impact of gaining a 1–2% market share from primary wood use could be in the range of 15–133 million m^3, corresponding to 2–21% of the industrial roundwood use in these countries in 2016 (Hurmekoski et al. 2018a). The majority of this demand would be for sawn wood for construction. Table 4.3 shows the additional impacts from a 10- and 100-fold market volume. The purpose of such hypothetical scenarios is not to predict the market developments, but simply to assess the scale of the emerging market opportunities. For example, the implications of different market diffusion scenarios can be compared to the net annual increment of forests in the EU (721 million m^3: Forest Europe 2015) or to the global roundwood production (2028 million m^3: FAOSTAT), to make the matter more tangible.

At least two observations arise. Firstly, a minute market share of the global markets would completely transform the forest-based sector. Secondly, it is not realistic to expect an expanding bioeconomy to fully cover the demand in any of these

Table 4.3 Approximate impacts of hypothetical market diffusion scenarios for roundwood and byproduct demand in 2030

~1% market share	Construction	Textiles	Biofuels	Biochemicals	Plastics and packaging	Total
Roundwood, Mm^3	7–117	7–15	–	–	2	15–133
Byproducts, Mt	2	–	28	33–45	2	66–73
~10% market share	Construction	Textiles	Biofuels	Biochemicals	Plastics and packaging	Total
Roundwood, Mm^3	70–1168	65–147	–	–	15	150–1331
Byproducts, Mt	20	–	280	331–452	25	656–732
~100% market share	Construction	Textiles	Biofuels	Biochemicals	Plastics and packaging	Total
Roundwood, Mm^3	698–11,684	650–1469	–	–	153	1501–13,306
Byproducts, Mt	200	–	2800	3311–4520	246	6557–7320

Adapted from Hurmekoski et al. (2018a)

markets, even though the amount of virgin wood resources required to satisfy the construction or textile markets, for example, could, in principle, remain surprisingly small—around the annual increment of the EU forests.

It can be assumed that many of the new products will be based on the existing byproduct flows of the sawmilling and pulping industry, due to the limited ability to pay for the feedstock. Here, wood-based construction is an important driver for raw material availability, both for the pulp and paper industries and for a number of emerging industries, creating both synergies and trade-offs (Hurmekoski et al. 2018a). On one hand, the forest-based product industries would benefit from the increased demand for byproducts (wood chips, bark, sawdust and forest residues), while an increasing production of sawn wood would make generous amounts of byproducts available for the market. On the other hand, there would be competition for the byproducts between the traditional and emerging uses, such as wood-based panels and chemicals or biofuels. Also, other forms of interdependencies between the industries are feasible, such as integrated biofuel and biochemical production in a pulp mill, which could help to lower the pretreatment and transportation costs, and improve energy efficiency (e.g. Kohl et al. 2013; Karvonen et al. 2018).

The future of the forest-based bioeconomy is dependent on the demand from the end markets, developments in substitute markets, biomass markets, as well as policies at varying levels (Hetemäki and Hurmekoski 2020). Due to the variation between and within markets and regions, the opportunities for the forest-based bioeconomy will vary, such that a single, successful strategy cannot be articulated. A greater volume and broader scope of research on these topics would undoubtedly help to enable the emerging opportunities to be grasped.

4.3 Outlook for the Demand for a Forest-Based Bioeconomy

The year 2030 is relatively close, in terms of the likelihood of major new structural changes having impacts in the markets. Thus, a *trend forecast* (using data from 2010 to 2018) to 2030 can provide a helpful baseline against which different assumptions of changes in policy and technology, for example, can be reflected (see Figs. 4.2 and 4.3). In contrast, beyond 2030, major structural changes are likely to occur and have a profound impact on the market, and therefore it is not as helpful to use current trends to provide outlooks that cover several decades (UNECE/FAO 2021).

As the trend projections indicate, the outlook for forest-based products in the coming decade seems increasingly diverse. Information and communications technologies will have several impacts on the demand for forest-based products. These will reduce the demand for communication (graphic) papers, but increase the demand for packaging paper grades, due to the boost in e-commerce (Hetemäki et al. 2013). The demand for consumer papers, such as tissue paper, is expected to continue to grow due to globally increasing middle-income consumers and urbanisation. There are likely to be regional differences in the demand patterns, such as between the OECD and non-OECD countries (Hetemäki et al. 2013). Packaging and tissue-paper consumption are expected to increase, particularly in Asia and Latin America (Pöyry Inc. 2015). Compared to many other industries, the COVID-19 pandemic may have had a relatively small impact on the forest- based industries, but it may alternatively have accelerated the decline in the communication-paper market and the increase in packaging and hygiene paper demand.

Solid wood products have experienced internal competition. The global per-capita sawnwood consumption has declined in a trend-like manner for decades, despite continued growth in the global GDP and population. This is partly explained by the rapidly growing demand for wood-based panels and EWPs that can serve the same markets as sawn wood (Bühlmann and Schuler 2013). For example, the production of CLT in Europe has been growing at an average annual rate of 15% since 2007, despite the economic downturn and stagnation (Pahkasalo et al. 2015). While the overall market share of wood in construction may not necessarily increase significantly by 2030, its growth in hotspots in certain regions and market segments seems likely. The regional differences in demand patterns for solid wood products resemble those for paper products. Notably, China's share of the global wood-based panel production has increased to close to 50% during the last two decades (Fig. 4.1).

The outlook for bioenergy is highly uncertain, and regional differences can be significant (Hetemäki et al. 2020). Of the global roundwood production, roughly half ends up as wood fuel (energy). The major users of wood fuel are Africa, Asia and South America, while Europe's share of the global consumption of wood fuel was 9% (173 million m^3) in 2018 (FAOSTAT). In the long-term, it seems likely that wood-fuel consumption will decline due to a transformation to other energy forms, such as solar, wind, natural gas, hydro and hydrogen, and increases in bioenergy efficiency (Glenn and Florescu 2015; Hetemäki et al. 2020). However, the transformation will also depend on how extensive, and in what time frame, bioenergy carbon capture and storage becomes a viable option. In the nearer future—in the 2020s—and especially in the EU, policies supporting the use of bioenergy may continue to increase the wood-fuel consumption, as major changes in the energy infrastructure tend to take a decade or more, although the likelihood of continued support for the policy remains contested (Hurmekoski et al. 2019).

For emerging forest-based products, their competitiveness depends heavily on the rate of innovation uptake in competing industries, which, in turn, depends on factors such as climate and energy policies and their impacts on oil feedstock and CO_2 emissions prices. For example, synthetic biology, or the conversion of fossil CO2 by industrial biotechnology routes, may have the prospect of providing new products, such as bioethanol and butanol, or organic acids for polyesters, at less cost and using more energy-efficient processes (BIO-TIC 2015; Kruus and Hakala 2017). Carbon dioxide captured from air can technically be directly converted into methanol fuel or plastics (Kothandaraman et al. 2016). Some of these technologies are expected to have already been commercialised by 2030 (BIO-TIC 2015).

It is unclear what the *net impacts* of forest-based product development on global roundwood demand will be (Hetemäki et al. 2020). Some trends point to a growing roundwood demand, including economic and population growth and the need to replace fossil-based materials and energy with more sustainable raw materials (Pepke et al. 2020). For example, Dasos Capital Oy (2019) projected that all the main forest-based products would grow at rates of 2.1–5.5% per annum until 2030. At the same time, the graphic-papers demand is declining and the wood-fuel (bioenergy) demand could decline significantly in Africa and Asia (Hetemäki et al. 2020). Also, resource-efficiency and resource-recovery trends (e.g. cascading, recycling, process technological improvements) may limit the demand for virgin raw materials. Importantly, much of the production of new wood-based products would be based on the byproducts of the mature industries (Hurmekoski et al. 2018a). Determining the extent to which the demand for wood resources for new products would be *additional,* rather than shifting from one use to another, would need to be determined by an optimisation model that also included new wood-based products (see Sect. 4.4). In addition to the challenge to compute net impacts from these diverse trends, the regional differences can be significant. Also, in regions where there is pressure for increasing forest biomass utilisation, there could be trade-offs between the different ecosystem services that forests provide, which could curb the demand.

In summary, through this decade (the 2020s), the trends we are observing today, that are summarised above, will most likely still be the dominant ones. In the longer term, forests will no doubt continue to provide products for the increasing needs of humanity, but the race towards a more sustainable economy will also undoubtedly shape the competition between the forest-based sector and other sectors. The net impacts of the structural changes of the forest-based sector reviewed in the previous sections remain very uncertain. In the next section, we will briefly review the methodological challenges associated with long-term forest-sector outlook studies that partly explain the lack of a more concrete picture of the coming decades.

Box 4.3 Where Will New Jobs Be Created?

In 2018, in the EU27 (excluding the UK), there were 2.1 million people working in the 'traditional' forest sector, comprising forestry, the solid wood industries (excluding furniture) and the pulp and paper industries. Unfortunately, the employment numbers in the sectors such as forest-based bioenergy, biochemicals, biotextiles, furniture, printing, etc. cannot be derived from existing statistical classifications, However, together, they could be even more than the employment in the traditional forest sector. The furniture industry alone employed 1.13 million in 2018, and probably a significant portion of that was based on wood furniture. Thus, it would not be surprising if all the forest-based industries with value-added activities in the EU27 had employed around four million people. Moreover, there are 16 million private forest owners in the EU, many of whom earn income from forests.

Given that fossil-based production needs to be phased out, this will inevitably mean that many people will need to find new jobs in the EU. For example, very basic, fossil-based raw-material manufacturing (coke and refined petroleum products) alone employed a total of 186,200 people in 2018 in the EU27. If we included the fossil-based-plastics industry and other fossil-based industry sectors, this number would be much greater. For example, rubber and plastics manufacturing alone employed 110,400 persons in 2018 in the EU27.

We are not aware of any projections for how employment in the fossil-based manufacturing sector will develop in the EU27 when we move towards carbon neutrality by 2050. In order to have at least some idea of the importance of the question, let us review a hypothetical example. Assume that CO_2 emissions from the manufacture of coke, crude oil, gas and petroleum in the EU is phased out from 2020 to 2050 by 2.5% points each year. This would imply that, by 2050, there would be a cut of 75% of this sector's CO_2 emissions. For the sake of simplicity, let us also assume that employment in the sector is falling at the same rate; that is, only 25% of the employment level of 2020 is left in 2050. That would mean the loss of about 140,000 jobs in the fossil sector of the EU27 during this period (Fig. Box 4.2). Naturally, the rate could be different, and there would be other fossil-based sectors, such as plastics and chemicals, also losing jobs.

The European Green Deal (EGD) acknowledges the need for a socially justifiable move towards carbon neutrality by 2050, for example, via compensation funds to countries and regions that are heavily dependent on fossil-based industries. However, these funds will not automatically and necessarily result in new jobs. Therefore, it will be crucial for the EGD to address more explicitly how new jobs will be created, and in which sectors, when we move towards a carbon-neutral society.

(continued)

Box 4.3 (continued)

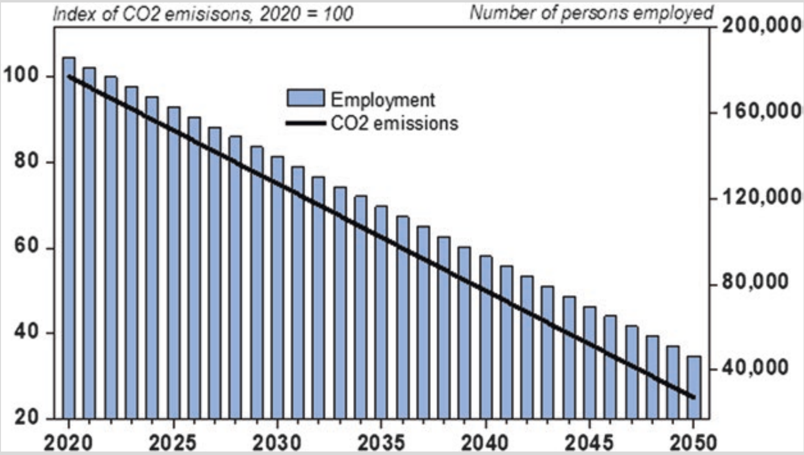

Fig. Box 4.2 Illustrative example of CO_2 emissions and number of people employed in the EU27 in coke, crude oil, gas and petroleum manufacturing in 2020–2050. (Source of employment data for 2018: EUROSTAT)

The creation of new jobs becomes an ever-bigger challenge if the EGD imposes policies that work towards cutting back economic activities in the renewable biological-resource-based sectors. Rather, the objective should be to boost the biological sector's economic activities in order to help phase out the fossil sectors, and to create employment opportunities in more-sustainable economic sectors. But this, of course, has to be done in an even more sustainable and resource-efficient way than in the past, while also considering the biodiversity needs. To this end, the approach outlined by researchers, termed 'climate-smart forestry', could provide the way forward in the forest sector (see Chap. 9).

4.4 Research Implications

As pointed out throughout this chapter, research on the future of the forest-based sector remains scarce. Moreover, the focus of outlook studies has primarily been on the sufficiency of wood resources, trends in the production of primary forest-based products and international competitiveness, while some of the equally important questions, such as value added, employment, changing demand patterns, and emerging forest-based products and services, have gained less attention, until recently (Hetemäki and Hurmekoski 2016; UNECE/FAO 2021).

The mainstream of the forest-sector outlook studies has been based on forest-sector modelling, combined with stakeholder interaction and scenario development, as a way of exploring and addressing the possible trade-offs that decision-makers will face (Hurmekoski and Hetemäki 2013). The strength of the forest-sector models is in capturing the interdependencies between different parts of the system, modelling the feedback and trickle-down impacts of changes in one part of the sector on the rest of the sector by making market adjustments through pricing and international trade (e.g. Toppinen and Kuuluvainen 2010).

The drawback of partial-equilibrium modelling and traditional econometrics is that determining the impacts of an exogenous shock requires a stable operating environment and the use of historical data, usually from a period of several decades. However, we have observed several major structural changes in the global and European forest-based sector in this century, which past data, and models based on these, have difficulties in capturing. The structural changes are a result of two primary factors—the expected market diffusion of new wood-based products and the changes in demand patterns for some of the established product groups. Regarding new wood-based products, the apparent limitation is the lack of reliable data (or long enough time-series) for the purpose of traditional econometric analysis. The changing demand patterns may be a less apparent, albeit equally important, factor to consider in modelling. However, apart from single cases, such as the substitution of graphic papers by electronic media (Hetemäki and Obersteiner 2001; Latta et al. 2016), the demand shifters for most forest-based products remain elusive, so that incorporating the omitted variables in demand equations may not necessarily be accomplished in a completely satisfactory way.

Thus, the strength of the forest-sector models in capturing the interdependencies between different parts of the forest sector can turn into a weakness in the presence of structural changes in demand. It can lead to distorted feedback effects, which may compromise the internal logic of the models. This means that, even if the primary research question was unrelated to structural changes, their impact may distort the findings in any ‘what if’ analysis or long-term projection. For example, we cannot assess whether an increase in forest-products production in one region, *ceteris paribus*, will signify a decrease in wood-products production in some other region, or a decrease in production of other materials. In the event of changes in the intersectoral market share, we are also lacking the means to reliably assess changes in the international market shares, even though it would otherwise be quite straightforward. This is a significant drawback when assessing the future uses of wood and their implications on the economy and the environment.

Models are always simplifications of reality and can never be expected to accurately predict market developments for several decades ahead. However, since forest-products-markets research clearly falls into the realm of applied science, it is essential to try to capture and explain market developments in order to maintain their practical relevance (Hetemäki and Hurmekoski 2016). Although the evidence-based models continue to be crucial elements of forest-sector outlook studies, they are unlikely to meet the needs of decision-making alone in the increasingly complex forest-based sector (Toppinen and Kuuluvainen 2010; Hurmekoski and Hetemäki 2013). For some forest products or regions, the traditional modelling framework could work well, but to complement the picture with emerging and declining markets, alternative approaches may be necessary.

4.5 Key Messages

- The state of the world's managed forests is determined by the societal demands for wood resources and other ecosystem services. The interplay of supply and demand thereby determines the employment and revenues created by the sector, as well as the ability of forests to provide a range of ecosystem services, such as wood-based products or carbon sinks.
- For the sake of the efficient planning of strategies, it can be useful to look ahead and try to anticipate possible changes that may take place in the future. Indeed, outlook studies have a long tradition in the forest-based sector.However, in the face of increasing structural changes taking place in the sector and the operating environment, the task of looking ahead is becoming evermore important, but also more challenging.
- In the twenty-first century, several structural changes have become evident. The demand for some of the traditional forest products is no longer developing on a par with consumers' available incomes. Instead, there are new factors influencing the demand for forest products, causing substitution between forest products and alternative products. As these factors are partly unknown or unmeasurable, future projections are subject to increasing uncertainty.
- A key trend in the forest industries is diversification, referring to new market opportunities for wood-based industries in, for example, the construction, textiles, packaging, biochemical and biofuel markets. As the importance of some of the traditional forest products—notably communication papers—are declining, the sector will not necessarily be dominated by single sectors in the long term. Moreover, the boundaries with other industries are becoming increasingly indistinguishable.
- There is a severe lack of systematic outlook studies that would illuminate the possible impacts of the expected structural changes of the forest-based sector (Hetemäki et al. 2020). As changes in the forest sector are usually gradual and slow, compared to the digital sector, for example, the current trends are likely set in a reasonable direction up to around 2030. However, over time, the uncertainties will grow bigger, owing to the large number of emerging market opportunities, as well as developments in the operating environment and other sectors. These uncertainties also imply significant uncertainties in the global demand for roundwood, and by extension, also the extent of the trade-offs between different ecosystem services and land uses. The implications for the climate impacts of wood use are reflected further in Chap. 7.

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