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Sectoral low-carbon roadmaps and the role of forest biomass in Finland's carbon neutrality 2035 target

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ABSTRACT

As a part of its climate policy, Finnish government facilitated the creation of low-carbon roadmaps by sectors of industry. The roadmap process and the roadmaps were promoted as an international benchmark in COP26. They also form a part of the policy process towards the government's goal of carbon neutrality by 2035. We analyse the need and role of biomass use contained in the roadmaps of the key sectors and compare it to data on available forest biomass. The combined need for forest biomass in the roadmaps is well over 140 Mm^3, which is over double that of the logging level in 2019, and drastically over the roadmaps' projection of future sustainable yield. This creates a challenge for the carbon neutrality goal via the loss of carbon sinks in forests, risking the carbon neutrality target and other sustainability goals. Although, up to date, the roadmaps present the most detailed picture of industrial transformation towards carbon neutrality in an EU member state, they are made unrealistic by the omission of a comprehensive material perspective. The addition of such a perspective and a clear setting of boundaries would increase the viability of the roadmaps as a policy tool.

1. Introduction

As the understanding of the scope and speed of climate change has become more concrete [1–4], countries have announced more ambitious climate targets. Concepts like "net-zero" and "carbon neutrality" have become more common in the expressed goals. These concepts rely on accounting where an entity, such as a nation or a company, tallies both its emissions and sinks, with the goal of the sinks being at least as big as the emissions.

The role of natural carbon sinks is especially important in Northern Europe where large tracts of land are forested. In many northern countries forests are central for multiple industrial sectors, as well as for biodiversity and carbon storage and sinks. Forests form a crucial hub in the material metabolism [5,6] of these societies, calling for careful attention in the face of rapid and far-reaching socio-ecological transformations [2]. As industries capture a major part of material and energy resources and cause environmental pressures [7,8], a comprehensive and realistic understanding of available resources and their limits is needed especially in industrial policies.

In this context, Finland's low-carbon industrial roadmaps are an interesting case for a number of reasons. Finland has been described as an "environmental state", meaning that environmental questions are an established site of politics, objects of political process and disagreement (e.g., Ref. [9]. Accordingly, Finland has been seen as belonging to the group of environmental leaders [10]. Recently, the government announced a goal of carbon neutrality by 2035 [11]. One policy tool towards this goal has been the preparation of low-carbon roadmaps by sectors of industry. The government initiated in 2019 the preparation of low-carbon roadmaps where industry sectors estimate when and how they will be carbon neutral [12]. Historically, the early inclusion of stakeholders in policy processes has been seen as a reason for the success of progressive environmental policy in Finland [13]. Along these lines, the roadmaps were prepared by the federations of the industry sectors, with guidelines set by the Ministry of Economical Affairs and Employment [12]. The commitment of the industry sectors is demonstrated by the fact that the Confederation of Finnish Industries promoted the

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roadmaps in the COP26 as an "international benchmark" [14].

At the same time, bioeconomy, a strategy that aims towards sustainable transition by promoting the increasing use of biomass [15,16], has occupied a key role in Finland's industrial policy and its energy and climate strategies for more than a decade [17,18]. The forest industry has promoted bioeconomy [19,20] and forest biomass plays an important role in the roadmaps of the energy and chemical sectors.

The government did not set clear limits for resource use in it's guidelines, thus making it possible for several industry sectors to project increased biomass use, leading to an unrealistic total in biomass use. This result is made possible by the lack of a comprehensive material perspective in the roadmap process. Consequently, we find that a policy process targeting carbon neutrality should pay more attention to biophysical limits, and that more research is needed on the relationship between efforts of emission reduction and resource use, both on the national and international scale.

2. Research question, data and methodology

The framing of our study is guided by Finland's national carbon neutrality target by 2035. Our first research question is: how big a role does forest biomass play in the Finnish national carbon neutrality target according to the sectoral low-carbon roadmaps, and what kind of uncertainties and risks does the role of biomass include for achieving carbon neutrality? Second, we investigate how could the roadmap process be developed so that the uncertainties and risks would be reduced. Accordingly, the first research task is to establish what the sectoral roadmaps' projections of emissions mean in term forest biomass use. Then we discuss the risks of the projected biomass use, and evaluate what features of the policy process have made the inclusion of these risks possible and how a similar result could be avoided.

Our primary data is formed by sectoral low-carbon roadmaps, and the governments guiding documents for the roadmap process [21–23], supported by interviews with actors in the roadmap work and other experts. Altogether 13 sectoral roadmaps were published by the end of 2020. Four key sectors, technology (including metal, electronics and electricity, ICT, and design and consultancy industry), energy, chemical and forest sectors, were prioritised by the Ministry, as they are responsible for the majority of emissions [12]; 16). We focus on three of these sectors, energy, chemical and forestry, as the roadmap for technology has only indirect bearing on biomass use via increased demand for clean electricity [24]. We also draw on roadmaps from other sectors (traffic and logistics, bioenergy), when relevant for forest biomass.

For each of the three main sectors, "the roadmap" consists of a different number of documents. The forest sector roadmap consist of five documents: a summary, an emissions scanario, a report on the climate effects of wood-based products, a report on forestry models, and a report on the economical effects of the roadmap. The roadmap for the chemical industry consists of a summary and a scenario analysis, the roadmap for the energy sector consists of a scenario analysis and a background review, and the technology sector roadmap of a summary, a scenario analysis and a technology review (see appendix A for a listing of all the analysed roadmap documents).

The primary method in our study is document review. We have read the above-mentioned material, focusing on the need for forest biomass. As suggested in the literature [5,6], we analysed what the roadmaps mean in material terms, in this case forest biomass inputs, and compared this resource need with information on current resource availability. The forest biomass requirement is in some cases expressed explicitly, and in other cases, the requirement is implicit or can be deduced from other quantitative information. In these cases, we established the material need through rough "ballpark" calculations, with conservative (i.e., systematically lowballing) estimates (premises for calculations in footnote 1).

Secondarily, we performed semi-structured interviews with participants in the roadmap process, including representatives of the MEAE, and other experts during spring 2021 (see Appendix A for details). The goal of these interviews was to deepen our understanding of the roadmap process, and to confirm our interpretations of the metabolic constraints on biomass use. The role of the interviews is supportive, and consequently we do not refer directly to them in the text.

3. Finland's carbon neutrality goal and the sectoral roadmaps

The current coalition government of Finland, with PM Sanna Marin representing the Social Democrats, set ecological sustainability high on its agenda, including it in the subtitle of its programme "Inclusive and competent Finland - a socially, economically and ecologically sustainable society" [11]. The goal of carbon neutrality by 2035 can be seen as more ambitious than Finland's obligations as a member of the EU, even if the target years differ. Currently the EU mandates a 40% reduction in emissions from the levels in 2005 by 2030; the EU Fit for 55 program increases the emission target to 55% [25], whereas the Finnish Climate Change Panel projects a reduction of over 60% by 2030 in its assessment of the 2035 target [26]. Basing on the UN climate change convention's equity principles, the FCCP has recommended that the target for carbon neutrality should be set to the early 2030's [27]. The present national climate law from 2015 mandates emission reductions of 80% compared to the level of 1990 by 2050 [28]. Currently, both the national energy and climate strategy and the climate law are under revision, and the sectoral roadmaps function as data for the revision [12]; 13).

During the 2000's, Finnish national emissions have decreased from 70 MtCO2eq in 2000 to 53 MtCO2eq in 2019, with a high of 85 MtCO2eq in 2003 [29]. At the same time, the land use, land use change and forest sector (LULUCF), has on average, formed a carbon sink of 21 MtCO2eq [27], with a high of 24 MtCO2eq in 2004 and a low of 10 MtCO2eq in 2018. Using the yearly average of 21 MtCO2eq for LULUCF sector sinks, the FCCP noted that current actions in the government's climate policy entail reductions for ca. 45% of the emissions, leaving ca. 55% with no actionable reduction measures [26]; 59).

Sectoral low-carbon roadmaps are a key part of the governments climate policy [12]. It is important to note that the roadmaps present the views of the industry sectors, not of the government. In the context of the functioning of the "environmental state" they are part of a political process, and their importance derives from the economic weight of the industry sectors, their role in the overall climate strategy and the promotion they have received on international fora [14].

To our knowledge, the fact that the roadmaps are used as basis for national climate and energy policy makes them, at the moment, unique in the world. Other European states which have produced similar roadmaps differ considerably how they use them in the policy processes. In Britain, the government commissioned in 2013 eight sectoral low-carbon roadmaps [30]. These roadmaps were not directly tied to specific policy processes. In Sweden, the government started in 2015 a multi-stakeholder Fossil Free Sweden initiative that has together with industry partners produced 22 sectoral roadmaps [31]. These roadmaps are not directly linked to a government strategy or its policies. In contrast, the Finnish low-carbon roadmaps are used as basis for the updated climate and energy strategy [12]; 13), and the mid-term climate plan [21]; 1), and have already been used as supporting information in the government's Sustainable Growth Programme [32], as part of the Next Generation EU recovery instrument. As such, the roadmaps provide the most detailed available picture to date of sector-specific transformation included in national carbon neutrality policy in an EU country.

The government's objectives for the roadmaps were delineated in three guideline documents, prepared by the ministry [21–23]. The objectives were: collecting information for climate and energy policy scenarios, identifying needs for research and development funding, avoiding overlaps in resource allocation, promoting economic growth and helping create a favourable policy environment [21]. The summary of the roadmaps notes that the coordination by the ministry was "light",

consisting of guidelines and support in terms of discussion events and seminars [12]; 16). The task set by the government is: "to map out the year when the sector will be carbon neutral" [23]. The documentation mentions that the government did not want to set target dates or other binding boundaries, since the sectors are experts on their own fields and the roadmaps are expected to be realistic, motivating engagement [12]. The documentation points out that even if Finland needs to be carbon neutral by 2035, individual sectors may reach the target later, which, in turn, entails a need for sinks [21,22].

4. Overview of the roadmaps of key sectors: energy, chemical, forestry

4.1. Energy sector

In 2017, the energy sector was responsible for emissions of 14.3 MtCO2eq, divided between electricity production 8.5 MtCO2eq and heat 5.8 MtCO2eq. In the roadmap the emissions drop to 2.4 MtCO2eq by 2035, with electricity at 1.1 MtCO2eq and heat at 1.3 MtCO2eq [33]. The roadmap projects a rapid increase in electricity production: from 86 TWh in 2017 to 112 TWh by 2035 [34]. One major source of increased demand is the technology sector, whose roadmap sees the sector's electricity use grow from the current 30 TWh/a to 50 TWh/a by 2035 [24]. Increased energy production with reduced emissions is possible mainly due to two low-carbon sources, nuclear and wind. The energy sector roadmap counts on two new nuclear plants by 2035, Olkiluoto 3 and Hanhikivi 1. Wind power is expected to power 22 TWh in 2035.

The roadmap notes that the emission reductions are mainly due to the end of coal use and decline in the use of oil and gas [33]. The use of coal in energy production is banned by law by 2029, and the roadmap expects that the use of oil and gas are marginalised by 2035. However, the need for heating during winter provides a challenge to the end-of-burning picture. Especially in large cities, district heating systems are hard to operate without burning [35]. Consequently, the roadmap sees that the use of wood as fuel will grow by 11 TWh/a by 2035, corresponding to ca. 5.5 Mm^3 of wood.[2] In addition, some continued use of peat and natural gas is expected. Therefore, while the specific emissions for electricity are projected to be 10 kgCO2/MWh (90 kgCO2/MWh in 2017), the specific emissions for district heating are expected to be 50 kgCO2/MWh (150 kgCO2/MWh in 2017).

4.2. Chemical sector

The emissions were 5.4 MtCO2eq in 2019, and the carbon-neutral scenario projects emissions of 2.6 MtCO2eq in 2035 [36]; 51). The prerequisite is a doubling of energy consumption from 7 TWh to 15 TWh by 2035 [36]; 52), due to the adoption of power-to-x technologies, carbon sequestration and utilization, and electrification of heat [36]; 62). A condition of success is a change in feedstock, currently dominated by fossil fuels, with annual use of ca. 15 Mt [37]; 12). The sector is already producing liquid fuels from biomass, as demand for them is created by the EU and national obligations for including renewable, in practice bio-based, fuel in traffic fuel. Nationally, the obligation will be raised to 30% by 2030 [38]. With current traffic volumes, the increased number would mean ca. 13.5 TWh of liquid fuel, corresponding to ca. 11 Mm^3 of wood.[3]

4.3. Forest sector

The roadmap consists of five documents, each with different authors. This relatively intensive involvement can be explained by the sector's multi-faceted importance. Economically, the forest sector is responsible for ca. 20% of exports [39]. Ecologically, the preservation of biodiversity depends on forestry practices, as the most important reason why species become threatened and regionally extinct in Finland is forestry [40]; 103). In terms of climate policy, the forest sector is paramount. This is due to the trade-off between logging and carbon sinks and storage. Harvested wood can replace fossil fuels and fossil feestocks, thus reducing emissions. At the same time, loggings affect carbon sinks and storage for some periods of time as the forest grows back. The details of how logging levels relate to levels of carbon sinks and storage are complicated, as the biophysics is complex (different types of logging, different types of forest, short- and long-term effects on soil and aerosols, etc.). However, the research consensus is that in Finnish forests with current or comparable forestry practices, increased loggings decrease sinks so that for the period of several decades net emissions increase [41–43]. The existence of this trade-off is explicitly noted in the document on forestry models [44]; 13).

In 2017, the emissions of the sector were 3 MtCO2eq, and the roadmap projects emissions of 0.3 MtCO2eq in 2035 [45]. This is due to electrification and replacement of fossil fuels and peat in industry processes [46]; 9); the roadmap expects that carbon capture and storage technology will be utilised only after 2035. At the same time, the roadmap projects an increase in production, so that the increment value of 12.1 billion euros in 2017 will be 19.4 billion euros by 2035 [46]; 13). Together these two goals, emission cuts through replacement of fossil fuels and increased production, mean that the forest sector will be utilising more wood. The roadmap expects that the need for wood in 2035 will be ca. 90 Mm^3, up from 70 Mm^3 in 2017. This oversteps the 2019 maximum level of sustainable (in terms of wood production, not taking into consideration biodiversity and other ecological issues) yield of 83 Mm^3 [47], so the roadmap presents also a model of intensified forestry practices [44] intended to increase forest growth, for instance, via widespread use of fertilisation and seedlings that have been selected or genetically modified for faster growth and changed climate. At the same time, the roadmap's report on the climate-effects of wood based products [48]; 1) explicitly omits considerations of biodiversity and carbon sinks, i.e., the other side of the trade-off.

5. The role of wood biomass in the three key sector's roadmaps

None of the three key sector's roadmaps project carbon neutrality by 2035, necessitating sinks in national accounting. The summary by the ministry [12] gathers together the needs for energy, investments, and capacity-building in the roadmaps, but not the combined need for biomass, or other natural resources. This is unfortunate, as the roadmaps for energy, chemical and forest sectors all contain increased use of biomass. In addition, the roadmap for bioenergy (separate from the roadmap for energy), notes that the volume of bioenergy is projected to grow between 10 and 20% until 2030 [49]; 110). Likewise, the roadmap for traffic and transportation includes an increase in the obligation of renewable energy use in road traffic from 30 to 34% by 2030 [50]; 57).

The most prominent domestic biomass produced and used in Finland is wood, with annual logging of ca. 70 Mm^3 in 2019 and energy production from wood at 105 TWh [47]. In comparison, the potential non-wood feedstock from food sector waste and agricultural residues is estimated at 11–15 TWh [51]. Consequently, the demand for domestic biomass will largely be dependent on forest biomass.

The forest sector's roadmap projects an annual use of 90 Mm^3 of wood [46]. The forest sector sees the main increase in production coming from wood products, fibre packaging and hygiene and textile products [46]; 6; [52]. The energy sector projects an increased production from wood at 11 TWh/a [33], corresponding roughly to 5.5

[2] The energy gain from wood varies widely depending on wood species, moisture content and wood type (stem, branches, bark, etc.). Following [78]; we use a (high) average of 2 MWh per one m^3 of wood.

[3] Efficiencies of conversion from wood to liquid fuel depend on details of the process. Following [79] we use 0.6 as the average conversion efficiency. Consequently, 13.5 TWh of liquid fuel would demand ca. 11 Mm^3 of wood.

Mm^3 of wood. The largest additional demand for biomass comes from the chemical sector. Currently, only 17% of feedstock is renewable or recycled, and the roadmap estimates an annual need corresponding to 15 M tons of fossil feedstocks [37]; 12). The sector also uses 15 TWh of fossil based process heat [36]; 81). We assume here, conservatively,[4] that the sector would replace ca. 40% of fossil feedstock by forest biomass, giving a demand of ca. 35 Mm^3; with process heat adding 7.5 Mm^3. The bio-obligation for traffic fuel projected in the roadmap for traffic and transportation [50] will demand 11 Mm^3 (this comes in addition to the replacement of the chemical sectors fossil feedstock). Altogether, the roadmaps would put the level of annual wood use over 140 Mm^3, well above the annual logging maximum of 90 Mm^3 in the model of intensified forestry practice, not to speak of the current sustainable logging maximum (see Fig. 1).

6. Risks with regard to climate, economy and global fairness

The first risk, paradoxically, concerns the goal of carbon neutrality itself. When targeting carbon neutrality, the net emission numbers are derived by subtracting the amount of carbon sinks from the amount of total emissions. When the emissions and sinks of the different parts of the LULUCF sector (including emissions and sinks from forests, cropland, grassland, deforestation, afforestation, etc.) are counted together, the sector in total can form an emission source or a sink. Sinks appear, in countries with large forest cover such as Sweden and Finland, due to uptake of carbon in forests. Furthermore, the emissions of biomass burning are reported in the LULUCF sector emissions (contributing to the reduction in the LULUCF sector sink), not as end-of-pipe emissions on the energy sector when wood is burned. Thus, when loggings are increased and the wood is used for energy, the national accounting gains carbon-free energy, but loses carbon sinks. This trade-off is significant, as in Finland 57% of harvested wood ended up used as energy in 2019 [47].

As noted above, the national path to carbon neutrality is dependent on sinks being at the level of 21 Mt in 2035. According to recent estimates, increased loggings of 1 Mm^3 decrease the forest carbon sink between 1.21 and 2.29 Mt in Finnish forests, with the average from six different models being 1.7 Mt [41]; 26; see also [53]. [54]; present similar results from the perspective of displacement factors, i.e. substitution of wood for other materials). Thus, when continued, increased logging levels may jeopardise the needed level of sinks, if forest growth does not rise in the same degree.

The increased wood use in the roadmaps is, to a major extent, a consequence of the substitution of wood for fossil fuel and fossil feedstock. Whether substitution is beneficial for the climate depends crucially both on the details of the substituted fossil material and the used wood biomass, including details on the species of wood, the age-structure of the felled forest, the time period under consideration and so on [42,43,55,56]. Given the relatively slow-growing forests in Finland, it typically takes several decades before a forest is regrown after felling. In an analysis of substitution impacts for various wood utilization scenarios, Soimakallio et al. ([60], 5133) conclude that "[i]t is exceptionally unlikely (cumulative $P \leq 1\%$) that the wood utilization in Finland provides significant unit reductions in net carbon emissions within the upcoming 100 years." The result is mostly due to the loss of carbon sinks via felling. In a similar vein, Kalliokoski et al. [42] find in an analysis of different harvest scenarios for Finnish forests that " [i] ncreasing harvests from baseline (65% of Current Annual Increment) decreased the total carbon sink (carbon in trees, soil and harvested wood products) at least for 50 years."

Using harvested wood for long-lived products that store carbon for decades if not longer, such as timber for construction, typically implies greater emission reductions than using it for bioenergy ([80]; [43,57]. Unfortunately, a great part of the increased use of wood implied by the roadmaps aims wood for energy use (all of the increase in the energy sector, all of biofuels, and the chemical sector process heat, and, with current practices, over 50% of forest sector increase; [47]. Likewise, when wood is used as feedstock for the chemical industry, a substantial number of the potential end products are going to release the carbon relatively shortly.

In terms of climate goals, the time-frame of carbon re-uptake is crucial [58–60]. It has been argued that for urgent climate mitigation, the use of biomass should be limited to feedstocks that have re-uptake times within the timeframe of the Paris agreement [61]. Given the multi-decadal re-uptake times in Finnish forests, the increased logging levels implied by the roadmaps clearly risk increased net emissions within the timeframe of the carbon neutrality goal by 2035.

In addition to jeopardizing the climate goal, increased harvesting also presents problems for goals with regard to the use of natural resources. According to the proposal for a national circular economy program, the use of natural resources in 2035 should not be higher than it was in 2015 [32]. Although the used indicator for resource use, raw material consumption (RMC), does not reflect the consumption of materials that end up in products that are exported, the increased use of forest biomass puts pressure for reductions in resource use in other parts of the economy.

The second risk is economic. Estimations of substitution benefits in modeling are often dependent on assumptions of what increased biomass demand means for future forestry practices. For instance, like the model of intensified forestry practices included in the forest sector roadmap [44], models may expect more efficient forest management. If these assumptions are not fulfilled, substitution benefits may be off-set by reductions in the forest sink [62]. In the literature, the sustainability of resource use is hierarchised as "theoretical > technical > economic > sustainable" [63]. The model of intensified forestry practices is, in this hierarchy, a technical scenario, with no economic or sustainability evaluation. This fact considerably increases the uncertainty of the low-carbon roadmaps.

The economic risk ties closely to the third risk, that of forest biomass availability. As noted above, the combined need of the three key sectors exceeds the annual growth of forests. The projected wood requirement of the forest sector alone is feasible only through a model of intensified forestry. Two factors make the intensification uncertain. First, it requires that the intensified practices are taken into use on all forest land immediately [44]; 10). Second, the scenario increases the costs for the forest owner by 16% [44]; 23). In Finland, ca. 60% of the forests are in private ownership [47]. The increased costs make voluntary adoption uncertain.

Barring an unforeseeable breakthrough in biomass production technologies, such as algae production, mentioned by the chemical sector roadmap as a potential future source [36]; 86), the other possibility to satisfy increased demand is to increase imports. The roadmaps do not contain an assessment of what kinds and how much sustainably produced biomass will be available in the coming 15 years. In Finland, the imports of wood have fluctuated between 10 and 20 Mm^3 during the past 20 years, with Russia and the Baltic states as biggest sources [47].

However, increasing imports are problematic from the perspective of climate mitigation and biodiversity [64]. For exporting countries, increased production includes potential problems such as over-exploitation, displacement of local biomass/land use, low value-added exports and dependency on shifting EU policy [81]. Researchers and policy-makers have called for unified criteria of sustainable biomass as a solution to regulate out high-risk feedstocks [61,65,66]. As biomass imports to EU have relied to a large extent on North America [67], it is

[4] As the possibilities for future feedstocks are highly speculative, we will consider the current fossil feedstock of 15 Mt, and disregard the annual volume growth of 0.75% in the roadmap [36]; 48). Circa 40% of the revenue of the sector comes from energy-bearing products [36]; 14), so we will use this proportion of feedstock replacement, and assume that the fossil feedstock is crude oil with energy content 42 GJ/ton.

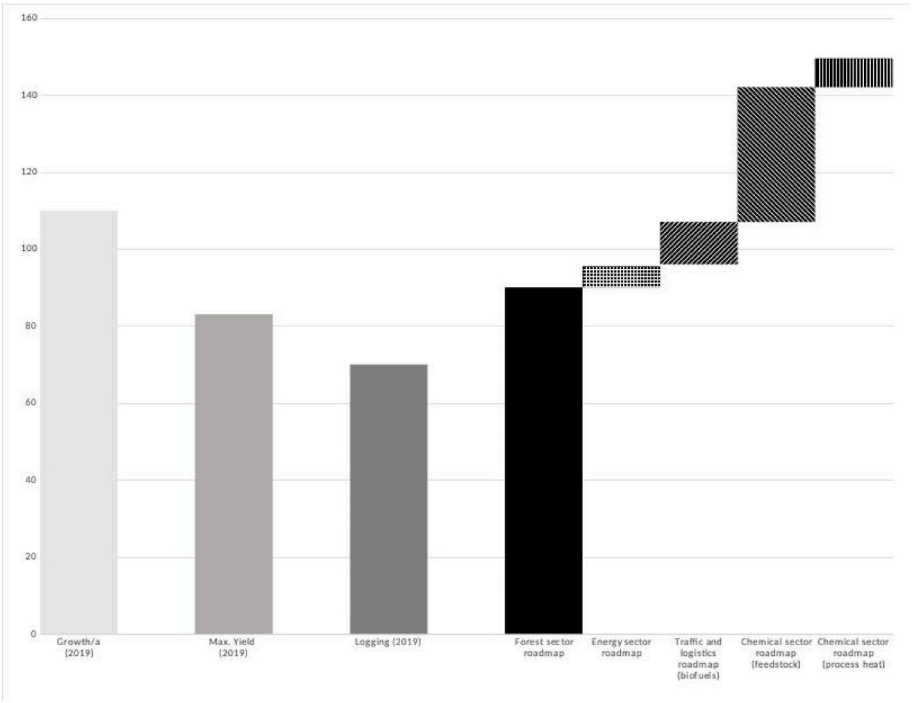

Fig. 1. Forest biomass use in the roadmaps compared to current use. Forest growth per annum was 110 Mm^3 (in 2019), giving a maximum (taking into account only sustainability of logging, not biodiversity or other environmental issues) yield of 83 Mm^3; in 2019, the logging total was 70 Mm^3 [47]. The roadmap for forestry relies on 90 Mm^3 of loggings, the energy sector plans to increase wood use by 5.5 Mm^3, 11 Mm^3 is needed for biofuel production, and, in addition, the chemical sector roadmap needs 35 Mm^3 for feedstock and 7.5 Mm^3 for process heat.

important to notice that those jurisdictions increasingly recognise that the export of pellets is not compatible with their domestic emission reduction goals [68].

Rogelj et al. [69], emphasise that carbon neutrality goals should be precise, transparent and fair, and suggest the question "would it be fair to apply the same logic to all countries?" to assess fairness. If it transpires that Finland, an affluent country with one of the largest percentage of forest cover in all EU countries, attains carbon neutrality through biomass imports, fairness is not achieved. From the point of view of global sustainable development goals, a practice where a highly developed country imports biomass in order to reach carbon neutrality is problematic [70]. Similar considerations have led groups of scientists to call on the EU to restrict forest biomass use [71,72]. Likewise, calls have been made to the EU to close the loophole where an importing country can record imported biomass as zero emission on combustion [73]. As the increased use of biomass also increases the consumption of energy and other resources, such as land and water, and increased carbon emissions within the time-frame of the Paris agreement [43,61], the reliance on biomass in carbon neutrality goals may result in a form of "greenwashing" [74].

7. Results and discussion

The most detailed documents on Finnish carbon neutrality 2035 target, the sectoral low-carbon roadmaps, are based on forest biomass use that, already on account of one sector, the forest sector, relies on unrealistic assumptions on future forest biomass availability. When taken together, the low-carbon roadmaps of three key industrial sectors, energy, chemical and forest sectors, and the roadmap for the traffic sector, contain a biomass demand of well over 140 Mm^3, which is ca. double that of the logging level in 2019, and drastically over the projected intensified forestry logging levels of 90 Mm^3 included in the forest sector roadmap.

The projected unrealistic level of use is possible for two reasons. First, the roadmap process itself did not contain an assessment of combined material use and the guidance by the government did not limit the use of material resources in any way. Thus, the industry sectors combined were free to overstep the available domestic forest biomass. Second, an incentive for the increased use of biomass is created by the fact that the emissions from wood use are accounted in the LULUCF sector of the country in which the wood was harvested, so that they matter in the national accounting in terms of loss of sinks, and not in the emission accounting and eventual emission trading costs of the industrial sector using the wood.

The roadmaps' lack of an overarching material perspective produces a number of lacunae of knowledge and concomitant risks. As noted above, the first risk concerns the climate target. The estimate of the climate effects of forest products [48] in the forest sector roadmap explicitly omits the effects on carbon sinks and biodiversity. Consequently both its effects on climate mitigation (via sinks) and ecological sustainability (via biodiversity) are uncertain. This omission means that the roadmaps' impact on the national level, where both emissions and sinks are accounted for, is unknown. As recent research suggests that increased logging in Finnish forests increases CO2 emissions for several decades [42,43,53,54,60], the effect of the roadmaps, if carried out, might mean an increase in carbon emissions by 2035. In addition, as the Red List of Finnish Species [40] contains several forest species, increased logging puts biodiversity goals at risk.

If the need for biomass is not domestic forest biomass, but imported biomass, the roadmaps present challenges with regard to fairness and climate justice. Securing the sustainability of imported biomass is one problem, but can be handled with proper diligence. A bigger problem concerns the implications of a situation where an affluent and amply forested country like Finland imports biomass resources, most likely, from less affluent areas of the world. This produces an unfair situation with regard to sustainable development goals [70].

The roadmap process was a success in promoting engagement from the industry sectors [14]. In this it follows the general pattern, according to which early engagement from stakeholders has been seen as a reason for the progress of the environmental state in Finland [13]. It also provides, up to date, the most detailed and comprehensive picture of industrial transformation towards carbon neutrality in a member of the EU, which, unlike the Swedish and British roadmaps, is directly connected to governmental policy work.

In contrast to this success, the roadmaps fall short of parts of the assignment set by the ministry. The guidelines for the roadmaps mention

that the scenarios should assess risks and uncertainties, and avoid overlaps in resource allocation [12]; 118). However, the availability of sustainably produced biomass is evaluated neither in the sectoral roadmaps nor in the summary by the ministry. Both also omit evaluation of sinks, even though sinks will be necessary, as the sectors will not be carbon neutral by 2035. Thus, the roadmaps continue the overly optimistic assumptions on the availability of biomass and on the climate effects of increasing forest use in the preceding Finnish bioeconomy strategies, repeatedly criticised by researchers [19,20,75].

The uncertainties in the numbers for biomass use presented in Fig. 1 are considerable, and not readily quantifiable. The roadmaps present scenarios of paths toward carbon neutrality, not scientifically evaluated predictions. Furthermore, some of the background information, such as quantities of biofuel feedstock [76], relevant to the scenarios is not public, due to commercial reasons. At any moment technological developments, new legislation or rapid changes in demand on global or domestic markets may change the need for biomass. However, these uncertainties do not invalidate the fact that the roadmaps have been presented as "[showing] that the Government's goal of a carbon neutral Finland in 2035 is achievable for industry and other sectors with existing or upcoming technologies" [12]; desciption page). The roadmaps have already been used in informing policy [32], and will continue to be used so. Thus the uncertainties included in the numbers emphasise the need for more rigorous attention to material metabolism in the policy process.

In addition to uncertainties, the numbers on biomass use contain potential overlaps. The increase in the wood use in the energy sector is due to the needs of district heating, and consequently does not overlap with the forest or chemical sector, nor the need for biofuels. Potential overlaps are, therefore, between the forest sector and the need for biofuels, between the forest sector and the chemical sector, and the chemical sector and the need for biofuels.

The forest sector does produce some amount of liquid fuels and raw materials (such as tall oil) for liquid fuel and chemical products. However, the production of liquid fuels, chemical products and raw materials for these by the sector is orders of magnitude smaller (in monetary terms millions rather than billions, and in volume terms kilotons rather than millions of tons) than its production of pulp, paper and board and of sawn and planed goods; and the roadmap projects no major change in this distribution (Finnish Forest, 2020, 6 [45]; 10).

The needed biofuel can be produced by both the forest sector and the chemical sector. Currently, over 80% of Finnish biofuel production comes from the chemical industry and is mainly biodiesel [76]; 8). In biodiesel production wood (tall oil) has a role, typically around ten percent of the feedstock [76]. For the increase in the wood use of the chemical sector, we calculated, conservatively, only replacing the feedstock for the energy-bearing products (see footnote 3). As the amount of wood-based feedstock currently used as feedstock of energy-bearing products in the chemical sector is very small (tall oil in diesel production), we can safely assume that the feedstock to be replaced is nearly completely fossil material. Consequently, the wood needed for the production of biofuel is additional with regard to the replacement of the fossil feedstock. As noted above, the same goes for the forest sector: as the sector sees no major shift in the relative amounts of its product groups, the needed amount of biofuel production (corresponding to 11 Mm^3 of wood) is additional to the forest sector's projected wood use.

8. Conclusion

Combining information of increased use of biomass in the roadmap documents of the chemical, forest and energy sectors, and the roadmap for traffic, we find that the roadmaps require over 140 Mm^3 of wood, well over any existing projections of sustainable yield (90 Mm^3 in the model of intensified forest practices; [44]. This increased demand for biomass can be satisfied by massively increased forest growth or increased biomass imports, or a combination of both. Both of these options are problematic. It is unclear if the model of intensified forestry can be implemented, and, even if implemented, it's maximum yield of 90 Mm^3 will not suffice. Also, given that increased logging by 1 Mm^3 will, according to modeling results, decrease the carbon sink in the range of 1.7 Mt [41], the projected logging levels jeopardise the 2035 climate neutrality goal. In addition, increased logging is a risk to biodiversity goals, as forestry is the most important cause of regional extinction in Finland [40]; 36). The picture given by the roadmaps is risky, unrealistic and potentially unfair, as the effects that the biomass needs would have on carbon sinks and biodiversity, both domestically and via imports, are unassessed and unknown.

The summary by the ministry [12]; desciption page) contends that "The roadmaps show that the Government's goal of a carbon neutral Finland in 2035 is achievable for industry and other sectors with existing or upcoming technologies". The message has been operationalised in the government's plan for green growth, where it is repeated, somewhat more ambiguously: "The carbon neutrality goal is dependent on substantial emission cuts in industry. The sectoral low-carbon roadmaps show that the reductions are possible." [32]; 30). Unfortunately, the summary of the roadmaps does not address the need for biomass, or any other material resource, thus also omitting any analysis of uncertainties and risks. These uncertainties and risks are entrenched when the roadmaps are used as the basis of further policy work.

In the roadmaps, the achievement of carbon neutrality is deferred via unstated material preconditions, specifically, radical biomass use increase. As an aspect in the development of the Finnish environmental state, the roadmap process represents a deeper engagement of industrial actors in low-carbon transition; an inclusion often recommended by environmental transition scholars [13,77]. However, our analysis indicates that the mere inclusion of industries is not enough to result in realistic overall scenarios, when an assessment of the material and environmental limits, risks and uncertainties is lacking. It is these aspects of material metabolism that environmental states as well as environmental scholars need to pay more careful attention to in order to promote successful socio-ecological transformations.

Credit author statement

Antti Majava: Conceptualization; Data curation; Investigation; Writing – original draft; Tere Vadén: Conceptualization; Data curation; Investigation; Writing – original draft; Writing – review & editing; Tero Toivanen: Conceptualization; Data curation; Investigation; Writing – original draft; Paavo Järvensivu: Conceptualization; Data curation; Investigation; Ville Lähde: Conceptualization; Data curation; Jussi T. Eronen: Conceptualization; Investigation; Visualization; Writing – original draft; Writing – review & editing.

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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.

Appendix A

Interviews

	Interviewee	Date
1	Confederation of Finnish Industries (CFI), participant in the roadmap process	3.2.2021
2	Chemical Industry Federation of Finland, participant in the roadmap process	17.2.2021
3	University of Eastern Finland, expert on forest sector	22.2.2021
4	MetsäGroup Ltd, senior director	26.2.2021
5	Finnish Environment Institute, expert on material flow accounting	8.3.2021
6	Lappeenranta–Lahti University of Technology LUT, expert on energy systems	11.3.2021
7	Finnish Energy Federation, participant in the roadmap process	30.3.2021
8	Ministry of Economic Affairs and Employment (MEAE), participant in the roadmap process	31.3.2021
9	Ministry of Economic Affairs and Employment (MEAE), representative of working group on sector intergration	6.4.2021
10	MetsäGroup Ltd, MetsäSpring, three senior representatives	6.4.2021
11	Finnish Forest Industries, three senior representatives	16.4.2021

Assessed roadmap documents

Sectoral roadmap, and responsible industry federation	Documents	In bibliography
Technology, Technology Finland	1. Roadmap report	1 [24].
Energy, Finnish Energy	1. Scenario analysis	1 [34].
	2. Background review	2 [33].
Forest, Finnish Forest Industry	1. Summary	1 [46].
	2. Roadmap on emissions	2 [45].
	3. Report on the climate effects of wood-based products	3 [48].
	4. Report on forestry models	4 [44].
	5. Report on the economical effects of the roadmap	5 [52].
Chemical sector, The Chemical Industry Federation of Finland	1. Summary	1 [37].
	2. Scenario analysis	2 [36].
Bioenergy, The Bioenergy Association of Finland	1. Roadmap report	1 [49].
Traffic ands logistics, seven different federations, including Finnish Freight Forwarding and Logistics Association and Service Sector Employers Palta	1. Roadmap report	1. [50]

References

[1] UNEP, Emissions Gap Report 2020, 2020. Retrieved from, https://www.unep.org/emissions-gap-report-2020.

[2] IPCC, Global Warming of 1.5°C, 2018. Retrieved from, https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_High_Res. pdf.

[3] W.J. Ripple, C. Wolf, T.M. Newsome, P. Barnard, W.R. Moomaw, Corrigendum: world scientists' warning of a climate emergency, Bioscience 70 (1) (2020) 100, https://doi.org/10.1093/biosci/biz152.

[4] W. Steffen, J. Rockström, K. Richardson, T.M. Lenton, C. Folke, D. Liverman, C. P. Summerhayes, A.D. Barnosky, S.E. Cornell, M. Crucifix, J.F. Donges, I. Fetzer, S. J. Lade, M. Scheffer, R. Winkelmann, H.J. Schellnhuber, Trajectories of the earth system in the anthropocene, Proc. Natl. Acad. Sci. Unit. States Am. 115 (33) (2018) 8252–8259, https://doi.org/10.1073/pnas.1810141115.

[5] H. Haberl, M. Fischer-Kowalski, F. Krausmann, J. Martinez-Alier, V. Winiwarter, A socio-metabolic transition towards sustainability? Challenges for another Great Transformation: a socio-metabolic transition towards sustainability? Sustain. Dev. 19 (1) (2011) 1–14, https://doi.org/10.1002/sd.410.

[6] H. Haberl, D. Wiedenhofer, S. Pauliuk, F. Krausmann, D.B. Müller, M. Fischer-Kowalski, Contributions of sociometabolic research to sustainability science, Nat. Sustain. 2 (3) (2019) 173–184, https://doi.org/10.1038/s41893-019-0225-2.

[7] R. Hildingsson, A. Kronsell, J. Khan, The green state and industrial decarbonisation, Environ. Polit. 28 (5) (2019) 909–928, https://doi.org/10.1080/09644016.2018.1488484.

[8] P. Johnstone, K.S. Rogge, P. Kivimaa, C. Farné Fratini, E. Primmer, Exploring the re-emergence of industrial policy: perceptions regarding low-carbon energy transitions in Germany, the United Kingdom and Denmark, Energy Res. Social Sci. 74 (2021) 101889, https://doi.org/10.1016/j.erss.2020.101889.

[9] A. Duit, P.H. Feindt, J. Meadowcroft, Greening Leviathan: the rise of the environmental state? Environ. Polit. 25 (1) (2016) 1–23, https://doi.org/10.1080/09644016.2015.1085218.

[10] R.K.W. Wurzel, D. Liefferink, D. Torney, Pioneers, leaders and followers in multilevel and polycentric climate governance, Environ. Polit. 28 (1) (2019) 1–21, https://doi.org/10.1080/09644016.2019.1522033.

[11] Finnish Government, Programme of Prime Minister Sanna Marin's Government, Retrieved from, http://urn.fi/URN:ISBN:978-952-287-811-3, 2019.

[12] MEAE, The Ministry of Economic Affairs and Employment. Summary of Sector-specific Low-Carbon Roadmaps, Retrieved from, https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/162851/TEM_2021_9.pdf, 2021.

[13] V. Koskimaa, L. Rapeli, J. Hiedanpää, Governing through strategies: how does Finland sustain a future-oriented environmental policy for the long term? Futures 125 (2021) 102667, https://doi.org/10.1016/j.futures.2020.102667.

[14] CFI, Confederation of Finnish Industries, COP26 Summit: Finnish Business Calls for High Ambition and Clear Outlook for Green Investments, Retrieved from, https://ek.fi/en/current/bulletins/cop26-summit-finnish-business-calls-for-high-ambition-and-clear-outlook-for-green-investments/, 2021.

[15] K. Birch, D. Tyfield, Theorizing the bioeconomy: biovalue, biocapital, bioeconomics or . . . What? Sci. Technol. Hum. Val. 38 (3) (2013) 299–327, https://doi.org/10.1177/0162243912442398.

[16] J. Goven, V. Pavone, The bioeconomy as political project: a polanyian analysis, Sci. Technol. Hum. Val. 40 (3) (2015) 302–337, https://doi.org/10.1177/0162243914552133.

[17] M. Kröger, K. Raitio, Finnish forest policy in the era of bioeconomy: a pathway to sustainability? For. Pol. Econ. 77 (2017) 6–15, https://doi.org/10.1016/j.forpol.2016.12.003.

[18] J. Kunnas, T. Myllyntaus, Lessons from the Past? A Survey of Finnish Forest Utilisation from the Mid-eighteenth Century to the Present, Environ. History (2020), https://doi.org/10.3197/096734020X15900760737121.

[19] T. Ahlqvist, H. Sirviö, Contradictions of spatial governance: bioeconomy and the management of state space in Finland, Antipode 51 (2) (2019) 395–418, https://doi.org/10.1111/anti.12498.

[20] T. Toivanen, A player bigger than its size – Finnish bioeconomy and forest policy in the era of global climate politics, in: M. Backhouse, R. Lehmann, K. Lorenzen, M. Lühmann, J. Puder, F. Rodríguez, A. Tittor (Eds.), Bioeconomy and Inequalities. Socio-Ecological Perspectives on Biomass Sourcing and Production across South America, Asia and Europe, Palgrave, London, 2021.

[21] MEAE, Muistio – Lähtökohdat Ja Sisältö, [Memorandum - preconditions and content], 2019. Retrieved from, https://tem.fi/documents/1410877/17156670/Muistio+-+l%C3%A4ht%C3%B6kohdat+ja+sis%C3%A4lt%C3%B6.pdf/fcc9f212-583f-8903-e7f3-46dc05ecd2bc/Muistio+-+l%C3%A4ht%C3%B6kohdat+ja+sis%C3%A4lt%C3%B6.pdf.

[22] MEAE, *UKK - toimialakohtaiset tiekartat vähähiilisyyteen.* [FAQ - sector specific low-carbon roadmaps], Retrieved from, https://tem.fi/documents/1410877/17156670/Usein+kysytyt+kysymykset+v1.1.pdf/92243ffd-d09c-1ed1-0ae5-44497873e005/Usein+kysytyt+kysymykset+v1.1.pdf, 2019.

[23] M. Paloneva, Tiekarttojen Lähtökohdat Ja Sisältö, Starting points and content of the roadmaps, 2019. Retrieved from, https://tem.fi/documents/1410877/17156670/Esitys+-+l%C3%A4ht%C3%B6kohdat+ja+sis%C3%A4lt%C3%B6.pdf/cdb96388-1664-db5d-8459-05db239fb587/Esitys+-+l%C3%A4ht%C3%B6kohdat+ja+sis%C3%A4lt%C3%B6.pdf.

[24] Technology Finland, Teknologiateollisuuden Vähähiilitiekartta 2035, [Technology sector low-carbon roadmap 2035], 2020. Retrieved from, https://teknologiateollisuus.fi/sites/default/files/inline-files/Teknologiateollisuuden-va%CC%88ha%CC%88hiilitiekartta-tiivistelm%C3%A4_2020-06-08_FINAL.pdf.

[25] OSF, Official Statistics of Finland, Greenhouse gases [e-publication], Helsinki, 2021. Statistics Finland. Retrieved from: http://www.stat.fi/til/khki/2020/khki_2020_2021-12-16_tie_001_en.html.

[26] FCCP, Finnish climate change Panel, Retrieved from, Emissions Pol Gap. (2019), https://www.ilmastopaneeli.fi/wp-content/uploads/2019/10/yhteiskunta_seminaari_slidet.pdf.

[27] FCCP, Finnish Climate Change Panel. *An Approach to Nationally Determined Contributions Consistent with the Paris Climate Agreement and Climate Science: Application to Finland and EU*, 2019. Retrieved from, https://www.ilmastopaneeli.fi/wp-content/uploads/2019/10/Finlands-globally-responsible-contribution_final.pdf.

[28] Finlex, Climate Change Act 609/2015, 2015. Retrieved from: https://www.finlex.fi/fi/laki/kaannokset/2015/en20150609.pdf.

[29] Statistics Finland, *Kasvihuonekaasupäästöt Suomessa*. [GHG emissions in Finland]. Statistics database, Retrieved from, https://pxnet2.stat.fi/PXWeb/pxweb/fi/StatFin/StatFin_ymp_khki/statfin_khki_pxt_111k.px/, 2020.

[30] DECC & BIS, Department of energy & climate change and department for business, innovation & skills. Industrial decarbonisation and energy efficiency roadmaps to 2050, Retrieved from, https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050, 2015.

[31] Fossil Free Sweden, Roadmap for Fossil Free Competitiveness, 2020. Retrieved from, https://fossilfrittsverige.se/wp-content/uploads/2020/12/Sammanfattning_Webb_ENG_2020.pdf.

[32] Finnish Government, Suomen Kestävän Kasvun Ohjelma, 2020 [Finland's sustainable growth programme]. Retrieved from, https://valtioneuvosto.fi/delegate/file/80327.

[33] AFRY, Finnish Energy. Low-Carbon Roadmap, 2020. Retrieved from, https://energia.fi/files/5064/Taustaraportti_-_Finnish_Energy_Low_carbon_roadmap.pdf.

[34] Finnish Energy, *Energia-alan vähähiilisyystiekartta*. [Low-carbon roadmap of the energy sector], Retrieved from, https://energia.fi/files/4946/Energia-alan_vahahiilisyystiekartta_2020.pdf, 2020.

[35] T. Vadén, A. Majava, T. Toivanen, P. Järvensivu, E. Hakala, J.T. Eronen, To continue to burn something? Technological, economic and political path dependencies in district heating in Helsinki, Finland, Energy Res. Soc. Sci. 58 (2019) 101270, https://doi.org/10.1016/j.erss.2019.101270.

[36] AFRY, Roadmap to Reach Carbon Neutral Chemistry in Finland by 2045, 2020. *Final report*. Retrieved from, https://kemianteollisuus.studio.crasman.fi/file/dl/i/0GtI_g/kBevzvIQojOC9zfO-Ztyug/Kemianteollisuusroadmap.pdf.

[37] AFRY, Roadmap to Reach Carbon Neutral Chemistry in Finland by 2045. Executive Summary, 2020. Retrieved from, https://kemianteollisuus.studio.crasman.fi/file/dl/i/uU5LVw/WnO5roKpmIavGNz8iYxLUA/Kemianteollisuusroadmapexecutivesummary.pdf.

[38] MEAE, Government Report on the National Energy and Climate Strategy, 2017. Retrieved from, https://tem.fi/documents/1410877/2769658/Government+report+on+the+National+Energy+and+Climate+Strategy+for+2030.pdf/0bb2a7be-d3c2-4149-a4c2-78449ceb1976/Government+report+on+the+National+Energy+and+Climate+Strategy+for+2030.pdf?t=1496315660000.

[39] Finnish Forest Industries, Forest Industry in Finnish Manufacturing, 2019. Retrieved from, https://www.forestindustries.fi/statistics/10-Forest%20Industry/Internet-EN/a90%20Forest%20industry%20in%20Finnish%20manufacturing.pptx.

[40] E. Hyvärinen, A. Juslén, E. Kemppainen, A. Uddström, U.-M. Liukko (Eds.), The 2019 Red List of Finnish Species, Ympäristöministeriö & Suomen ympäristökeskus, Helsinki, 2019. Retrieved from, http://hdl.handle.net/10138/299501.

[41] FCCP, Finnish Climate Change Panel. *Skenaarioanalyysi metsien kehitystä kuvaavien mallien ennusteiden yhtäläisyyksistä ja eroista*. [Scenario analysis of differences and similarities in models of forest growth], Retrieved from, https://www.ilmastopaneeli.fi/wp-content/uploads/2019/02/Ilmastopaneeli_mets%C3%A4mallit_raportti_180219.pdf, 2019.

[42] T. Kalliokoski, J. Bäck, M. Boy, M. Kulmala, N. Kuusinen, A. Mäkelä, K. Minkkinen, F. Minunno, P. Paasonen, M. Peltoniemi, D. Taipale, L. Valsta, A. Vanhatalo, L. Zhou, P. Zhou, F. Berninger, Mitigation impact of different harvest scenarios of Finnish forests that account for albedo, aerosols, and trade-offs of carbon sequestration and avoided emissions, Front. Forest. Global Change 3 (2020) 562044, https://doi.org/10.3389/ffgc.2020.562044.

[43] S. Soimakallio, T. Kalliokoski, A. Lehtonen, O. Salminen, On the trade-offs and synergies between forest carbon sequestration and substitution, Mitig. Adapt. Strategies Glob. Change 26 (1) (2021) 4, https://doi.org/10.1007/s11027-021-09942-9.

[44] Luke, *Metsien Käsittelyskenaariot. Metsäteollisuus Ry:n Ilmastotiekartta.* [Forestry Scenarios. The Roadmap of Finnish Forest Industries], 2020. Retrieved from, https://global-uploads.webflow.com/5f33b1bfbd4fdb69d3afe623/5fd363c220057bccfdff506b_Ilmastotiekartta_mets%C3%A4skenaariot_loppuraportti_Luke_16_06_2020.pdf.

[45] AFRY, Tiekartta Metsäteollisuudelle Vähähiilistyvässä Yhteiskunnassa, [Roadmap for the forestry sector in a low-carbon world], 2020. Retrieved from, https://global-uploads.webflow.com/5f33b1bfbd4fdb69d3afe623/5fd364e8a24bef1db9ceedb8_Mets%C3%A4teollisuus_ilmastotiekartta_AFRY_p%C3%A4%C3%A4st%C3%B6suus_raportti_12062020.pdf.

[46] Finnish Forest Industries, Vihreä Ja Vireä Talous. Metsäteollisuuden Ilmastotiekartta. [Green and Energetic Economy. The Climate Roadmap of the Forest Sector], 2020. Retrieved from, https://global-uploads.webflow.com/5f44f62ce4d302179b465b3a/5fae9c3de86a240e06b76565_Metsa_Esite_Email.pdf.

[47] Luke, National Resource Institute (Luke). *Forest Statistics. Statistics database*, 2021. Retrieved from, https://stat.luke.fi/.

[48] VTT, *Metsäteollisuuden tuotteiden ilmastovaikutukset.* [Climate impacts of forest industry products], Retrieved from, https://global-uploads.webflow.com/5f33b1bfbd4fdb69d3afe623/5fd364e8b614d6a0be63ca8e_Mets%C3%A4teollisuuden%20tuotteiden%20ilmastovaikutukset%20VTT_160620.pdf, 2020.

[49] Bioenergy, The Bioenergy Association of Finland. *Bioenergia-alan panos hiilinegatiiviseen tulevaisuuteen Suomessa*. [The contributon by the bioenergy sector to low-carbon future in Finland], Retrieved from, https://www.bioenergia.fi/wp-content/uploads/2020/05/Bioenergia-alan-panos-hiilinegatiiviseen-tulevaisuuteen-Suomessa-.pdf, 2020.

[50] AFRY, Tie Vähähiiliseen Liikenteeseen, [The road to low-carbon traffic], 2020. Retrieved from, http://www.logistiikkayritykset.fi/media/uutiset/200612-liikenteen-ja-logistiikan-tiekartta-poyry-loppuraportti-200612-final.pdf.

[51] MEAE, Biokaasuohjelmaa Valmistelevan Työryhmän Loppuraportti, [Final report on the prepapration of the biogas programme], 2020. Retrieved from, https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/162032/TEM_2020_3_Biokaasuohjelmaa%20valmistelevan%20tyoryhma.

[52] J. Lintunen, J. Ali-Yrkkö, M. Kulvik, Metsäteollisuuden Vähähiilisyystiekartan Taloudelliset Vaikutukset, [Economic impacts of the forest sector low-carbon roadmap], 2020. Retrieved from, https://pub.etla.fi/ETLA-Raportit-Reports-105.pdf.

[53] B. Berg-Andersson, V. Kaitila, M. Kulvik, J. Lintunen, Suomen Metsäteollisuuden Näkymiä Vuoteen 2025. [The Finnish Forest Industries up to Year 2025] ETLA Report No 112, 2021. Retrieved from, https://pub.etla.fi/ETLA-Raportit-Reports-112.pdf.

[54] J. Seppälä, T. Heinonen, T. Pukkala, A. Kilpeläinen, T. Mattila, T. Myllyviita, A. Asikainen, H. Peltola, Effect of increased wood harvesting and utilization on required greenhouse gas displacement factors of wood-based products and fuels, J. Environ. Manag. 247 (2019) 580–587, https://doi.org/10.1016/j.jenvman.2019.06.031.

[55] A. Agostini, J. Giuntoli, A. Boulamanti, Carbon accounting of forest bioenergy: conclusions and recommendations from a critical literature review. European Commission. Joint Research Centre. https://data.europa.eu/doi/10.2788/29442, 2014.

[56] J.D. Sterman, L. Siegel, J.N. Rooney-Varga, Does replacing coal with wood lower CO_2 emissions? Dynamic lifecycle analysis of wood bioenergy, Environ. Res. Lett. 13 (1) (2018), 015007, https://doi.org/10.1088/1748-9326/aaa512.

[57] P. Leturcq, GHG displacement factors of harvested wood products: the myth of substitution, Sci. Rep. 10 (1) (2020) 20752, https://doi.org/10.1038/s41598-020-77527-8.

[58] T. Skytt, G. Englund, B.-G. Jonsson, Climate mitigation forestry—temporal trade-offs, Environ. Res. Lett. 16 (11) (2021). https://iopscience.iop.org/article/10.1088/1748-9326/ac30fa.

[59] T. Helin, H. Salminen, J. Hynynen, S. Soimakallio, S. Huuskonen, K. Pingoud, Global warming potentials of stemwood used for energy and materials in Southern Finland: differentiation of impacts based on type of harvest and product lifetime, GCB Bioenergy 8 (2) (2016) 334–345, https://doi.org/10.1111/gcbb.12244.

[60] S. Soimakallio, L. Saikku, L. Valsta, K. Pingoud, Climate change mitigation challenge for wood utilization—the case of Finland, Environ. Sci. Technol. 50 (10) (2016) 5127–5134, https://doi.org/10.1021/acs.est.6b00122.

[61] M. Norton, A. Baldi, V. Buda, B. Carli, P. Cudlin, M.B. Jones, A. Korhola, R. Michalski, F. Novo, J. Oszlányi, F.D. Santos, B. Schink, J. Shepherd, L. Vet, L. Walloe, A. Wijkman, Serious mismatches continue between science and policy in forest bioenergy, GCB Bioenergy 11 (11) (2019) 1256–1263, https://doi.org/10.1111/gcbb.12643.

[62] J. Giuntoli, S. Searle, R. Jonsson, A. Agostini, N. Robert, S. Amaducci, L. Marelli, A. Camia, Carbon accounting of bioenergy and forest management nexus. A reality-check of modeling assumptions and expectations, Renew. Sustain. Energy Rev. 134 (2020) 110368, https://doi.org/10.1016/j.rser.2020.110368.

[63] N.S. Bentsen, C. Felby, Biomass for energy in the European Union—a review of bioenergy resource assessments, Biotechnol. Biofuels 5 (1) (2012) 25, https://doi.org/10.1186/1754-6834-5-25.

[64] European Commission, Our Life Insurance, Our Natural Capital: an EU Biodiversity Strategy to 2020, 2020. Retrieved from, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0244.

[65] CCC, UK committee on climate change, Biomass Low Carbon Econ. (2018). Retrieved from, https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/.

[66] M. Banja, R. Sikkema, M. Jégard, V. Motola, J.-F. Dallemand, Biomass for energy in the EU – the support framework, Energy Pol. 131 (2019) 215–228, https://doi.org/10.1016/j.enpol.2019.04.038.

[67] A. Camia, J. Giuntoli, R. Jonsson, N. Robert, N.E. Cazzaniga, G. Jasinevicius, V. Avitabile, G. Grassi, J.I. Barredo, S. Mubareka, *The use of Woody Biomass for Energy Production in the EU*. European Commission. Joint Research Centre, 2021. https://data.europa.eu/doi/10.2760/831621.

[68] S.H. Xie, W.A. Kurz, P.N. McFarlane, Inward- versus outward-focused bioeconomy strategies for British Columbia's forest products industry: a harvested wood products carbon storage and emission perspective, Carbon Bal. Manag. 16 (30) (2021), https://doi.org/10.1186/s13021-021-00193-4.

[69] J. Rogelj, O. Geden, A. Cowie, A. Reisinger, Net-zero emissions targets are vague: three ways to fix, Nature 591 (7850) (2021) 365–368, https://doi.org/10.1038/d41586-021-00662-3.

[70] T.D. Beuchelt, M. Nassl, Applying a sustainable development lens to global biomass potentials, Sustainability 11 (18) (2019) 5078, https://doi.org/10.3390/su11185078.

[71] T.D. Searchinger, T. Beringer, B. Holtsmark, D.M. Kammen, E.F. Lambin, W. Lucht, P. Raven, J.-P. van Ypersele, Europe's renewable energy directive poised to harm

global forests, Nat. Commun. 9 (1) (2018) 3741, https://doi.org/10.1038/s41467-018-06175-4.
[72] J. Beddington, et al., Letter from Scientists to the EU Parliament Regarding Forest Biomass, 2018. Retrieved from, https://empowerplants.files.wordpress.com/2018/01/scientist-letter-on-eu-forest-biomass-796-signatories-as-of-january-16-2018.pdf.
[73] EASAC, Commentary by the European Academies' Science Advisory Council (EASAC) on Forest Bioenergy and Carbon Neutrality, 2018. Retrieved from, https://easac.eu/fileadmin/PDF_s/reports_statements/Carbon_Neutrality/EASAC_commentary_on_Carbon_Neutrality_15_June_2018.pdf.
[74] C. Kemfert, 'Climate neutral' is a lie—Abandon it as a goal, Nature 591 (7848) (2021) 34, https://doi.org/10.1038/d41586-021-00543-9.
[75] Researchers' Statement, Finland's forest utilisation plans would accelerate climate change and reduce diversity of nature, *Public Statement by 68 Researchers*, 2017. *Retrieved from*, https://bios.fi/publicstatement/publicstatement240317.pdf.
[76] AFRY, Increasing the Level of Distribution Obligation in Road Transport, 2021. VN/13807/2021. Retrieved from, https://tem.fi/documents/1410877/53440649/AFRY_jakeluvelvoite_selvitys_joulukuu2021.pdf/2409f3ce-89d2-5178-7cb7-6a5ad3931ca1/AFRY_jakeluvelvoite_selvitys_joulukuu2021.pdf?t=1638529141014.
[77] K. Bäckstrand, J. Khan, A. Kronsell, E. Lövbrand (Eds.), Environmental Politics and Deliberative Democracy: Examining the Promise of New Modes of Governance, Edward Elgar, Cheltenham, 2010. http://site.ebrary.com/id/10397663.
[78] VTT, Properties of Indigenous Fuels in Finland, 2016. Retrieved from, https://www.vttresearch.com/sites/default/files/pdf/technology/2016/T272.pdf.
[79] J. Forsström, K. Pingoud, J. Pohjola, T. Vilén, L. Valsta, H. Verkerk, Wood-based biodiesel in Finland: market-mediated impacts on emissions and costs, VTT Technol. 7 (2012) 1–48. Retrieved from: https://www.vtt.fi/inf/pdf/technology/2012/T7.pdf.
[80] R. Birdsey, P. Duffy, C. Smyth, W.A. Kurz, A.J. Dugan, R. Houghton, Focus on The Role of Forests and Soils in Meeting Climate Change Mitigation Goals, Environ. Res. Lett. 13 (5) (2018), https://doi.org/10.1088/1748-9326/aab9d5.
[81] L. Pelkmans, M. Van Dael, M. Junginger, U.R. Fritsche, R. Diaz-Chavez, G.-J. Nabuurs, I. Del Campo Colmenar, D.S. Gonzalez, D. Rutz, R. Janssen, Long-term strategies for sustainable biomass imports in European bioenergy markets: understanding how feedstock properties affect process economics, Biofuels, Bioproducts and Biorefining 13 (2) (2019) 388–404, https://doi.org/10.1002/bbb.1857.