Ministry of Economic Affairs and Employment

Finland's long-term low greenhouse gas emission development strategy

October 2020

Unofficial translation

Contents

1 OVERVIEW AND PROCESS FOR ESTABLISHING THE PLAN

1.1 Executive summary

Finland's long-term strategy (LTS) is based on the agreement of the twenty-first session of the Parties to the United Nations Framework Convention on Climate Change in Paris, 30 November to 11 December 2015, also known as the 'Paris Agreement'.

According to the Article 4, paragraph 19, of the Paris Agreement, "All Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies, mindful of Article 2 taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances."

This long-term strategy is to its content identical to the long-term strategy that Finland submitted to the European Commission in March 2020. The long-term strategy submitted to the Commission is based on Regulation (EU) 2018/1999 of the European Parliament and of the Council on the Governance of the Energy Union and Climate Action, also known as the 'Governance Regulation', and its Article 15, which requires each Member State to prepare and submit to the Commission its comprehensive long-term strategy by 1 January 2020.

Finland's long-term strategy lays out scenarios and impact assessments concerning the national carbon neutrality target set for 2035 and developments in greenhouse gas (GHG) emissions and removals by 2050. The strategy explores the following three scenarios. Alongside the reference scenario depicting the development achievable with current policy measures, known as the 'With Existing Measures' (WEM) scenario, the strategy presents two alternative low-emission scenarios, known as the 'Continuous Growth' and 'Savings' scenarios. The Continuous Growth and Savings scenarios describe alternative pathways to achieve the emission reduction target set by Finland and the European Union by 2050. In order to achieve Finland's national emission reduction targets, the emission reduction potential and needs are also assessed by sector in the medium (by 2035) and long (by 2050) term. The long-term strategy does not consider the transition to a low-emission society from the perspective of regional or social justice; instead, its underlying calculations are based on the premise that emission reduction costs will be minimised across the country.

The long-term strategy does not identify the sectors to which emission reductions should be allocated; nor do the impact assessments derived from the scenarios include any quantitative analysis of the concrete measures or political decisions that would be required to achieve the carbon neutrality target or the 2050 targets considered here. The allocation of emission reductions and policy measures, including those for the land use sector, will be decided in 2020–2021 as part of the process of drafting the Climate and Energy Strategy, the Medium-term Climate Change Policy Plan, the roadmap for fossil-free transport and the climate programme for the land use sector.

The 2050 target for GHG emission reductions under the Continuous Growth scenario is 87.5% compared to 1990 levels (excl. the land use sector), while the corresponding target under the Savings scenario stands at 90%. Furthermore, both low-emission scenarios achieve the 2035 carbon neutrality target, which is in line with the Government Programme. Instead of setting any specific quantitative carbon-negative target beyond 2035, its level was allowed to be determined by the size of the net carbon sink of the land use sector.

With existing measures (WEM), carbon neutrality will not be achieved until 2050 – and even then only with land use net sinks at about 30 Mt CO_2-eq. Conversely, the Continuous Growth and Savings scenarios will achieve carbon neutrality in 2035, but this requires substantial reductions in greenhouse gas emissions over the 2030–2035 period while also keeping the size of forest carbon sinks at a reasonable level.

Achieving the carbon neutrality target by 2035 requires swift measures and political decisions geared towards reducing greenhouse gas emissions across all sectors while also strengthening land use net sinks when compared with current levels. The low-emission scenario calculations suggest that significant reductions by 2035, not only in energy production, but also in transport and industry, are a prerequisite for reaching the carbon neutrality target.

The differences between the low-emission scenarios in terms of emission reduction trajectories can be attributed to their underlying technology assumptions, on the one hand, and to assumptions on the structures of industry, society and the economy as a whole, on the other. Perhaps the most essential of the technology assumptions is related to the opportunities to make use of carbon capture and storage (CCS). Based on the scenario parameters, this will become reality under the Savings scenario after 2030, whereas the Continuous Growth scenario will fail to do so throughout the period considered. The absence of CCS from the means available under the Continuous Growth scenario will lead to extremely stringent emission reduction measures across all sectors, including agriculture and industrial processes, which are identified in technical-economic assessments as the sectors where it will be most difficult to make substantial reductions in emissions. The input assumptions of forest industry development in Finland, in turn, are closely linked to the development of land use net sinks and, consequently, to the level of GHG emission reductions required to reach carbon neutrality. The Savings scenario assumed that the forest industry would develop and expand, which would also lead to a growing demand for domestic wood raw material. Under the Savings scenario, the circular and sharing economies and significantly increasing energy efficiency are key elements in reaching the emission reduction target. This scenario also invested relatively more in sustainable biorefinery production, while demand for biorefinery products was also slightly higher to account for the growing demand in heavy-duty road transport. Uncertainties relating to forest carbon sinks have a fundamental impact on achieving the carbon neutrality target.

1.2 Legal and policy context

The Programme of Prime Minister Sanna Marin's Government of 10 December 2019 states as follows: "The Government will work to ensure that Finland is carbon neutral by 2035 and carbon negative soon after that. We will do this by accelerating emissions reduction measures and strengthening carbon sinks." The Government will decide on the additional actions needed to bring the emission reduction path in line with the goal of achieving carbon neutrality by 2035. The Government has established a ministerial working group on climate and energy issues to prepare climate policy as a whole. The ministerial working group is chaired by Krista Mikkonen, Minister of the Environment and Climate Change.

Besides the timetable for the carbon neutrality target and the related emission reduction path, another key issue for Finland is the development of land use net sinks by 2050. These were addressed in the autumn of 2019 by launching the PITKO follow-up study to assess the long-term trend in total emissions[1] and the MALUSEPO project on the scenarios for greenhouse gas emissions and removals in the agricultural and LULUCF sectors by 2050. The projects aimed to update some of the earlier

---

[1] Finland's opportunities to transition to a low-carbon society were explored in the PITKO project carried out in 2018–2019 to study the long-term trend in total emissions. The project's key objective was to assess the suitable emission reduction target for Finland by 2050 and the primary options to proceed in different sectors in order to achieve the target.

scenario calculations so as to achieve the carbon neutrality target set out in the Government Programme. Commissioned by the Ministry of Economic Affairs and Employment, the PITKO follow-up study was carried out in cooperation between VTT Technical Research Centre of Finland Ltd, the Finnish Environment Institute SYKE and Merit Economics. The MALUSEPO project, in turn, was commissioned by the Ministry of Agriculture and Forestry and carried out by the Natural Resources Institute Finland (Luke).

Finland's long-term strategy is based on the agreement of the twenty-first session of the Parties to the United Nations Framework Convention on Climate Change in Paris, 30 November to 11 December 2015, also known as the 'Paris Agreement'. This long-term strategy submitted to the UNFCCC Secretariat draws on the results of quantitative and qualitative analyses included in the PITKO follow-up study report. However, this long-term strategy is not legally binding on Finland and its climate policy-making process.

Finland's long-term strategy was discussed on several occasions by the Government's Ministerial Working Group on Climate and Energy Policy, which adopted it on 1 April 2020. The strategy has not been considered by Parliament.

1.3 Public consultation

The preliminary results of the PITKO follow-up study assessing the long-term trend in total emissions and emission reduction paths and the MALUSEPO reports evaluating the scenarios for greenhouse gas emissions and removals in the agricultural and land use, land-use change and forestry sectors were presented at a seminar organised by the Ministry of Economic Affairs and Employment on 15 November 2019. These follow-up studies updated the calculations of the PITKO and MALULU reports published in February 2019 to correspond to the 2035 target for a climate-neutral Finland set out in the Government Programme.

The seminar was attended by a wide variety of stakeholders and the audience were also able to ask questions and participate in discussions. A recording of the Finnish-language seminar is available at: https://www.mediaserver.fi/video/tem/10021/awqz4Q. The study project continued after the seminar and was completed on 23 January 2020.

Finland organised a public consultation on its long-term strategy towards carbon neutrality via the central government's otakantaa.fi service in March 2020. The otakantaa.fi service is part of a broader package of democracy services provided by the Ministry of Justice for democratic participation and influence to promote mutual dialogue between and participation by citizens, NGOs and public authorities. The public consultation was open to all citizens and stakeholders for a period of two weeks.

The consultation requested responses to the following four questions:

1) The 2050 greenhouse gas emission reduction target (excl. the land use sector) is set at 87.5% under the Continuous Growth scenario and at 90% under the Savings scenario compared to 1990 levels. Both of the low-emission scenarios also achieve the 2035 carbon neutrality target. Is the 2050 target to reduce greenhouse gas emissions ambitious enough and what should Finland's greenhouse gas emission reduction target be for 2050?

2) In your opinion, have the long-term strategy scenarios successfully identified realistic emission reductions, or has something been overlooked?

3) The land use sector will remain a net sink under all of the scenarios; in other words, the sector's greenhouse gas removals will exceed emissions, increasing its carbon stocks. What measures do you consider the most important in the long term to strengthen carbon sinks and stocks and to reduce emissions in the land use sector (land use, land-use change and forestry) in Finland?

4) Do you have any other comments concerning the long-term strategy?

A total of 23 parties filled in the survey. A summary of responses received is included in Appendix 1. Respondents made observations on the scenario calculations and suggested measures to reduce emissions, among other things. These aspects could not be taken into account in the context of drafting this strategy, but the issues raised will be addressed as part of drafting Finland's Climate and Energy Strategy and the Medium-term Climate Change Policy Plan, scheduled to start in the spring of 2020.

2 TOTAL GHG EMISSION REDUCTIONS AND ENHANCEMENTS OF REMOVALS BY SINKS

2.1 National targets

The EU Effort Sharing Regulation (EU) 2018/842 includes emission reduction obligations for all EU Member States for a period from 2021 to 2030. Under the Regulation, Finland is required to reduce its greenhouse gas emissions in sectors outside the EU emissions trading system (EU ETS) by a minimum of 39% from 2005 levels by 2030. This is also Finland's national target. Final annual emission allocations will be confirmed when the 2018 emission data has been verified in 2020. This is due to the fact that the 2016–2018 emissions will have a bearing on the calculation of the emission allocations for the 2021–2030 period. The obligation applies to non-ETS sectors, such as transport, agriculture, waste management and heating of buildings.

The Government's 2035 carbon neutrality target is based on the Finnish Climate Change Panel's estimate of what the 1.5 °C obligation set out in the Paris Agreement entails for Finland.[2]

Carbon neutrality must be pursued with due consideration for the language of Article 2.1(b) of the Paris Agreement, which provides that the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development should be increased in a manner that does not threaten food production.

According to its Government Programme, the Government will amend the Climate Change Act (609/2015) by updating its 2050 emission reduction target and adding targets for 2030 and 2040 in line with the path to carbon neutrality. The land use sector and a target for strengthening carbon sinks will also be included in the Climate Change Act. The current goal laid down in the Climate Change Act for 2050 is to reduce greenhouse gas emissions by at least 80% compared to 1990 levels. The Act provides that if an international treaty binding on Finland or European Union legislation includes a target that differs from that mentioned above, it must be used as the basis for Finland's target.

Directing finance flows towards climate-resilient development

Under the Paris Agreement, all Parties must direct both national and international investment and finance flows towards low-carbon and climate-resilient development. Finland has joined forces with Chile to establish the Coalition of Finance Ministers for Climate Action, which has already been joined by over 50 countries. Their cooperation is based on the so-called Helsinki Principles. Its aim is to integrate climate change as part of planning economic policy and financing solutions and to identify the most effective instruments available to Finance Ministers to mitigate and adapt to climate change.

---

[2] An Approach to Nationally Determined Contributions Consistent with the Paris Climate Agreement and Climate Science: Application to Finland and the EU. Finnish Climate Change Panel Report 7/2019. Available at: https://www.ilmastopaneeli.fi/wp-content/uploads/2019/10/Finlands-globally-responsible-contribution_final.pdf.

2.2 Scenarios underlying the national long-term strategy

Estimates of Finland's long-term total emission trend[3] (PITKO project) and emission trends in agriculture and the land use sector[4] (MALULU project) were published in February 2019. Both research projects were carried out as part of implementing the 2018 Government plan for analysis, assessment and research. Both of these projects were continued in follow-up studies launched in the autumn of 2019, with a view to updating parts of the qualitative and quantitative analyses to bring the premises for calculations and the GHG emission reduction target in line with Prime Minister Sanna Marin's Government Programme. The follow-up studies produced a report entitled 'Carbon neutral Finland 2035 – Scenarios and impact assessments'[5], which was published on 23 January 2020. The research report's scenarios form the basis for those included in this Finland's long-term strategy (LTS) under the EU Governance Regulation.

The premises for modelling the national LTS scenarios were achievement of the Government's objective of carbon neutrality by 2035 across the country and minimisation of emission reduction costs. In the context of the Government Programme, 'carbon neutrality' refers to a balance between Finland's regional GHG emissions and removals by sinks. According to the Government Programme, "Emissions reduction measures will be carried out in a way that is fair from a social and regional perspective and that involves all sectors of society." The allocation of emission reductions and measures required for different sectors will be outlined in keeping with the Government Programme as part of drafting the Climate and Energy Strategy, the Medium-term Climate Change Policy Plan and the climate programme for the land use sector. The process of drafting these medium-term plans will start in the spring of 2020 with the intention of submitting them to Parliament as government reports by the autumn of 2021 at the latest. Consequently, the scenarios laid out in the national LTS are only indicative of future developments.

The national LTS lays out three scenarios. The scenarios were prepared through to 2050 in such a way that they achieve the 2035 carbon neutrality target.

The With Existing Measures (WEM) scenario is a reference scenario based on developments in line with existing policy measures. The WEM scenario conforms to the premises of the 2016 National Energy and Climate Strategy and the 2017 Medium-term Climate Change Policy Plan by 2030 while extrapolating developments for the 2030–2050 period along the same trendline through to 2050. The basic premise of the WEM scenario is that Finland will achieve the national energy and climate policy objectives for 2020, which will also remain unchanged beyond that year. The WEM scenario therefore projects that emissions in the effort sharing sector will be reduced by 16% on 2005 levels, which is equivalent to emissions at 28.4 Mt CO_2-eq in 2020. The WEM scenario expects that the rest of the EU Member States will not only achieve the 2020 energy and climate targets but also the climate target set for 2030, which means that the EU-level GHG emission target stands at -40% compared to 1990 levels.

The WEM scenario's key baseline data includes an assumption of emission allowance price developments through to 2050 in accordance with the Commission guidance on input assumptions

---

[3] Pitkän aikavälin kokonaispäästökehitys [*Long-term development of total emissions*] (VTT 2019). Available in Finnish (English abstract) at: http://julkaisut.valtioneuvosto.fi/handle/10024/161409.
[4] Maatalous- ja LULUCF-sektorien päästö- ja nielukehitys vuoteen 2050 [*Development of emissions and sinks in the agricultural and LULUCF sectors until 2050*] (Luke). Available in Finnish (English abstract) at: http://julkaisut.valtioneuvosto.fi/handle/10024/161408.
[5] Hiilineutraali Suomi 2035 – Skenaariot ja vaikutusarviot [*Carbon neutral Finland 2035 – Scenarios and impact assessments*] (VTT). Available in Finnish (English abstract) at: https://www.vtt.fi/inf/pdf/technology/2020/T366.pdf.

for the reference scenario. The emission allowance price is assumed to amount to EUR 15/t CO_2 in 2020 and to EUR 30/t CO_2 in 2030. After 2030, the allowance price is expected to rise more steeply, reaching EUR 50/t CO_2 in 2040 and EUR 90/t CO_2 in 2050. The emission allowance price developments are based on the so-called PRIMES Reference Scenario from 2016.

Two alternative low-emission scenarios were developed for this strategy. The Continuous Growth and Savings scenarios describe alternative pathways to achieve the emission reduction target set by Finland and the European Union by 2050. The scenarios were contextualised with 'scenario narratives'. Under the Continuous Growth scenario, emission reduction targets will be achieved by accelerated deployment of new technologies, including robust electrification, digitalisation and industrial renewal. Carbon capture and storage (CCS) technologies will not be in use in this scenario. The scenario projects that Finland will achieve export-driven economic success. Under the Savings scenario, the circular and sharing economies and significantly increasing energy efficiency are key elements in reaching the emission reduction target. CCS technologies will be in use. Agriculture and forestry will promote the circular economy, as will the replacement of mineral oil-based products with new bioproducts.

Under the Continuous Growth scenario, the GHG emission reduction target is 87.5% compared to 1990 levels, while the corresponding target under the Savings scenario stands at 90%. Furthermore, both low-emission scenarios achieve the 2035 carbon neutrality target, which is in line with the Government Programme. The low-emission scenarios were assigned a number of energy and climate policy targets for 2030, including:

- a 39% GHG emission reduction target for the effort sharing sector compared to 2005 emission levels;
- phasing out the use of coal for energy by 2029;
- cutting back the use of peat at least by half by 2030;
- share of biofuels in road transport energy consumption at 13.5% of the energy content part in 2020 and at 30% in 2030 (linear growth); a 10% bioliquid blending obligation for light fuel oil used in building-specific heating and for diesel oil used in mobile machinery, with linear growth between 2020 and 2030;
- the number of electric vehicles at least 250,000 (full electric vehicles, hydrogen-powered vehicles, plug-in hybrids) and, correspondingly, that of gas-powered vehicles at least 50,000 by 2030;
- a 38% minimum share of renewable energy in final energy consumption in 2020 and, correspondingly, a 50% minimum target for renewable energy in 2030;
- a 55% self-sufficiency target for energy supply in 2030 and halving the use of imported oil for energy purposes.

More detailed assumptions for the scenarios are presented in Chapter 4 of a Finnish-language research report entitled 'Carbon neutral Finland 2035 – Scenarios and impact assessments'.

2.3 Estimated trends in emissions and removals by 2050

Figure 1 presents the trends in Finland's GHG emissions by main source under the basic scenario (WEM) and under the two low-emission scenarios (excluding LULUCF). The WEM scenario only includes existing policy measures by 2020, whereas the low-emission scenarios cover planned additional domestic measures, the EU energy and climate policy goals for 2030, and an assumed EU target of reducing GHG emissions by at least 85% by 2050. In other words, the overall EU target was also assumed to increase to a slightly more ambitious level from the previous 80%.

Based on the results, total emissions in 2020 amount to a little under 55 Mt CO_2-eq under the WEM scenario, standing 23% below 1990 reference year levels. The emission trajectories of the low-emission scenarios start to clearly diverge from the WEM scenario as early as during the 2020s, such that the reduction in total emissions in 2030 compared to 1990 levels will be about 50% under the Continuous Growth scenario and about 47% under the Savings scenario. Since the baseline trajectory (WEM) uses the European Commission's reference scenario assumptions on emission allowance price developments, emissions will also decrease under the WEM scenario at a relatively steady rate after 2030, reaching the level of about 27 Mt CO_2-eq by 2050, which is already equivalent to quite a substantial reduction at 63%.

The 87.5% minimum emission reduction target for 2050 assumed in the Continuous Growth scenario will be achieved through domestic measures without carbon capture and storage (CCS), according to the scenario's input assumptions. Conversely, the Savings scenario projects that the targets of both carbon neutrality by 2035 and a 90% emission reduction in 2050 will be achieved with support from substantial negative emissions largely produced by bio-CCS. In 2050, the emission reduction from CCS will amount to a total of about 14 Mt CO_2-eq. In other words, the reduction achieved in gross emissions (without negative carbon offsets) under the Savings scenario will stand at about 82% in 2050.

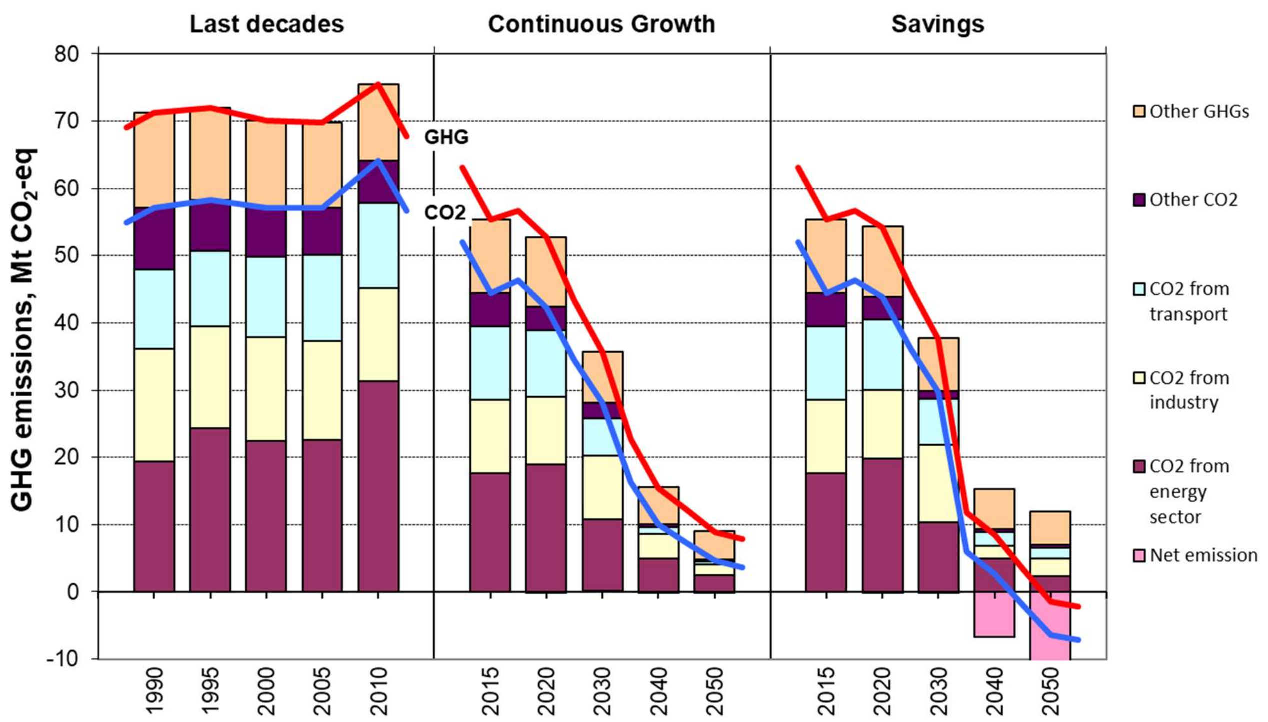

Figure 1. GHG emission trends by scenario.

Appendix 2 provides the GHG emissions balances for 2030 and 2050 compiled from system modelling results, using the emission inventory classification, excluding LULUCF.

Figure 13 in Section 5.4 shows net sink trends in the LULUCF sector under different scenarios. While all of the three scenarios – WEM, Continuous Growth and Savings – produced diverging trajectories for the LULUCF sector, the sector will remain a net sink under all of the scenarios; in other words, the sector's GHG removals will exceed emissions. When compared with the WEM scenario, the net sink reached by 2050 is 15 Mt CO_2-eq larger under the Continuous Growth scenario and 10 Mt CO_2-eq smaller under the Savings scenario. The scenario trends take shape up until 2030, after which point their differences become more pronounced. With regard to agriculture, the Continuous Growth and Savings scenarios assume a considerable reduction in national consumption of livestock products (-30% to -50% by 2050). As a result, the arable area under active cultivation will shrink due to declining demand for forage area. Indeed, the Continuous Growth and Savings scenarios specifically sought emission reductions by focusing measures on agricultural lands. In this context, 'measures' mostly refer to the types of soil (mineral soil, peatland) that the scenarios project to remain under cultivation and the amounts of agricultural land that could be allocated for other uses in their calculations. While cropland emissions can be cut down by limiting the agricultural land area, these sites will move under other categories and will therefore still be included in LULUCF totals. Changes in agriculture in the above-mentioned scenarios will also lead to major changes in agricultural income and working hours in agricultural production.

These scenarios considered afforestation the primary alternative for agricultural land being freed up. Although afforestation areas were significant, they show little impact on increasing carbon sinks due to the relatively short time span involved and to the fact that the afforestation area is small relative to the existing forest land area.

The scenarios demonstrate the impact of changes in forest sinks on the sector's balance. Increasing the amount of harvested timber will decrease the sinks (Savings) and, vice versa, reducing the amount of harvested timber (biomass) will increase the sinks (Continuous Growth). Harvested wood products will not fully compensate for decreasing sinks, even if production focused on durable products (Savings).

Net sink trends in the LULUCF sector by 2050 under different scenarios are discussed in more detail in Section 5.4.

2.4 Adaptation policies and measures

Guidance for adaptation to climate change is based on Finland's National Climate Change Adaptation Plan 2022, which was adopted as a Government Resolution on 20 November 2014. The government adopts a national adaptation plan as part of the planning system under the Climate Change Act at least once in every ten years. According to the Act, the adaptation plan includes a risk and vulnerability review, as well as action plans on adaptations specific to each administrative branch, if necessary.

The aim of the National Climate Change Adaptation Plan 2022 is to ensure that Finnish society has the capacity to adapt to changes in climate and manage the risks associated with climate change. The plan sets the following three objectives for 2022:

a) Adaptation has been integrated into the planning and activities of both the various sectors and their actors.

b) The actors have access to the necessary climate change assessment and management methods.

c) Research and development work, communication and education and training have enhanced the adaptive capacity of society, developed innovative solutions and improved citizens' awareness on climate change adaptation.

The Adaptation Plan describes the key actions to be launched in order to achieve the objectives, as shown in Figure 2.

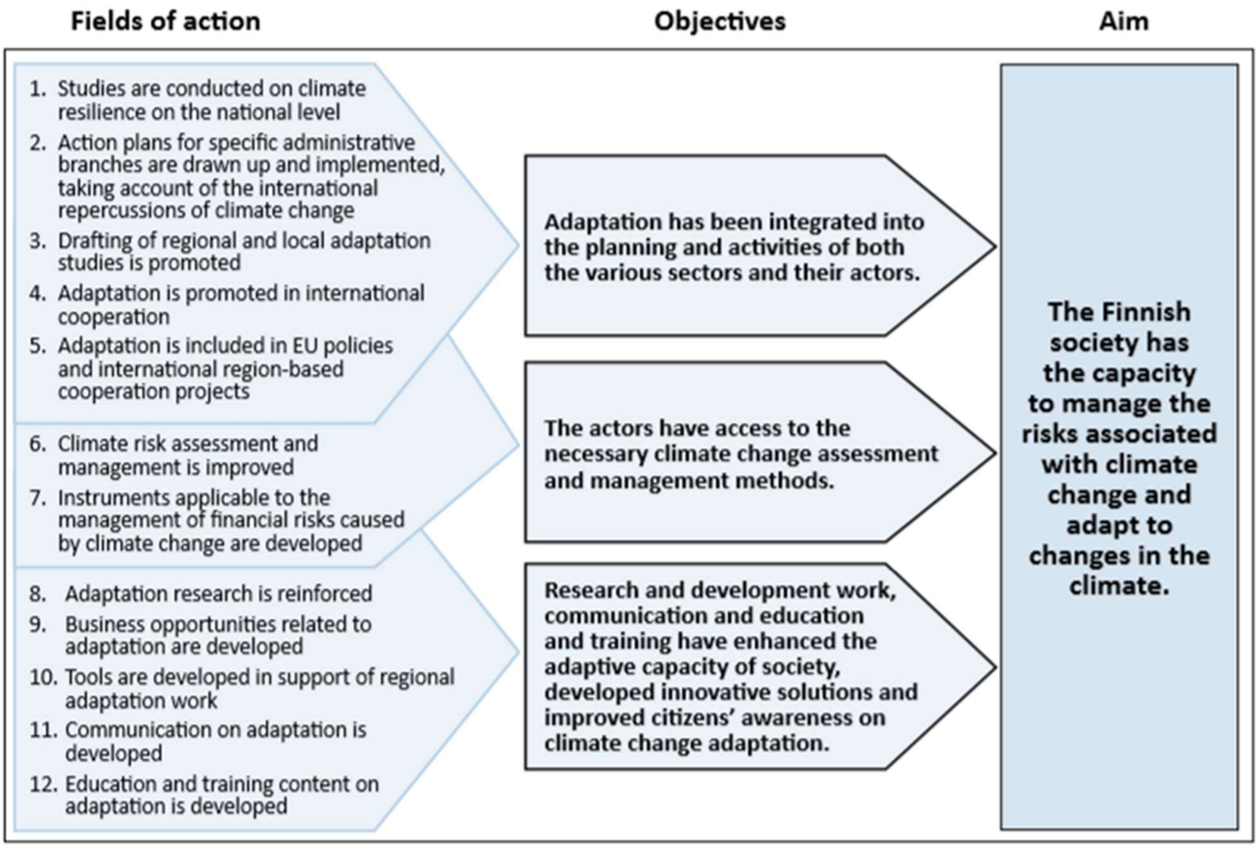

Figure 2. Key actions to achieve the objectives of the Adaptation Plan.

In addition to the actions described in the National Adaptation Plan, practical adaptation actions are also included in action plans specific to different administrative branches. Such specific adaptation action plans have been drawn up within the administrative branches of the Ministry of the Environment and the Ministry of Agriculture and Forestry and another plan is being drafted within the administrative branch of the Ministry of Social Affairs and Health. The Ministry of Transport and Communications and the Ministry of Defence have included adaptation actions in more extensive climate programmes within their respective branches.

According to the 2019 interim review of the National Adaptation Plan, awareness of climate change and adaptation needs has increased among public bodies. The impacts and risks of climate change are also currently discussed more widely as part of data production. However, there are still some gaps in climate risk management and marked differences between sectors. The adverse effects of climate change could be limited more efficiently with increased focus on and investment in planning and implementing adaptation actions. Key development needs include increasing awareness about weather and climate risks and adaptation opportunities, clarifying the roles and responsibilities relating to adaptation while ensuring coordination, and developing the monitoring of adaptation policy implementation. Furthermore, it is essential to develop sectoral guidance as well as tools and guidance to help regional and local parties, in particular, to independently build up their adaptive capacities. The recommendations put forward in the interim review were used to revise the Adaptation Plan's actions for the 2020–2022 period.

3 RENEWABLE ENERGY

The share of renewable energy in final consumption modelled under different scenarios is shown in Figure 3. Final consumption of renewable energy, calculated according to EU rules, is projected to increase steadily in the WEM scenario, whereas the modelled low-emission scenarios see it rising to about 55% in 2030 and to almost 80% in 2050. In other words, the share growth projected in the low-emission scenarios surpasses the target set out in the National Energy and Climate Strategy, which requires renewable energy to exceed 50% of final energy consumption over the 2020s. Beyond 2030, the share of renewable energy will increase exceptionally fast through to 2035 as a result of the carbon neutrality target, but will then stabilise by 2050, settling close to a realistically achievable maximum level (accounting for nuclear power and energy from waste). The share of biofuels in transport modelled under the WEM scenario will account for about 16% of final consumption in 2030, while the figure will stand as high as at about 35% under the Continuous Growth scenario and at about 30% under the Savings scenario. In 2050, the share of biofuels will stand at 41% under the Continuous Growth scenario and at 53% under the Savings scenario.

The renewable energy source with the highest quantitative growth is wood bioenergy and the strongest increase in its use focuses on forest chips and black liquor and other concentrated liquors. In addition, bioenergy will be increasingly produced from agricultural by-products, largely as biogas, but also from energy crops, especially under the Savings scenario. The low-emission scenarios project wind power generation to continue to increase vigorously up until 2035, at which point solar energy will catch up with it as an energy source that will further expand the renewables share. Besides these, a significant proportion of the increase in renewable energy will come from ambient heating and cooling energy generated by heat pumps. Overall, the sharp increase in renewables use will also be almost directly reflected in energy self-sufficiency, which will be a few percentage points higher than the renewables share.

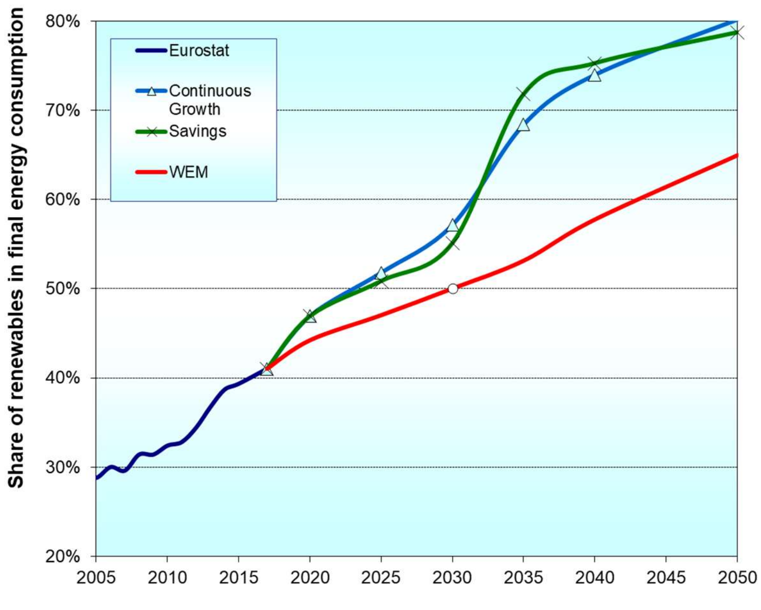

Figure 3. Modelled shares of renewable energy in final consumption by scenario.

The modelled share of renewables in primary energy consumption will grow by 50%–64% by 2030 compared to 2010 levels, as shown in Figure 4. The corresponding increase by 2050 will be 100%–110%. While the increase is naturally highest under the low-emission scenarios, their absolute differences from the WEM scenario are not very significant due to improved energy efficiency. Wind and solar energy will gain a significant role in the supply of renewables under both of the low-emission scenarios. In 2017, their share was only 3.6%. Even the WEM scenario projects their share to more than quadruple, reaching 14%. With regard to wind power, however, it is worth noting that its competitiveness development has been exceptionally fast in recent years and it is very difficult to estimate the pace of development over the next few decades, which means that the results also involve some uncertainty.

In Figure 4, 'solid wood fuels' refers to any wood primary energy, excluding black liquor and other concentrated liquors and recycled wood. By 2030, the combined energy use of wood fuels (black liquor and other concentrated liquors and solid wood fuels) will grow substantially under the Savings scenario, in particular, which is partially attributable to forest industry production volumes pushing up the number of by-products (incl. black liquor, bark, sawdust), on the one hand, and to the increasing use of forest chips, on the other. While the energy use of wood fuels in 2016 amounted to a total of about 360 PJ (100 TWh), it will reach the level of 430–450 PJ (120–126 TWh) in 2030 under different scenarios. Beyond 2030, wood fuel use will remain at more or less the same level, amounting to 440–450 PJ (123–126 TWh) in 2050, regardless of the differences between the scenario narratives. Under the Savings scenario, wood fuel use is limited by increasing pulp production in the forest industry, as its use of commercial timber will curb the availability of energy wood while driving up its price. At the same time, however, demand for advanced bioliquids will create pressure to increase the use of wood for energy. Under the Savings scenario, the energy use of black liquor will be limited by the use of lignin and hemicellulose for new bioeconomy products instead of energy. Furthermore, the use of agricultural by-products is highlighted in the results of the low-emission scenarios both in terms of biogas production and the use of straw for energy. All of the scenarios expect the use of municipal waste for energy to remain at the current level of about 20 PJ (about 6 TWh) by 2030 and start declining slightly thereafter as a result of enhanced recycling.

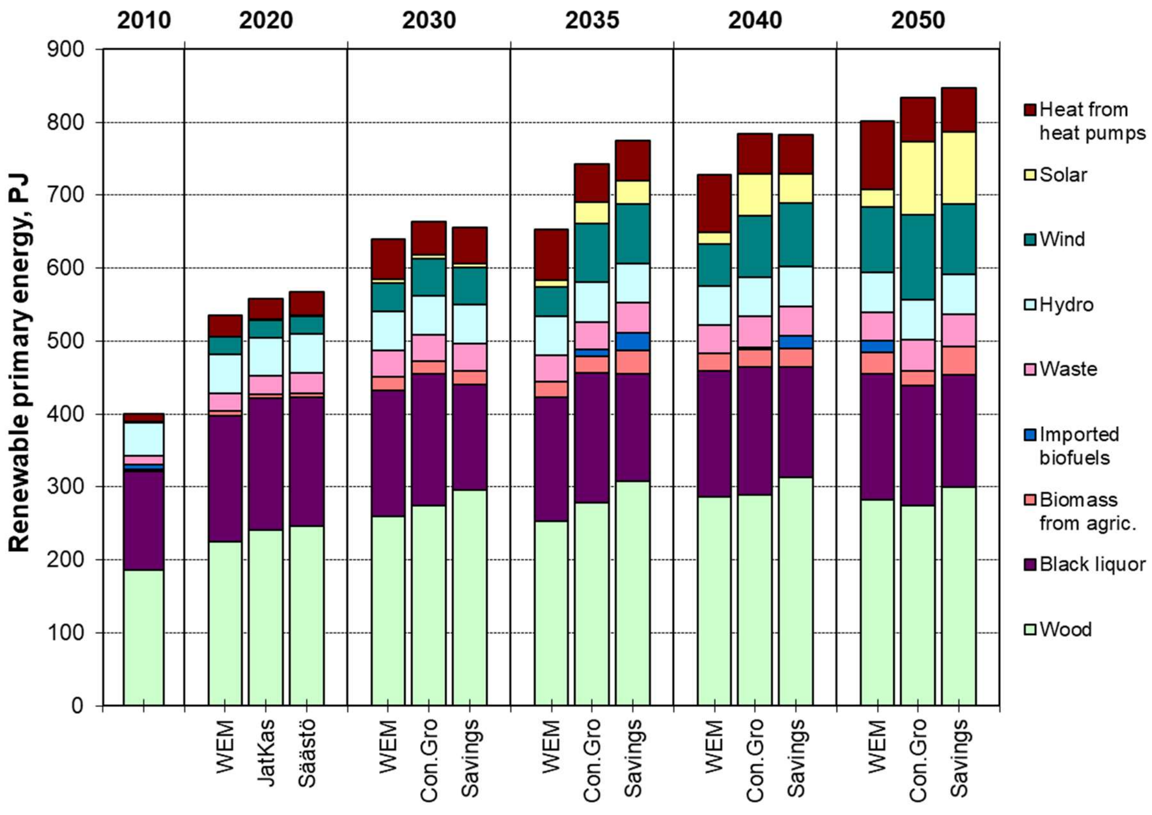

Figure 4. Modelled consumption of renewable primary energy by scenario.

4 ENERGY EFFICIENCY

The low-emission scenarios entail quite significant changes in the structure of electricity consumption. While electrification is an essential change in all sectors, its impact on growing consumption will be largely offset by increasing efficiency of electricity use. However, new electricity consumption will also be generated as a result of expanding digitalisation, energy storage and carbon-neutral electric fuel processing.

In the industrial sector, growth in energy industry consumption is the single largest factor impacting on changes in electricity consumption. This growth in consumption will mainly come from energy storage and conversion losses, carbon-neutral e-fuel production and expanding use of heat pumps for municipal district heating and cooling. In process industries, changes involving significant growth in electricity consumption include the gradual introduction of direct reduction in manufacturing ore-based steel, use of hybrid electric furnaces in the mineral industry and, under the Continuous Growth scenario, electrolytic hydrogen production in the petrochemical industry.

As a result of both improved energy efficiency and the limited capacity of competitive generation of carbon-neutral district heat, consumption will fall below half the current levels under the low-carbon scenarios, driving down the potential for combined municipal heat and power generation. All other types of final energy consumption in the heating of buildings will also decline as specific heat consumption rates drop both in new buildings and due to extensive energy repairs – by as much as about 60% on 2010 levels under the best-case assumptions. Under all of the scenarios, key impacts in the industrial sector include electrification in process heat generation and replacement of fossil fuels with biofuels.

In 2010, final energy consumption in Finland amounted to a total of about 300 TWh, of which electricity, heat and direct fuel use accounted for 28%, about 13% and 59%, respectively. Based on the modelling results, the total amount of final consumption under the WEM scenario will remain close to 2015 levels through to 2030 (Figure 5). The results suggest that significant emission reductions require considerable electrification in all energy-consuming sectors, as fossil fuels cannot be replaced sustainably with bioenergy on a sufficiently large scale.

Figure 6 shows the trend in total primary energy consumption produced by the TIMES-VTT model. The WEM scenario projects total primary energy consumption to peak at around 1,570 PJ (436 TWh) from 2030 to 2035 and start declining afterwards.

Fossil fuel consumption will shrink significantly as early as by 2030 under all of the scenarios, as the rising prices of emission allowances and advancements in renewable energy technologies, already assumed in the WEM scenario, will undermine the competitiveness of fossil fuels. When compared with the WEM scenario, the low-emission scenarios show a sharper drop in the total consumption of mineral oil and hard coal, in particular, as early as by 2030, but natural gas will still retain a relatively strong foothold due to existing infrastructure and production capacity. As condensing power plants, the one or two new nuclear power plants expected to come online between 2020 and 2030 will have a substantial impact on the structure and magnitude of the primary energy balance, as will the prolonged lifetimes of the existing Loviisa and Olkiluoto plants assumed in the modelling exercise.

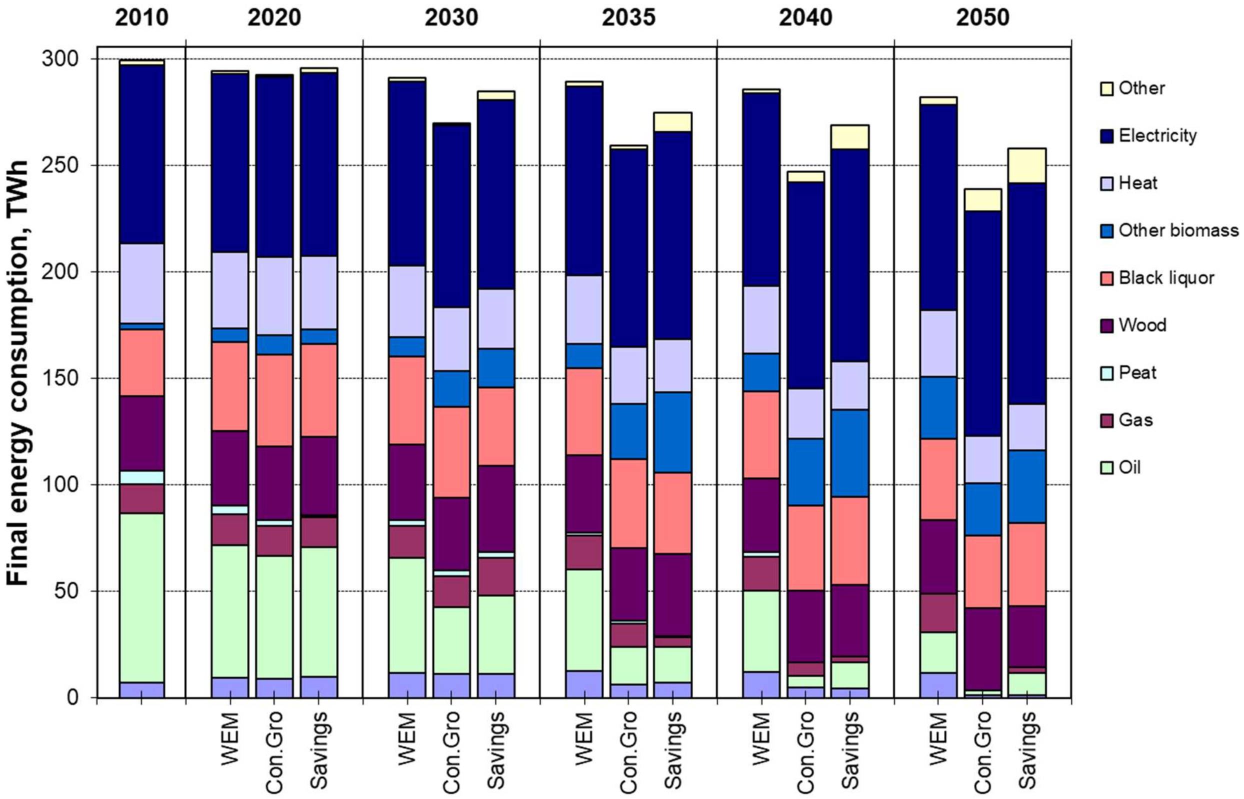

Figure 5. Modelled final energy consumption by sector under different scenarios.

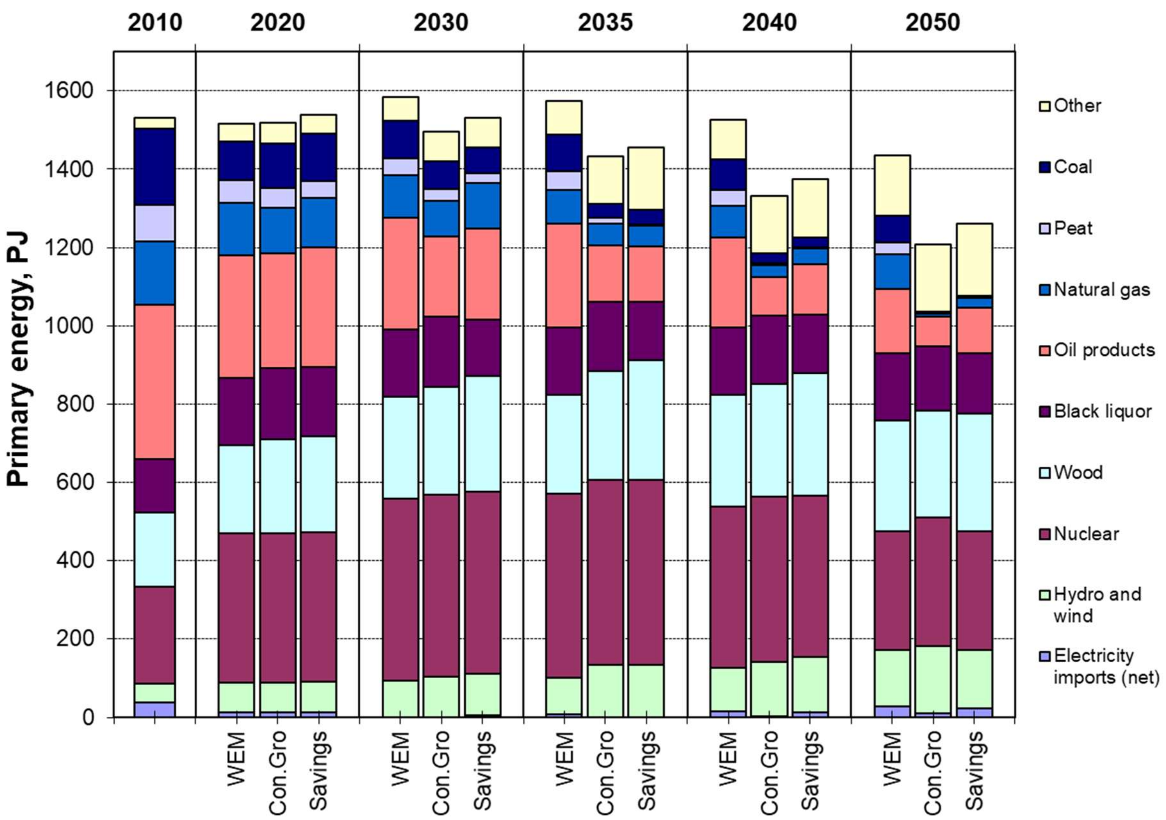

Figure 6. Modelled trends in total primary energy supply by scenario.

5 SECTOR-SPECIFIC RELATED CONTENT

5.1 Energy system

The development of energy production plays a key role in the emissions trajectory under both low-emission scenarios. In this context, ‘emissions from energy production’ refers to emissions from combustion of fuels as part of producing electricity, district heat and industrial process steam.

Figure 7 shows the trends in carbon dioxide emissions from energy production by source (coal, oil, natural gas, peat, and the fossil part of waste fuel used for energy production). In 2015, CO_2 emissions from energy production amounted to just over 17 million tonnes, but the modelling results suggest that even the WEM scenario will already lead to emissions decreasing to about 10 million tonnes by 2030, after which they will fall below 5 million tonnes by 2050. Although the price of emission allowances is expected to rise, peat will retain its competitiveness in energy production through to 2030 due to its currently more lenient tax treatment.

The low-carbon scenarios suggest that, as a result of the carbon neutrality target, energy production emissions will decline significantly more steeply after 2030, to the extent that emissions will fall below 2 million tonnes in 2040 under both scenarios. Emissions from energy production will settle at 1.6 million tonnes under the Continuous Growth scenario and at 1.4 million tonnes under the Savings scenario. The Savings scenario assumes changes in energy taxes, which will especially affect the use of peat. As waste fuel will account for 40% to 50% of the remaining emissions, those from actual fossil fuels and peat will amount to less than a million tonnes in total and will be distributed fairly evenly between peat, natural gas and oil. By 2050, non-waste fuel emissions will already be more or less insignificant.

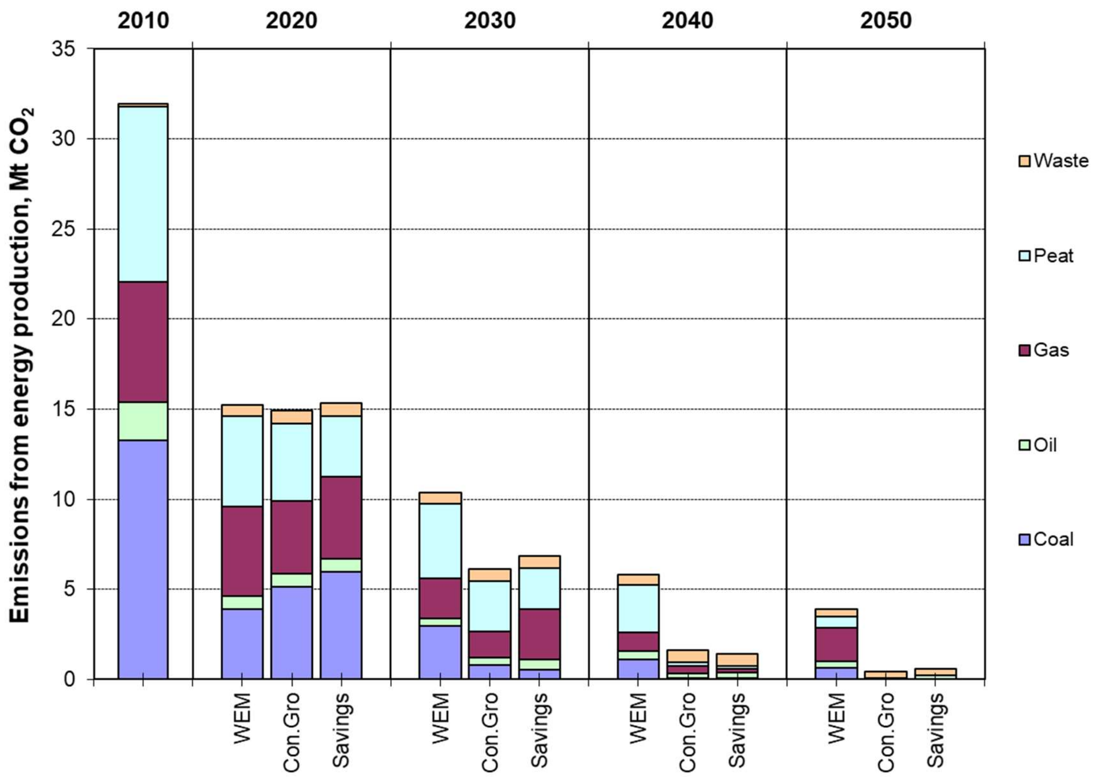

Figure 7. Development of CO_2 emissions from energy production under different scenarios.

Figure 8 shows the development of total electricity supply by source according to model calculations. The results indicate that, by 2030, total electricity consumption will rise to 93 TWh under the WEM scenario and only slightly less under the low-emission scenarios, to 91–92 TWh. By 2030, electricity consumption and production will be close to balance due to two new nuclear power plants and rapidly growing wind power generation. The Savings scenario projects the need to import at just under 2 TWh in 2030, whereas the other scenarios suggest a turn to modest net exports. The impacts of the carbon neutrality target on the electricity balance will become more visible beyond 2030, when electrification will intensify in all sectors while electricity will also become more widely used for processing so-called electric fuels (Power-to-X technology). The results indicate that total electricity consumption will amount to 105–127 TWh by 2050, showing a growth in the range of 11%–39% on 2030. Electricity consumption will reach the highest level under the Continuous Growth scenario, where economic growth will remain healthy and electricity will substitute most widely for fuels, as carbon capture and storage will not be available. The Savings scenario, in turn, assumes that CCS will be available, resulting in more moderate changes in the energy system in other respects. Based on the results, by 2050, the need to import electricity will only amount to 3–8 TWh under different scenarios, suggesting that security of supply will remain at a relatively healthy level in this respect when compared with the current situation, for example.

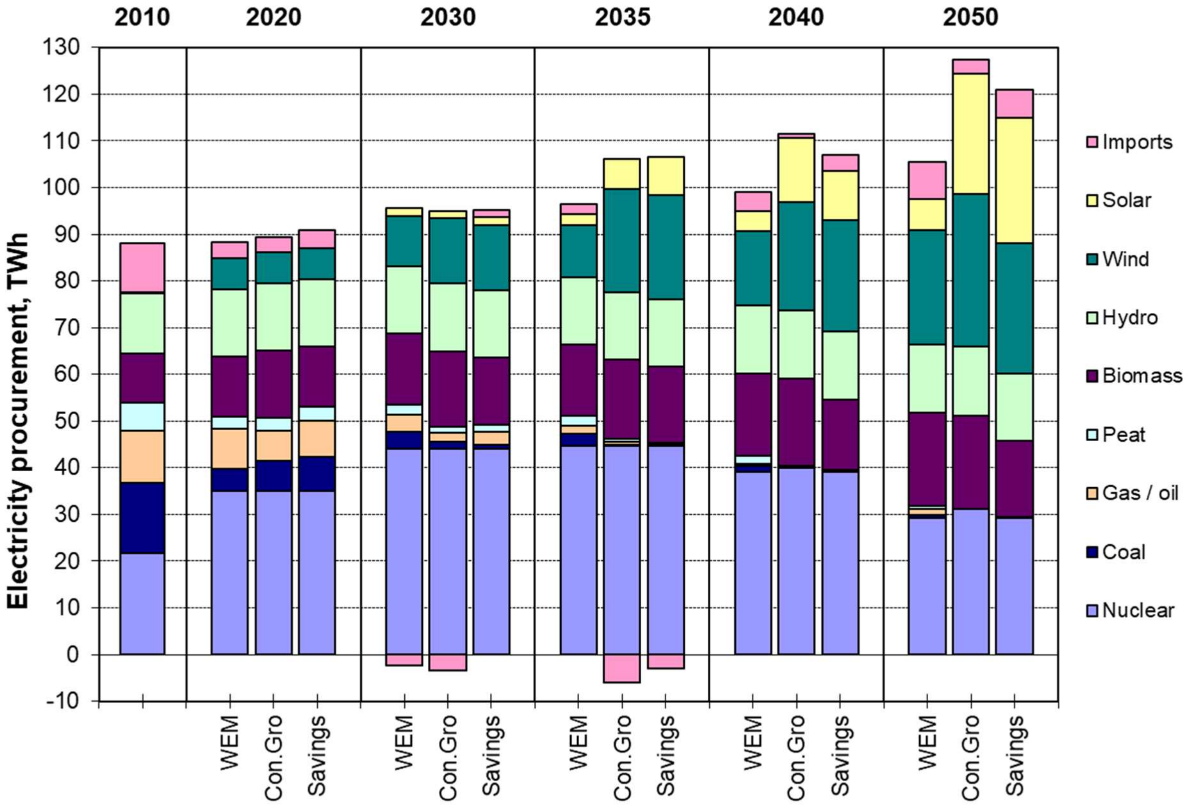

Figure 8. Electricity supply by source under different scenarios.

The costs of solar power have plummeted over the last ten years and this favourable trend was expected to continue, especially under the low-emission scenarios. Based on the results of the model calculations, the assumptions lead to a breakthrough in solar power beyond 2030 even in Finland's conditions, to the extent that its production will amount to 25–27 TWh in 2050 under both low-emission scenarios. Wind power generation will draw near the level of 7 TWh in 2020, while both low-emission scenarios project it to more than double to just over 14 TWh by 2030 and move on to exceed 20 TWh by 2035. For 2050, VTT wind power experts have estimated its realistic technical-economic potential at 28 TWh, of which offshore wind would account for about 40%. These estimates have also accounted for limitations on wind power investments, such as those set by the Finnish Defence Forces, which means that higher potential might also be possible in the future if barriers to investment can be dismantled. The model calculations indicate that wind power generation will reach 27–33 TWh by 2050 under the low-emission scenarios.

Due to variations in wind and solar power generation, the electricity system requires substantial flexible capacity as their role becomes more prominent. The model results increase flexibilities through investments in storage capacity, electricity connection lines and intelligent grids that steer demand flexibilities. According to the model results, variable generation will be widely used in areas such as Power-to-X applications producing hydrogen or hydrocarbon, which are considerably easier to store than electricity.

5.2 Industry

The low-emission scenarios assume that the key means to reduce emissions in the industrial sector include electrification in process heat generation and replacement of fossil fuels and peat with biofuels. Another key assumption is that the process of manufacturing ore-based carbon steel will switch to direct reduction after 2030 by replacing coke as a reducing agent with either hydrogen or an electrolytic process. Emissions from cement manufacturing can be reduced by hybrid furnaces, which allow about half the fuel to be replaced with electricity. Under the Savings scenario, which assumes that CCS will be available, it can be applied in cement manufacturing, fuel refining processes and, to a limited extent, in pulp production. Under the Continuous Growth scenario, in turn, the absence of CCS from the available means will make it more difficult to achieve the emission targets in process industries. The calculations therefore included an assumption that blast furnace slag, commonly used as an additive in cement manufacturing, could be replaced with recycled materials – naturally to a limited extent – thus reducing the pressure to increase fossil cement clinker production.

Based on the results, GHG emissions in the industrial sector will remain at the level of about 14 Mt under both the WEM and Savings scenarios from 2020 to 2030, whereas the Continuous Growth scenario projects a substantial decline as early as by 2030 (Figure 9). Between 2030 and 2040, both low-emission scenarios expect emissions to fall below five million tonnes, where the largest drop, 6–8 Mt, will come from fuel combustion emissions. Due to hydrogen technology and CCS applications (Savings scenario), a reduction of about 70% on 2010 levels will also be achieved in process emissions by 2050, while combustion emissions can almost be pushed down to zero under the Continuous Growth scenario, mostly by means of electrification and carbon-neutral renewable and synthetic fuels. The distribution of final energy consumption in industry is illustrated below (Figure 10).

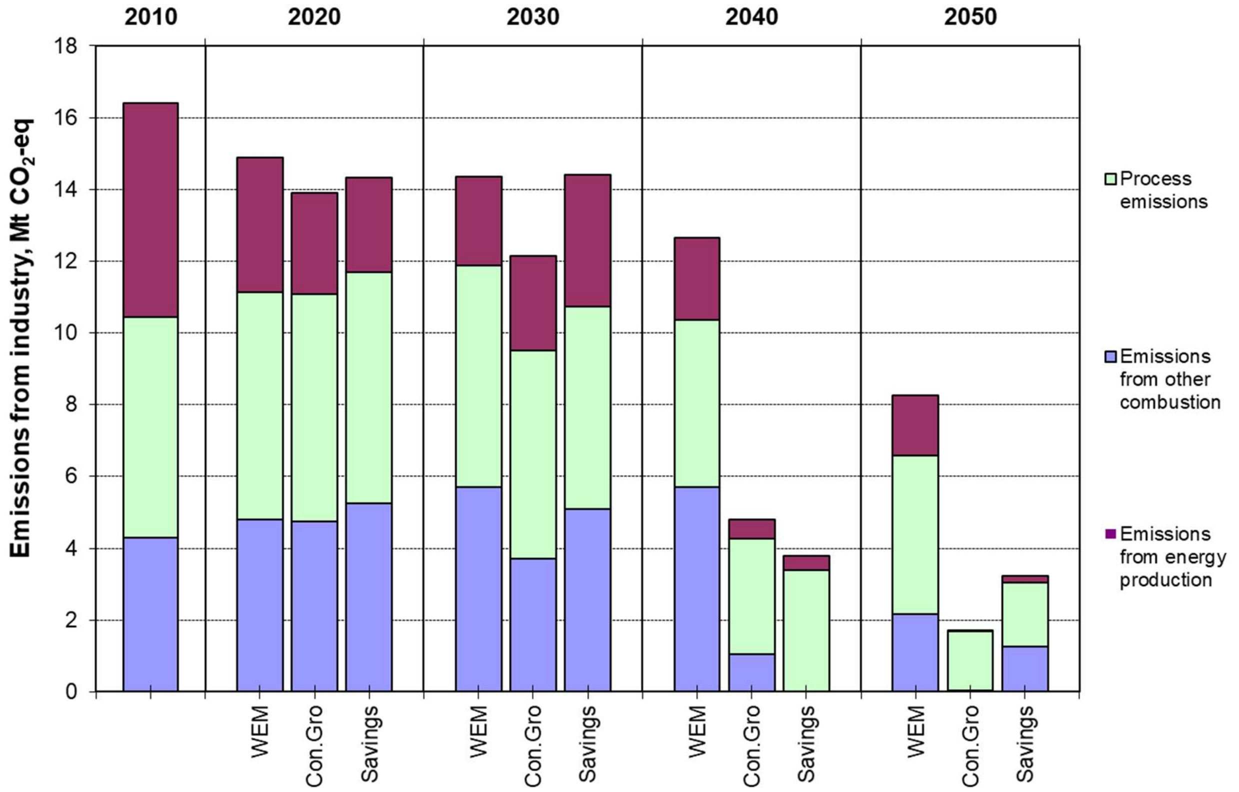

Figure 9. GHG emission trends in industry by scenario.

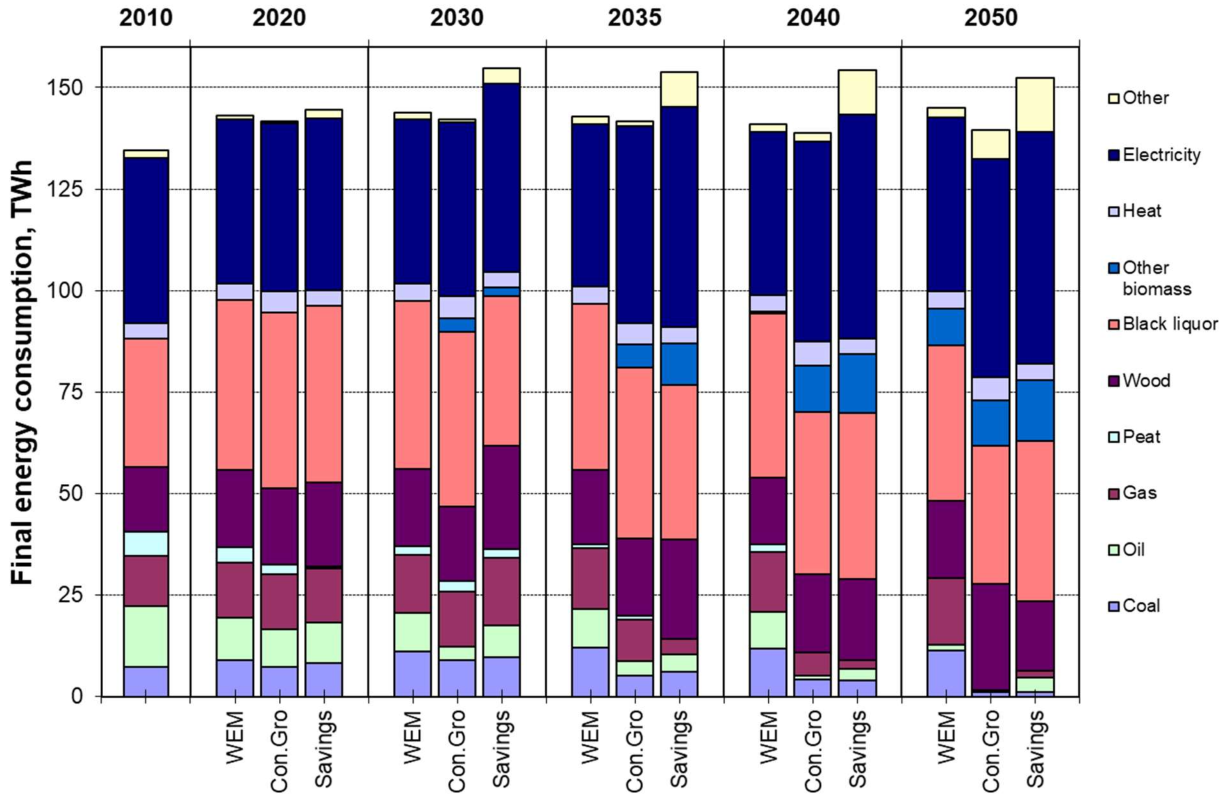

Figure 10. Final energy consumption in industry by scenario ('Other' covers hydrogen, synthetic fuels, etc.).

5.3 Transport

In this context, the transport sector is only analysed in terms of domestic transport, although the calculation model also covers international air and maritime transport. GHG emissions in domestic transport turned into a downward trend in 2010, but the decline bottomed out in 2016. The reasons for the 2016–2017 upswing in emissions include an upturn in fuel consumption in road transport, on the one hand, and a clear drop in the share of biofuels, on the other. The variation in the bio-share can be attributed to the national blending obligation to increase the share of biofuels, which Finland has been implementing in a slightly frontloaded manner. At the same time, however, the VTT LIISA 2018 calculation model indicates that road transport performance has remained stable or even slightly declined, leaving the real reason for the change in consumption partly unclear.

Based on the results, emissions will increase slightly under the WEM scenario up until 2020 but will then take a downward turn (Figure 11). The low-emission scenarios' trajectories for emissions will start to diverge as early as in 2020 as a result of assumed additional measures and will then take a steep plunge through to 2035, followed by a slower decline. By 2035, when carbon neutrality will be achieved, the modelled GHG emissions in transport will only amount to about 2.5 Mt under the Continuous Growth scenario and to about 3 Mt under the Savings scenario. The Continuous Growth scenario assumes that even transport emissions will need to be limited to a level very close to zero in 2050, whereas the Savings scenario considers a reduction to the level of 1.8 Mt sufficient due to CCS applications (in other sectors). Under both scenarios, transport emission reductions will mostly be achieved by technological means, as the modelling assumed changes in mobility patterns to remain fairly modest.

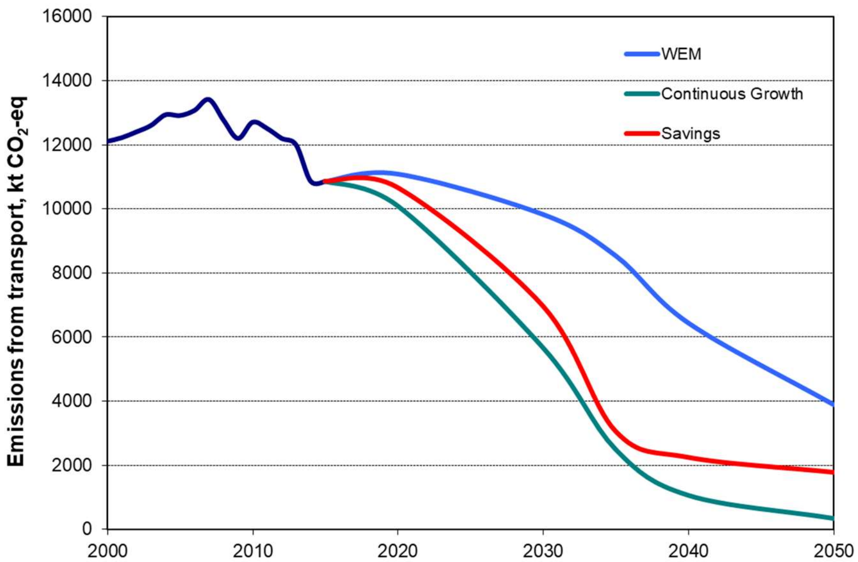

Figure 11. GHG emission trends in domestic transport by scenario.

One of the key objectives of increasing the use of renewable energy put forward in the National Energy and Climate Strategy and the Medium-term Climate Change Policy Plan is to raise the share of renewable energy sources in transport. In road transport, the obligation to distribute biofuels is set at 30% in 2030[6], which will be achieved under both the Savings and Continuous Growth scenarios. It would indeed be technically possible to replace fossil petrol and diesel in transport fuels almost fully with biofuels or by switching to electric, gas-powered or fuel cell electric vehicles. The scenarios considered here assume that the share of ethanol can only rise to 10% of traditional motor petrol, but it will nevertheless be complemented with the market entry of second-generation biopetrol, which can practically replace fossil petrol in full, just as fossil diesel oil can be substituted with renewable diesel. In air transport, it is likewise assumed that biokerosine will enter the market at production costs comparable to renewable diesel.

While it is also possible to expand the use of biogas in vehicles to a substantial extent, its role will remain considerably less significant as a whole when compared with other biofuels. Manufacturing of synthetic biogas from solid biomass, for example, is not financially profitable under these scenarios due to the price and limited availability of sustainable raw material. Its technical-economic production potential will therefore not become very significant and, at the same time, it also has other applications besides transport that are conducive to reducing emissions. The declining livestock numbers assumed in the modelling for agriculture will likewise diminish the potential of biogas derived from manure.

Based on the results, the share of biofuels under the WEM scenario will account for about 16% of final consumption in transport in 2030, while the share will stand as high as at 35% under the Continuous Growth scenario and at about 30% under the Savings scenario. In other words, regardless of the much faster growth in the market share of electric vehicles, the Continuous Growth scenario projects a slightly higher increase in bio-share than the Savings scenario, which is due to their differences in terms of the market situation and foreign trade. The Savings scenario, where vehicle technology is expected to remain dominated by combustion engines, also projects a clearly slower reduction in transport emissions as a result. While the share of biofuels will stand at 41% under the Continuous Growth scenario and at 53% under the Savings scenario in 2050, both scenarios also envision that synthetic fuels (hydrogen, methanol) will assume an increasingly prominent role, especially in heavy-duty transport. Figure 12 shows the modelled distributions of transport fuels under different scenarios.

[6] Laki biopolttoaineiden käytön edistämisestä liikenteessä annetun lain muuttamisesta [*Act amending the Act on Promoting the Use of Biofuels in Transport*] 419/2019. Available in Finnish at: https://www.finlex.fi/fi/laki/alkup/2019/20190419.

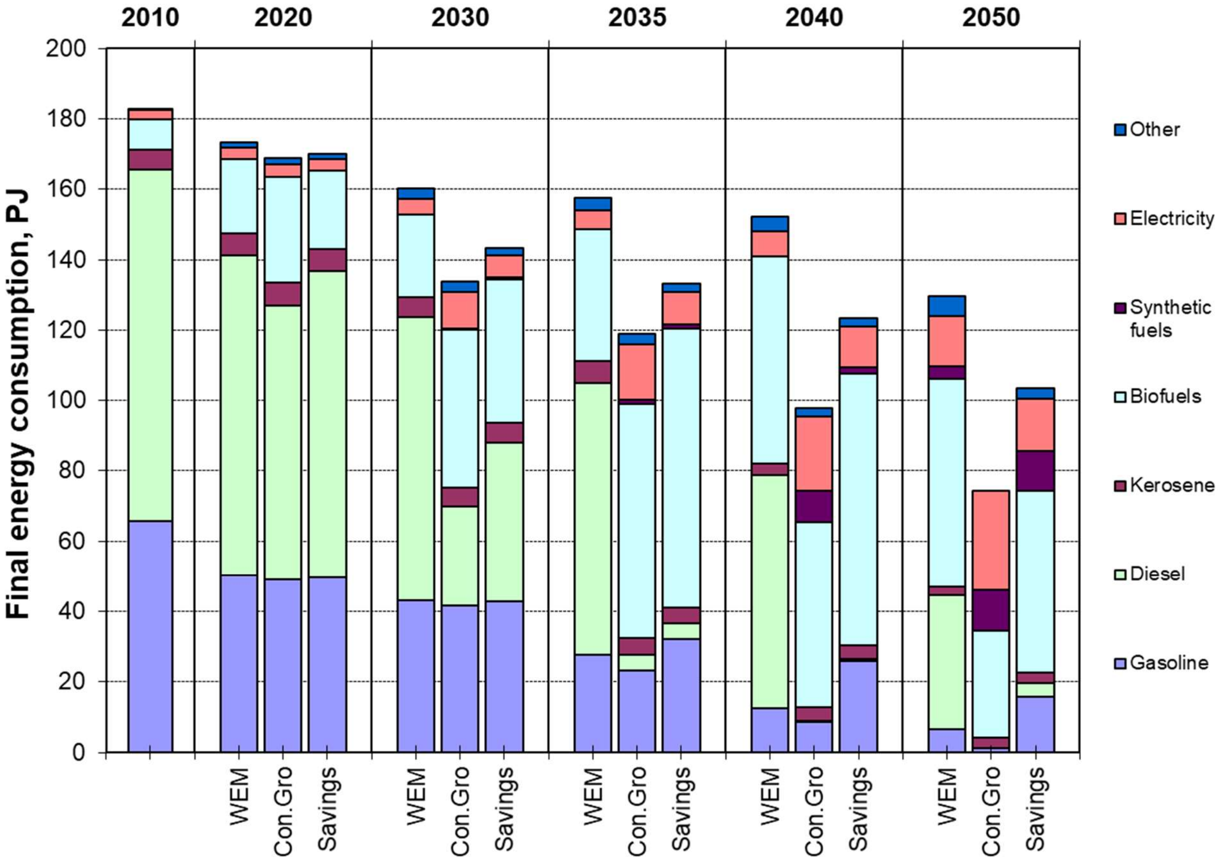

Figure 12. Modelled distribution of transport fuels by scenario.

5.4 Land use, land-use change and forestry (LULUCF) and agriculture

The key factors with impacts on emissions and removals in the land use, land-use change and forestry (LULUCF) sector include changes in land use, forest growth and harvesting, agriculture and peatland management.

The scenarios for the LULUCF sector were made up of scenarios separately calculated for harvested wood products and for each land use category. The calculations produced development scenarios for the surface areas of land use categories and land-use change categories; forest development scenarios; and production scenarios for harvested wood products to calculate changes in the carbon stocks of harvested wood products. Emissions and removals in the LULUCF sector were calculated in six land use categories covering Finland's land area and inland waters.

Under all of the three scenarios, the LULUCF sector produced a net sink; in other words, its greenhouse gas removals exceeded emissions. In Finland, measures focused on forests play a more significant role in the LULUCF sector's balance than other forms of land use. The scenario trends took shape up until 2030, after which point their differences became more pronounced.

The WEM scenario places the LULUCF sector's net sink in 2050 at 26 Mt CO_2-eq. Under the Continuous Growth scenario, the LULUCF sector's net sink will first remain at the current level and then take a swift upswing in 2030, standing as high as at 40 Mt CO_2-eq in 2050. The favourable development in terms of the sink will especially result from lower levels of roundwood removals when compared with the WEM scenario. The Savings scenario produced the smallest sink for the LULUCF sector, putting its net sink below 20 Mt CO_2-eq in 2050. The LULUCF sector's small sink under the Savings scenario was especially attributable to the assumption of change in forest industry production structures and the resulting annual roundwood removals in excess of 90 million cubic metres after 2035. Figure 13 shows the LULUCF sector's net sink trends under different scenarios. The following sections provide further details of the assumptions made under the scenarios in terms of land-use change, forest growth and harvesting, as well as agricultural developments.

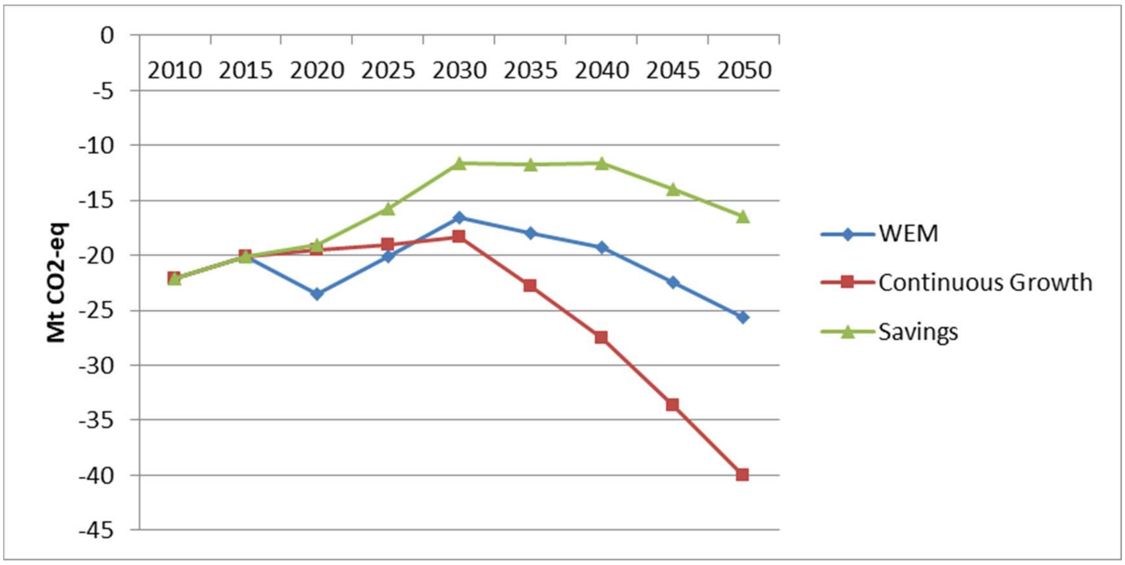

Figure 13. Net sink trends in the LULUCF sector in different scenarios.

Land-use change under different scenarios

The scenarios for land-use change are based on trends calculated from previous changes in land use and the averages of annual land-use change areas. The land-use change areas were estimated using the methodology presented by Haakana et al. (2015)[7], taking account of each scenario's underlying assumptions on aspects such as wind farm construction or field afforestation.

The WEM scenario did not assume any significant changes in measures carried out in the land use sector. With regard to agriculture, the Continuous Growth and Savings scenarios assume a considerable reduction in national consumption of livestock products (-30% to -50% by 2050). As a result, the arable area under active cultivation will shrink due to declining demand for forage area. The Continuous Growth scenario, in particular, assumed the arable area to shrink considerably, while also expecting that peat field areas, in particular, would be taken out of agricultural production. The Savings scenario pointed to similar but milder assumptions. The scenarios considered afforestation the primary alternative for agricultural land being freed up. Both scenarios also projected sharp reductions in peat production areas. There are relatively small variations in settlement areas between different scenarios. The total forest land area changes under the scenarios according to the amounts

[7] Haakana, M., Ollila, P., Regina, K., Riihimäki, H. & Tuomainen, T. 2015. Menetelmä maankäytön kehityksen ennustamiseen: Pinta-alojen kehitys ja kasvihuonekaasupäästöt vuoteen 2040 [*Methodology for forecasting land use developments: Developments in surface areas and greenhouse gas emissions by 2040*]. Luonnonvara- ja biotalouden tutkimus [*Natural Resources and Bioeconomy Studies*] 51/2015.

of areas being afforested and those converted for other uses. Although the scenarios included significant afforestation areas, they show little impact on increasing the carbon sink due to the relatively short time span involved and the limited size of the afforestation area in proportion to Finland's existing forest land. Table 1 below shows the assumptions made on developments in surface areas in different land use categories.

Table 11. Developments in surface areas under different scenarios.

WEM

1,000 ha	2010	2015	2020	2025	2030	2035	2040	2045	2050
Forest land	21,943	21,888	21,861	21,817	21,771	21,727	21,687	21,653	21,624
Cropland	2,474	2,486	2,489	2,491	2,491	2,489	2,488	2,488	2,488
Grassland	238	241	243	244	245	245	246	247	249
Wetlands	2,989	2,987	2,973	2,956	2,943	2,934	2,927	2,917	2,906
Settlements	1,432	1,476	1,517	1,574	1,631	1,683	1,731	1,774	1,813
Other land	1,312	1,311	1,310	1,309	1,308	1,307	1,306	1,305	1,305
Inland waters	3,455	3,455	3,456	3,457	3,458	3,459	3,460	3,461	3,462
Total	33,843	33,843	33,843	33,843	33,843	33,843	33,843	33,843	33,843

Continuous Growth

1,000 ha	2010	2015	2020	2025	2030	2035	2040	2045	2050
Forest land	21,943	21,888	21,880	21,937	21,994	22,051	22,112	22,186	22,264
Cropland	2,474	2,486	2,486	2,353	2,219	2,085	1,952	1,814	1,676
Grassland	238	241	243	277	310	343	377	401	425
Wetlands	2,990	2,986	2,952	2,937	2,923	2,912	2,902	2,891	2,881
Settlements	1,432	1,476	1,517	1,574	1,632	1,686	1,736	1,786	1,832
Other land	1,312	1,311	1,310	1,309	1,308	1,307	1,306	1,305	1,304
Inland waters	3,455	3,455	3,456	3,457	3,458	3,459	3,460	3,461	3,462
Total	33,843	33,843	33,843	33,843	33,843	33,843	33,843	33,843	33,843

Savings

1,000 ha	2010	2015	2020	2025	2030	2035	2040	2045	2050
Forest land	21,943	21,888	21,864	21,885	21,904	21,930	21,958	21,985	22,017
Cropland	2,474	2,486	2,486	2,408	2,331	2,251	2,171	2,092	2,013
Grassland	238	241	243	263	282	302	322	342	362
Wetlands	2,990	2,986	2,967	2,949	2,932	2,915	2,899	2,890	2,881
Settlements	1,432	1,476	1,517	1,573	1,628	1,681	1,727	1,769	1,805
Other land	1,312	1,311	1,310	1,309	1,308	1,307	1,306	1,305	1,305
Inland waters	3,455	3,455	3,456	3,457	3,458	3,459	3,460	3,461	3,462
Total	33,843	33,843	33,843	33,843	33,843	33,843	33,843	33,843	33,843

Trends in forest growth, forest harvesting and forest land carbon sink levels under the scenarios

The WEM scenario assumes that annual forest growth in forest and scrubland will amount to about 116 million m^3 at 2050 levels. When compared with the WEM scenario, the annual levels of forest growth would be slightly lower under the Savings scenario, standing at 113 million m^3, and slightly higher under the Continuous Growth scenario, standing at 117 million m^3. The most recently measured annual growing stock increment amounts to 108 million cubic metres.

The scenarios examine forest harvesting in terms of roundwood removals. As a concept, ‘roundwood’ covers both commercial timber for use by the forest industry and wood used for energy purposes. The WEM scenario assumes that the annual roundwood removal will amount to 72 million cubic metres up until 2024 and would then rise to about 80 million cubic metres. Between 2025 and 2054, annual roundwood removals are expected to remain stable at 80–81 million cubic metres. The WEM scenario’s assumptions on both the forest industry production volumes and roundwood removal trends are in line with the currently valid National Forest Strategy and National Energy and Climate Strategy. The other two scenarios considered here made assumptions on changes in forest industry production structures that also had a bearing on roundwood removals.

The WEM scenario’s key input assumptions for forest industry production by 2050 are that board production will decline slightly in Finland, whereas net exports of pulp and sawn timber will increase slightly. These assumptions were based on the basic estimate prepared by Pöyry PLC in 2016.

All three scenarios assumed that the current downward trend in paper products would continue. Conversely, the assumption on board products was that global demand and, consequently, domestic production would grow over the next few decades, but the growth trend would decelerate starting from 2030.

The Continuous Growth scenario made the assumption that forest industry production volumes would begin to decline most distinctly starting from 2030. The highest production volumes were projected in the Savings scenario, which assumes that both the chemical and mechanical forest industry will gradually switch to manufacturing new, higher value-added products. In pulp production, this means a shift to new fibre products and manufacturing biochemical products from materials such as lignin and hemicellulose fractions of residual lyes, currently used primarily for energy purposes. As for the mechanical forest industry, in turn, it involves manufacturing wood products that are considerably more advanced than classic sawn timber, which can be seen in a downward turn in classic sawn timber production volumes after 2030 and in a corresponding surge in the volumes of processed sawn timber.

Based on these assumptions on forest industry production, the Continuous Growth and Savings scenarios also differ from the WEM scenario in terms of roundwood removals. The Continuous Growth scenario projects annual roundwood removals to stand at 81.8 million m^3 for the 2025–2034 period, followed by a slight decline just below 80 million m^3 starting from 2035. The Savings scenario assumes clearly higher total roundwood removals for the 2035–2054 period than the other scenarios, amounting to about 92 million cubic metres annually. Instead of any material change in the proportion of imported wood, the scenarios assumed that the forest industry’s demand for raw material would focus on domestic harvesting operations.

The differences between the scenarios in terms of roundwood removals will only become visible over the last two decades (2035–2054). The total growing stock volume on forest and scrubland will continue to develop steadily from 2015 to 2055. The Continuous Growth and WEM scenarios arrived at a total volume of over 3.2 billion m^3 for 2055, whereas the Savings scenario put the figure at just under 2.9 billion m^3. As the most recently measured volume of growing stock is 2.5 billion cubic metres, all of the scenarios project a growth in the total volume compared to current levels.

Calculated on the basis of annual roundwood removals, the net carbon sink of forest land will vary between 25 and 28 Mt CO_2-equivalents over the 2030–2040 period under the WEM scenario and will reach the level of 34.4 Mt CO_2-equivalents by 2050. When compared with the WEM scenario, the 2050 forest carbon sink will be slightly higher under the Continuous Growth scenario because it assumes a lower level of roundwood removals. Conversely, the forest net sink projected in the

Savings scenario will fall considerably below that of the WEM and Continuous Growth scenarios due to the fact that the Savings scenario expects roundwood removals to reach a clearly higher level than the other two scenarios. The scenarios place the turning point around 2030.

The scenarios analysed the impact of harvested wood products using the greenhouse gas inventory method. Increasing the amount of harvested timber will decrease forest carbon sinks (Savings) and, vice versa, reducing the amount of harvested timber under a scenario will increase sinks (Continuous Growth). Harvested wood products will not fully compensate for decreasing sinks, even if production focused on durable products (Savings).

It should be borne in mind that the scenario forecasts for forest developments were based on the forest industry's projected wood consumption and the estimates for roundwood removals, as well as on calculations performed using the MELA software on the basis of these assumptions. The level of harvesting chosen under the scenarios has a bearing on the increment of growing stock and its total volume developments and, consequently, on the amount of carbon sequestered in trees. The model assumptions and the parameters applied have a significant effect on the end results, especially in the long run, due to the dynamic nature of forest growth. Calculation methods are also developing constantly and new research may change the results significantly.

Scenarios for the agricultural sector

The WEM scenario for the agricultural sector forecasts that domestic demand for all food products will increase by about 5% by 2030, assuming that per-capita food consumption will remain at 2018 levels over the 2019–2050 period. An exception is poultry consumption, where the robust growth that has continued since the turn of the millennium is expected to stagnate.

The rapid increase in energy prices forecast for the 2020s will especially raise agricultural fuel prices (by 23% from 2018 to 2028) and, to a lesser extent, fertiliser prices (by 13% over the same period).

The WEM scenario assumes that product prices will remain unchanged after 2028. The real prices of agricultural products, i.e. product price developments relative to input prices, will remain more or less the same, especially in plant products. Real prices will rise slightly in some dairy products, such as milk powder and cheese, but the dairy sector as a whole will also see very moderate price developments.

The WEM scenario assumes that agricultural policy will be the same as during the 2014–2020 period. No potential reductions in EU aid have been taken into account beyond 2020. Any minor decrease in area-based subsidies would have a very limited impact on agricultural production volumes.

Productivity will continue to grow in the agricultural sector, particularly in dairy farming, which will see a large-scale shift from units with a single milking robot to those with two or more robots over the 2020s and 2030s. This shift is already underway and will increase the efficiency of labour used in production. Productivity will also continue to grow in other areas of livestock production, mostly in terms of labour productivity, but to a lesser extent in crop production, where yields are expected to remain unchanged. However, the increase in fertiliser prices by several percentage points in the early 2020s will reduce yields by one to three per cent for different plants.

The WEM scenario projects the poor productivity of agriculture to continue from the 2014–2018 baseline. Due to structural developments, agricultural production will remain more or less unchanged, with the exception of a slight decline in beef and cereal production. In dairy production, structural and other productivity developments will maintain output at previous levels through to 2050, whereas beef production, which fell short of domestic demand by over 20% in 2018, is highly likely to drop to at least 30% below domestic consumption by 2050. The profitability of suckler beef production is not good enough to enable any large-scale expansion.

The WEM scenario expects the arable area under active cultivation to shrink by about 200,000 hectares during the 2020s, which is due to the low baseline of profitability in cereal cultivation, energy and fertiliser price increases during the 2020s and the resulting concentration of production on croplands with higher than average yields. As a whole, despite agricultural aid, the relative proportion of fields with lower than average yields being taken out of cultivation will be highest in the eastern and northern parts of Finland, but this will also take place in other parts of the country.

The WEM scenario projects the total sum of emissions in the agricultural sector to stand at 6.45 Mt CO_2-eq in 2050, or one per cent below 2015 levels, mostly due to the decreasing number of animals.

The Savings and Continuous Growth scenarios for agriculture assumed that the consumption of meat and dairy products would decline by 30% to 50% by 2050. Consumption of livestock products would be replaced with plant protein and fish products. A further assumption was that EU price levels would not rise while agricultural aid would see some decline. The Continuous Growth and Savings scenarios expect the arable area under active cultivation to shrink considerably due to declining demand for forage area, which will lead to substantial reductions in GHG emissions. However, this requires the incentives for the necessary change in land use to be acceptable, substantial and long-term from the perspective of land owners and farmers. The scenarios also assume that large livestock farms will channel increasing amounts of manure into biogas production.

The Savings scenario projects 2050 emissions to stand at 4.36 Mt CO_2-eq, or 33% below 2015 levels, whereas the figure for the Continuous Growth scenario is 3.84 Mt CO_2-eq, or 41% below 2015 levels.

Under the Continuous Growth and Savings scenarios, emission reductions come from: (1) decreasing numbers of animals; (2) taking peat fields out of production; (3) declining use of synthetic fertilisers; and (4) declining demand for arable land and steering demand towards reducing GHG emissions, especially on peat fields (LULUCF).

Impacts of agricultural changes on land use

The WEM scenario expects that more than 200,000 ha of arable land will be freed up from agricultural production by 2050. Of this, over 100,000 ha would already be released during the 2020s, provided that the increase in the prices of production inputs will manifest and will not be offset by a higher increase in agricultural product prices. Low profitability and cost pressures will lead to streamlining: low-yield arable land will be taken out of production but will remain as agricultural land with current agricultural policy due to decoupled area payments for eligible agricultural land irrespective of whether it is used for production or not.

The Continuous Growth and Savings scenarios project the croplands to shrink by 470,000 to 815,000 hectares by 2050. As a result of the assumptions made under the Savings and Continuous Growth scenarios, agricultural changes will especially have an impact on peatland emissions classified under the LULUCF sector's 'cropland' emissions, which would decline by 4–5 Mt CO_2-eq over a period from 2015 to 2050.

Points to consider in the change

The climate action relating to agricultural land-use change may have a negative impact on agricultural biodiversity. Unproductive fields and open agricultural landscapes play an essential role in terms of agricultural biodiversity and threatened species. There is little open land in Finland. Fields only account for about 7% of the country's total area.

Measures such as afforestation and rewetting of open areas will reduce the important area for agricultural biodiversity. Overgrowth is and will continue to be the main threat for almost all threatened habitats dependent on agriculture. In addition to traditional rural biotopes, the types of current and former fields of most importance for biodiversity are slightly nutrient-poor, extensively used old perennial grass areas.

Major changes in agriculture and arable land will have broad impacts on society and these impacts will be very unevenly distributed between different population groups and regions. Major changes in agricultural production and arable land use will involve significant localised impacts on the regional economy and employment, especially in areas where agriculture is based on peatland use.

One of the main pillars of food security is the continuity of food supply, which refers to security of food availability at all times. Indeed, domestic agriculture is, first and foremost, linked to food security precisely from the perspective of security of supply. Maintaining food security at levels that correspond to domestic demand and its change requires constant investments in agricultural restructuring, productivity, skills, and the competitiveness of the entire domestic food chain. This means, among other things, that if the arable area in use shrinks and is steered towards achieving climate and various environmental objectives, it will be all the more important to ensure the soil condition of the remaining arable land used for production.

It is highly likely that weather extremes and market price fluctuations are intensifying rather than declining. At the same time as global food demand is growing, particularly in terms of protein-rich products, challenges of global and European food security are increasing. This must also be borne in mind when planning measures to reduce greenhouse gas emissions.

Links to agricultural and rural development policies

The choice of instruments for steering the agricultural sector is influenced by climate policy objectives and the cost-efficiency and effectiveness of the measures to be chosen, as well as many other factors. The instruments need to be compatible with EU provisions. Agriculture is regulated at the EU level more broadly than any other sector. No measures may conflict with the EU Common Agricultural Policy (CAP) and any national support measures should comply with the EU state aid rules. Instruments should be chosen with due consideration for their impact on the objectives of other policy sectors and the consistency of objectives. While the impacts of agriculture on water bodies and nutrient cycles are key environmental impacts, its effects must also be assessed in terms such as biodiversity.

Maintaining the profitability and competitiveness of food production must be taken into account to ensure self-sufficiency. The applicability, reasonableness and equitability of the measures across the country form part of their legitimacy. Steering instruments must also be chosen with due account of the need to streamline administrative procedures.

The EU Common Agricultural Policy (CAP) contributes to the arable area under cultivation, the choice of crops to be grown and the number of animals. Climate change mitigation and adaptation are increasingly shaping the EU Common Agricultural Policy. The need for more efficient and effective climate and environmental actions has intensified as the EU Common Agricultural Policy is being reformed.

The Rural Development Programme for Mainland Finland 2014–2020 includes an agri-environment payment, which is a key instrument to promote sustainable development in agriculture. The measures of the Rural Development Programme to reduce GHG emissions include: balanced use of nutrients; plant cover on fields in winter; catch crops; incorporation of slurry into fields; recycling of nutrients and organic matter; and environmental grasslands. The investment support of the Rural Development Programme can be granted for setting up controlled subsurface drainage as well as renewable energy and manure storage and handling solutions.

There is a currently ongoing CAP27 reform. Its climate and environmental objectives include contributing to climate change mitigation and adaptation, as well as sustainable energy production and use. The reform also aims to foster sustainable development and efficient management of natural resources such as water, soil and air. Further objectives include contributing to biodiversity protection, enhancing ecosystem services and preserving habitats and landscapes. As for financing, the CAP27 reform target is to channel 40% of CAP measures into climate action and it includes an obligation to allocate 30% of rural development funds to environmental and climate measures.

5.5 Waste sector

Greenhouse gas emissions from waste management have historically played a significant role, in particular due to methane emissions from landfilling, but the level of emissions has been decreasing sharply since the turn of the millennium as a result of advancements in waste sorting and recycling. Waste management emissions are generated as part of landfilling, composting, anaerobic digestion and wastewater treatment. Although the energy use of waste is part of waste management, its emissions are not included in the sector's statistics.

Inventories indicate that the total emissions from waste management decreased by 50% over a period from 2000 to 2017, at the same time as the amount of landfilled municipal waste dropped from 1.58 million tonnes to 0.03 million tonnes. Correspondingly, the material and energy recovery of waste has increased significantly. As the amount of landfilled waste has shrunk by 98%, methane emissions from solid waste will decline in the future as a result of waste decomposition. The WEM scenario's results also suggest that landfill gas recovery will be somewhat enhanced in old fills, where gas may still escape into the air even in quite large quantities. In addition, waste management emissions may also be reduced to some extent by improving biological waste and wastewater treatment processes, but additional measures have quite limited impacts on the overall greenhouse gas balance.

The system model included a few additional technical measures to reduce emissions from wastewater treatment, roughly described in generic terms, and the low-emission scenarios also assumed methane emissions from biological treatment of solid waste to decline by 15%. As a combined effect of these, the level of emissions from waste treatment over the 2035–2050 period was about 0.1 Mt CO_2-eq lower under the low-emission scenarios than under the WEM scenario.

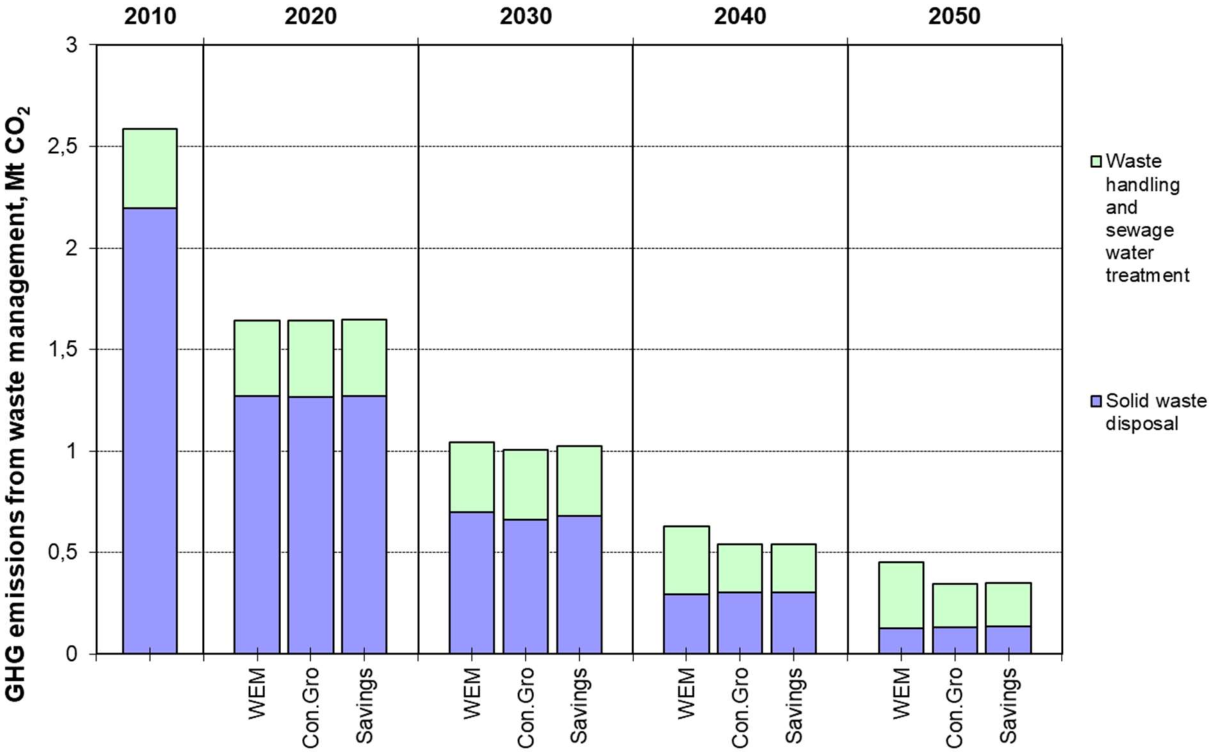

Figure 14. GHG emissions from waste management by scenario.

6 FINANCING

6.1 Estimates of investment needed

The investments required to achieve the climate neutrality objective particularly concern industry. The investment survey 1/2020 published by the Confederation of Finnish Industries (EK) suggests that industries expect to invest a total of about EUR 10.2 billion in 2020. The investments are divided as follows: about EUR 4.5 billion in fixed assets by manufacturing industries; about EUR 2.8 billion by energy industries; and about EUR 2.9 billion in R&D (intangible investments) in total by the entire industrial sector.

According to the EK investment surveys, the annual level of industrial investment varied between eight and ten billion euros over a period from 2009 to 2018. The annual levels of investment varied between EUR 3 and 5 billion in manufacturing industries and between EUR 1.5 and 3 billion in energy industries, while R&D investments ranged between EUR 2.5 and 4 billion. Should the annual level of investment remain at about EUR 10 billion, this would mean total industrial investments to the tune of EUR 300 billion from 2020 to 2050, more than EUR 200 billion of which would consist of fixed investments in industries and the energy system. However, reduction of GHG emissions is likely to call for additional investments. Some Finnish industrial players have even estimated that achievement of climate objectives would double the level of investment needed in their own industry.

Based on information obtained from surveys and other sources, it is possible to estimate that the total investments required to achieve the climate objectives in Finnish industries will exceed EUR 100 billion between 2020 and 2050. Bringing energy system emissions close to zero will require approximately at least EUR 20 million in investments in clean energy production between 2020 and 2050. In addition, substantial investment will be needed in energy grids and systems as well as in renewable processes within energy-intensive industries. The industrial sector’s climate solutions will be closely linked to energy solutions; by way of example, hydrogen production for industrial processes may also have a considerable impact on energy distribution and production investments.

Renovations

According to Finland’s principles, improvements in energy efficiency will be integrated into regular repairs, allowing material- and energy-efficient implementation. Estimated on the basis of the 2018 cost-optimal levels of minimum energy performance requirements applicable to renovations, implementing Finland’s long-term renovation strategy will cost a total of EUR 24 billion over 30 years, equating to EUR 800 million per year. VTT Technical Research Centre of Finland estimates that this will correspond to a total of 12,000 person-years within manufacturing industries, services and worksites. According to the 2018 estimate of the Confederation of Finnish Construction Industries, the costs account for six per cent of the annual volume of building renovations, which totals EUR 13 billion.

Phasing out the use of peat for energy

On 14 January 2020, the European Commission adopted legislative proposals on the Just Transition Mechanism. One part of the mechanism is the Just Transition Fund (JTF) amounting to EUR 7.5 billion, which would be used to support all Member States. Finland’s allocation of the JTF amounts to EUR 165 million, accounting for about 2.2% of the total JTF resources. However, tapping into the funding requires each Member State to transfer their resources from the European Regional Development Fund (ERDF) and the European Social Fund Plus (ESF+) equivalent to at least 1.5

times the JTF allocation and corresponding national co-financing set according to the relevant category of region. Accordingly, Finland would have access to (at least) about EUR 750 million to support a just transition over the forthcoming 2021–2027 programming period. The resource allocation method would be based on five weighted criteria, among which production of peat is especially relevant to Finland.

According to the proposed Regulation, the Just Transition Fund will be established “to provide support to territories facing serious socio-economic challenges deriving from the transition process towards a climate-neutral economy of the Union by 2050”. The Member States should identify the territories and activities that are the most impacted by the transition towards a climate-neutral economy and where support from the Just Transition Fund will be concentrated. For Finland, the Commission proposes that support based on peat production be concentrated on the NUTS2 region of Northern and Eastern Finland, as it accounts for the largest proportion of the total peat production volume among Finland’s NUTS2 regions. The Commission further considers that this region is less equipped to overcome the socio-economic problems caused by declining peat production than other major regions.

In the context of the Commission’s proposal, Finland has focused attention on the exclusion of three significant peat production regions – South Ostrobothnia, Central Finland and Satakunta – from the proposed target territory. Even if the allocation of resources were based on peat production, the JTF measures are not required to concentrate exclusively on alleviating the effects of phasing out the use of peat for energy; rather, just transition plans may also define other measures relating to the effects of the climate transition. The employment effects of peat production are estimated at about 2,300 person-years and, with multiplier effects included, at about 4,200 person-years. These are especially focused on South and North Ostrobothnia. As the details of phasing out the energy use of peat are not currently known, the specific allocation of JTF resources will only be determined at a later date. Specific aspects to consider include whether some energy use of peat will be replaced with other uses and how this would be allocated in regional terms.

6.2 Policies and measures for related research, development and innovation

Implementing measures towards the climate objectives in industry and energy supply requires significant investments in research, development and demonstration of climate-friendly solutions. In total, the industrial sector will probably invest at least about EUR 100 billion in R&D over the 2020–2050 period, with a significant proportion focusing on R&D into climate solutions. If these accounted for 35%, for example, equating to the target defined in Horizon Europe preparations, investments in R&D into climate solutions would amount to at least about EUR 35 billion over the 2020–2050 period.

Research, development and innovation policy actions and measures will be implemented so as to enable the development of a wide range of climate solutions to meet the needs of industry and energy supply by means such as sectoral integration and digitalisation. The measures will take account of the needs to find new solutions for sectors facing challenges with putting low-carbon technologies into use. These include certain energy-intensive industrial processes, transport and development of flexible energy systems. Examples of technological solutions may include digital energy systems, batteries and energy storage, as well as Power-to-X solutions.

7 IMPACT ASSESSMENT OF THE SOCIO-ECONOMIC ASPECTS

7.1 Environmental impact assessments

Similar to the previous PITKO project, the key environmental impacts that can be identified under the updated scenarios include impacts on climate change, biodiversity, water bodies, non-renewable natural resources, and human health, comfort and wellbeing. As a general rule, if realised, the scenarios considered in this long-term strategy can be assessed to have positive environmental impacts, as the scenario narratives are premised on the assumption that achieving the below two-degree climate goal will succeed globally. This will likely make significant positive contributions to a wide variety of environmental impacts when compared with the WEM scenario, where the climate goal will not be achieved. However, the scenarios also involve some climate impacts that were not assessed in the context of this long-term strategy.

The updated scenarios diverge in terms of the trends in emissions and removals in different sectors. The most significant difference is in forest sinks, which are clearly smaller under the Savings scenario when compared with the Continuous Growth scenario due to the higher levels of forest harvesting. In addition to greenhouse gases, climate impacts are caused by factors such as changes in the Earth's surface reflectivity (albedo), black carbon emissions and aerosol emissions from forests. Some of these impacts have global warming potential, whereas others have global cooling potential and many factors involve significant insecurities. The trend or scale of these impacts under the scenarios considered were not assessed in this context.

The scenarios considered expect that air quality will improve as transport performance declines, electric transport increases and small-scale combustion of wood decreases with wider deployment of alternative heating solutions and improved energy efficiency. The growing prevalence of walking, cycling and vegetarian diets and improved pleasantness of environments will also bring about health benefits. At the same time, however, the increasing density of urban structures will lead to higher numbers of people exposed to air pollution while also creating challenges for preserving green areas.

The climate change mitigation measures required under the scenarios considered may also involve significant impacts on people's living conditions, including those that will highlight income disparities.

7.2 National economic impact assessments

In the modelling exercise performed using the FINAGE model, the scenarios aim to describe the development of the national economy in the light of different technological choices and trajectories and emission reduction targets. The differences between the scenarios in terms of economic development stem from divergent technologies and production in the energy, industrial and transport sectors. In other sectors of the economy, their differences will ultimately remain relatively limited.

The Continuous Growth scenario highlights growth in exports and manufacturing based on domestic resources. The scenario projects net exports to have a very pronounced impact on growth, which can indeed be easily called 'export-driven'. Growth will be distributed more evenly among different industries than under the WEM scenario and, consequently, the value of machinery and equipment production, for example, will increase by a factor of almost 2.5. When compared with the WEM scenario, growth will also be more capital- and labour-intensive – in other words, the impact of capital and labour input on growth will be clearly larger. The growth impact stemming from technological advancements will nevertheless be significant. After all, growth will lead to new technology being put into use, while sectors such as transport will electrify very rapidly. General government revenue from emissions trading and indirect taxes will increase, unlike under the other scenarios. The focus of taxation will shift more clearly towards taxing consumption when compared with the other scenarios.

The Savings scenario underlines domestic measures to reduce emissions, ranging from energy savings to biofuels. However, this scenario also makes room for exports, although growth in the output of several export industries will remain slower than under the Continuous Growth scenario. Trends in transport are similar to the WEM scenario. Consumption taxes will also increase almost in step with the WEM scenario. However, economic growth will fall slightly short of the level projected in the Continuous Growth scenario. Increases in environmentally-related indirect taxation, used as an instrument of steering household behaviour based on environmental considerations, will remain at a lower level when compared with the previous scenarios, as the proportion of CO_2 taxation will decrease due to growth in the use of domestic biofuels.

The Continuous Growth and Savings scenarios aim to describe economic development in the light of different technological choices and trajectories and emission reduction targets. As the scenarios differ in all of these respects (first and foremost in terms of reducing emissions), they are not unambiguously comparable to the extent that it would be possible to shift from one scenario to the other by making different choices. Rather, the scenarios describe the outcomes to which the choices and objectives decided in the very near future could lead.

The differences between the scenarios stem from divergent technologies and production. In other sectors of the economy, their differences will ultimately remain relatively limited. In other words, while the scenarios may involve quite different choices in terms of technologies and emission reductions, the choices will spread from the key sectors to other sectors of the economy to a moderate extent and none of the scenarios entails endangering the prerequisites of economic growth and the welfare state, as shown in Figures 15 and 16. Nevertheless, the focus of growth will be slightly different under different scenarios. Technological advancements – growth in total factor productivity – will play a key role in the future as well. However, deploying new technologies will require increasing investments – as energy will be replaced with capital – and this will manifest as a higher growth impact of capital when compared with the WEM scenario. More stringent emission targets, in turn, will be reflected in quite a pronounced increase in the contribution of economic steering – i.e. indirect taxes – on growth.

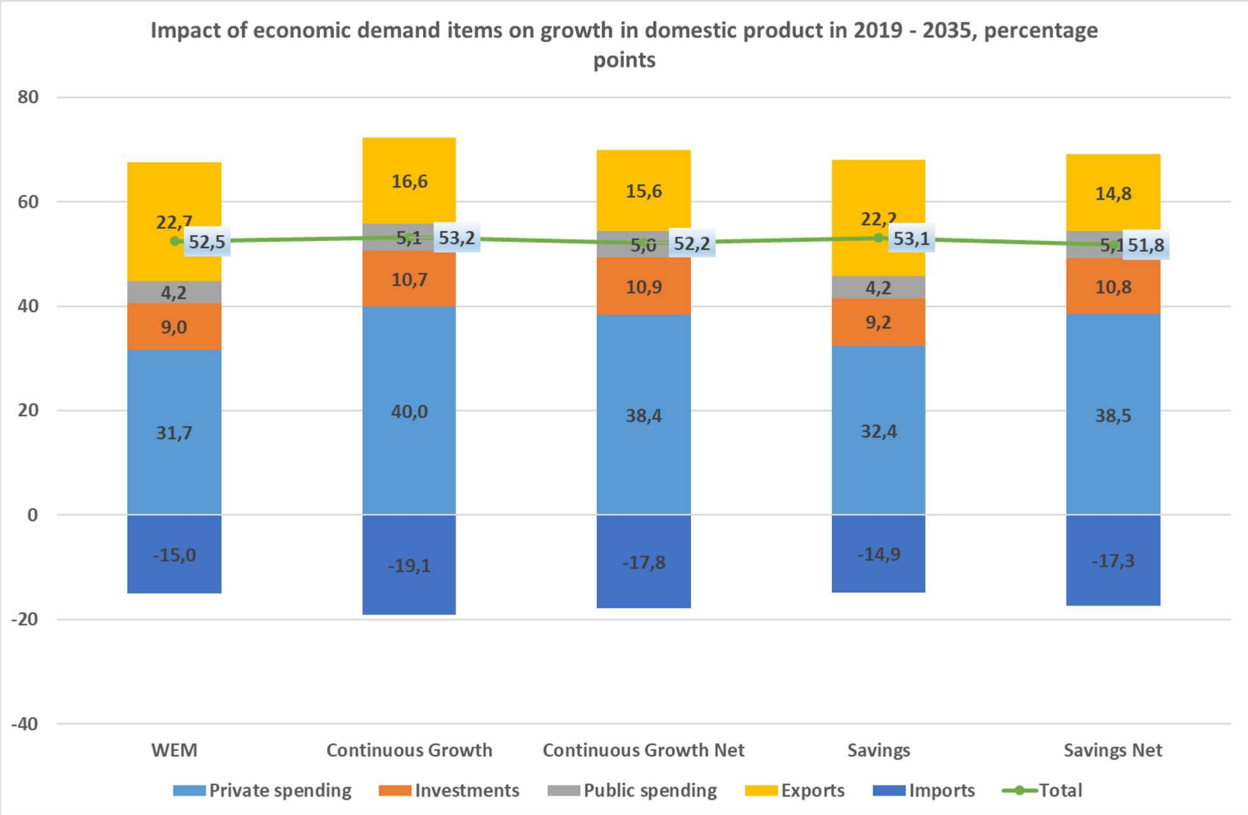

Figure 15. Impact of economic demand items on growth in domestic product in 2019–2035, %.

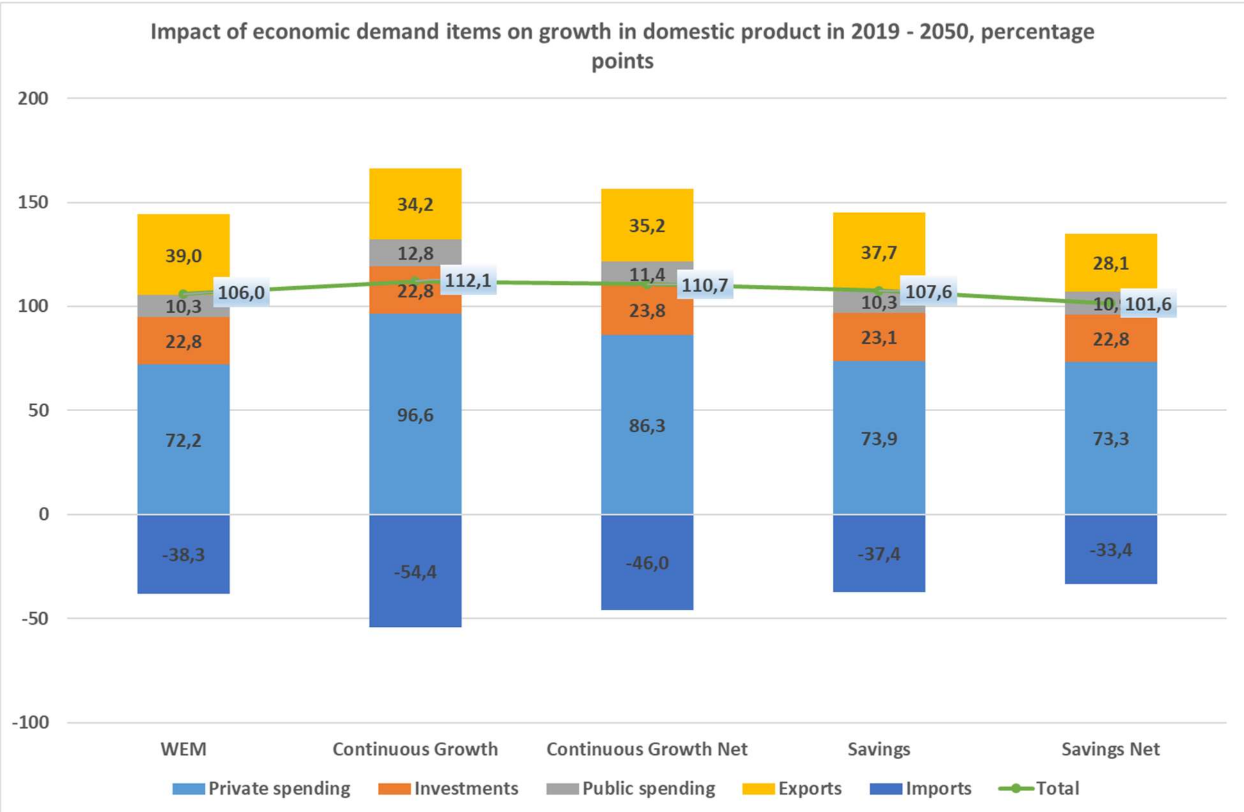

Figure 16. Impact of economic demand items on growth in domestic product in 2019–2050, %.

The differences between the scenarios in terms of economic wellbeing can be described by means of a decomposition of aggregate demand growth, presented for 2035 and 2050 in Figures 17 and 18, respectively. Economic wellbeing will grow even with the transition to a low-carbon society. When analysed through the lens of growth in consumption, the technology-driven differences between the scenarios will also become clearer because of their quite different focus and timing for deployment of new technologies.

In conclusion, it is fair to say that, based on the modelling, economic wellbeing will grow even with the transition to a low-carbon or carbon-neutral society. When approached through both supply and demand, however, it becomes clear that an early pursuit of carbon neutrality will entail additional costs when compared with the previous timetable for reducing emissions. Nevertheless, it is assessed that this will neither jeopardise household wellbeing nor the public sector's fiscal position and future provision of welfare services.

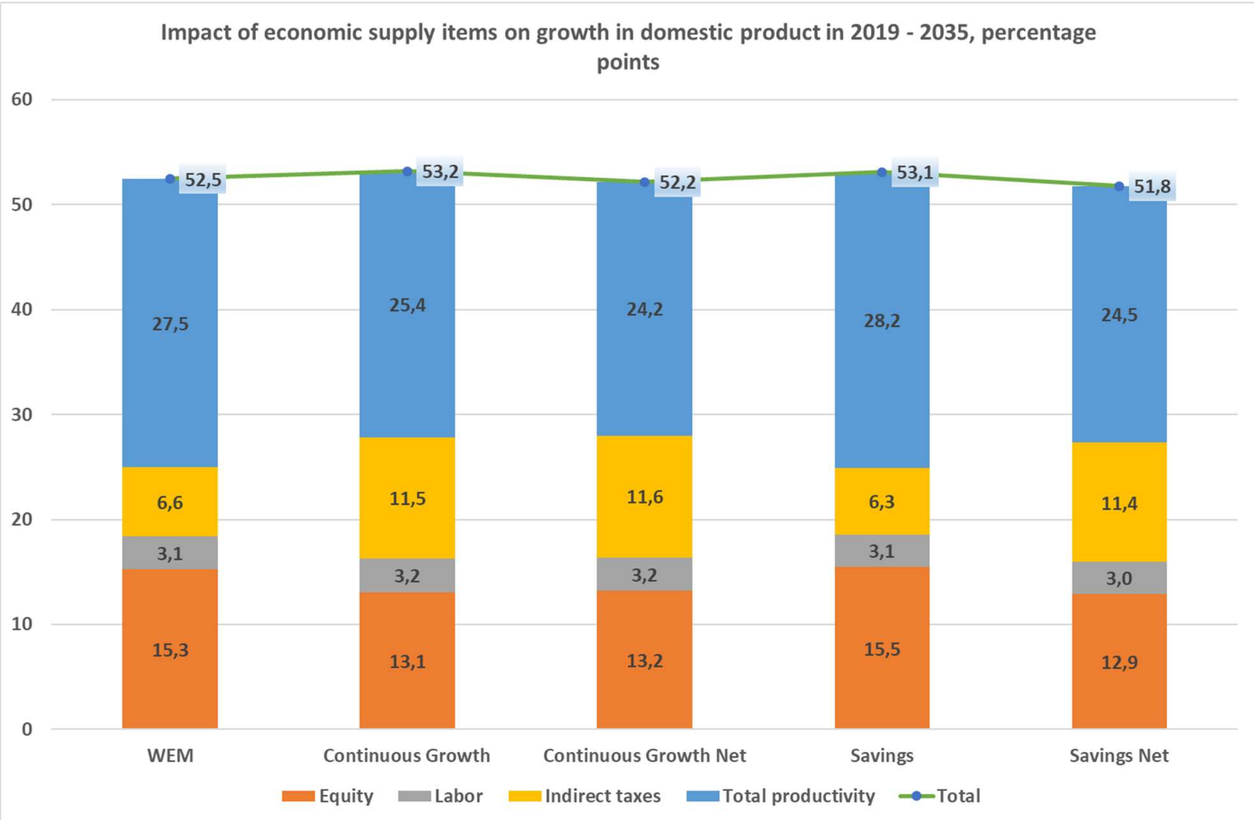

Figure 17. Impact of economic supply items on growth in domestic product in 2019–2035, %.

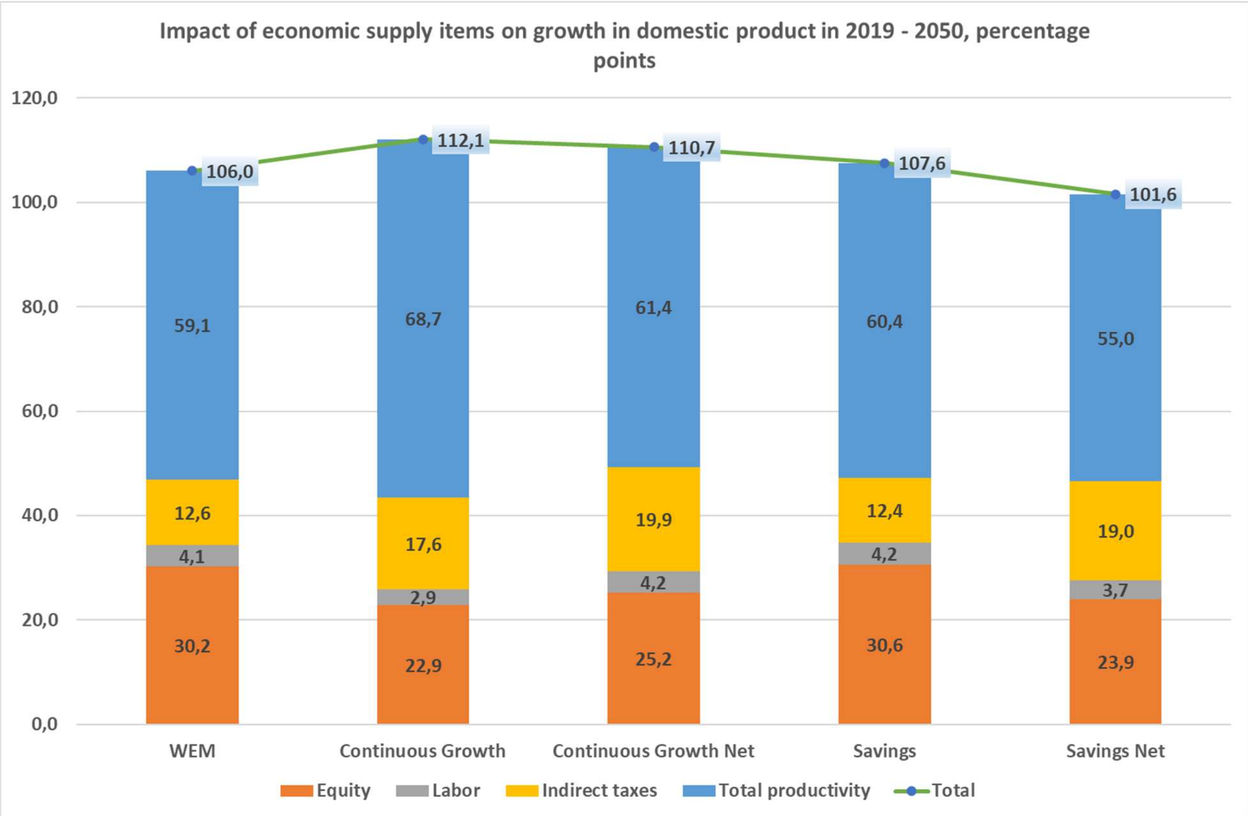

Figure 18. Impact of economic supply items on growth in domestic product in 2019–2050, %.

Figures 19 and 20 describe the impact of the carbon neutrality target on economic energy and emissions intensity under the WEM scenario and in the low-emission scenarios. Emissions intensity, in particular, has declined significantly since the turn of the millennium. However, it is also considered that energy intensity should continue to fall to half the current levels, while emissions intensity should correspondingly drop to a level close to zero by 2050. Energy intensity will also decline under the WEM scenario, which means that energy efficiency will improve even with existing measures.

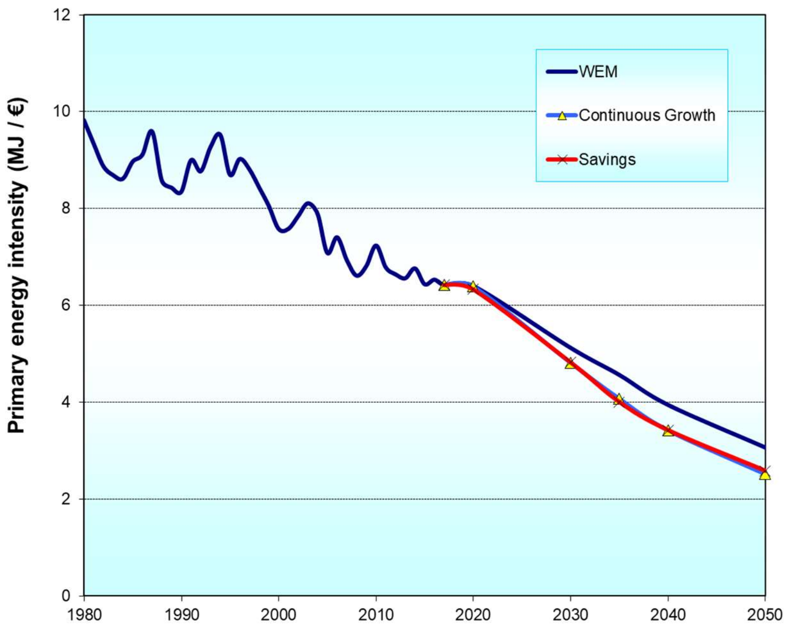

Figure 19. Trends in economic energy intensity under the WEM scenario and in the low-emission scenarios.

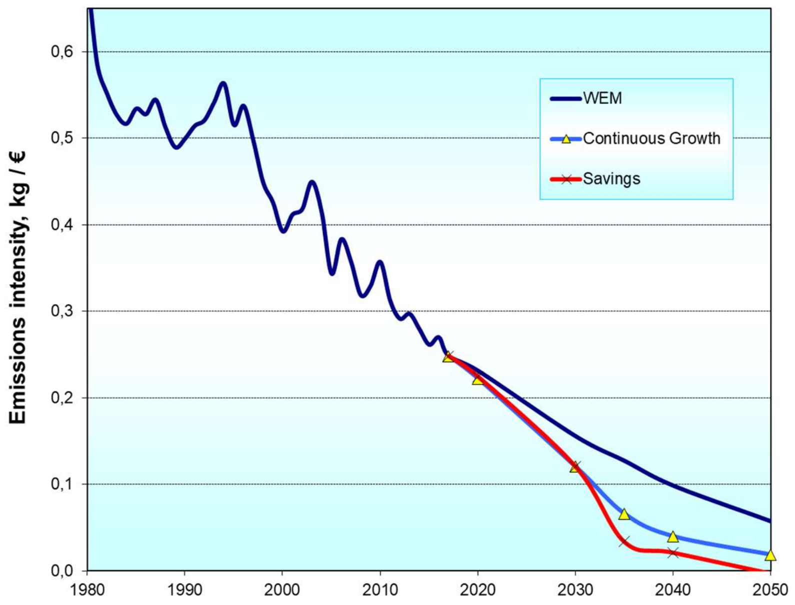

Figure 20. Trends in economic emissions intensity. Emissions include GHG emissions under the Kyoto Protocol but exclude land use emissions and removals (i.e. the LULUCF sector).

ANNEXES

1. Summary of the results of the public consultation organised on Finland’s long-term strategy
2. Balance between GHG emissions and removals under different scenarios
3. Descriptions of scenario modelling processes

Summary of the results of the public consultation organised on Finland’s long-term strategy

Question 1:

The 2050 greenhouse gas emission reduction target (excl. the land use sector) is set at 87.5% under the Continuous Growth scenario and at 90% under the Savings scenario compared to 1990 levels. Both of the low-emission scenarios also achieve the 2035 carbon neutrality target. Is the 2050 target to reduce greenhouse gas emissions ambitious enough and what should Finland’s greenhouse gas emission reduction target be for 2050?

Summary of responses:

There were varying responses about the level of ambition of the emission reduction target. Some thought that it would be sufficiently ambitious if carbon neutrality were to be achieved by 2035, whereas others felt that it was still too soon to judge whether the level of ambition was adequate. The level of ambition of the 2050 target, in particular, was considered to be too low, especially in terms of what level of emission reductions would be fair for Finland.

There were also comments arguing that too stringent emission reduction targets would lead to loss of cost-efficiency and additional economic costs and that emission reductions should be planned so as not to stop at 2050. Respondents also mentioned carbon negativity and the absence of measures to achieve climate neutrality on time. More important than precise numerical targets was the trend.

Question 2:

In your opinion, have the long-term strategy scenarios successfully identified realistic emission reductions, or has something been overlooked?

Summary of responses:

The role of consumption and emissions generated elsewhere from Finnish consumption should be taken into account in emission reductions and various steering instruments should be used to encourage more responsible consumption patterns. Aspects that seem to have been overlooked include the possibility of using steering instruments to encourage emission reductions in the land use sector; the full potential of electrification in energy production; the opportunities provided by the circular economy, material efficiency and digitalisation; as well as the potential of sustainable mobility modes.

All sectors of society should pitch in with the joint emission reduction effort. The Finnish energy sector is already well advanced and the sector has a clear roadmap in place to reduce emissions on the journey towards carbon neutrality. The greatest emission reduction challenges can indeed be found outside the energy sector, which is why, moving forward, climate action should especially focus on reducing emissions from industrial processes, as well as on urban planning, transport and agricultural policy. Different technologies must be applied simultaneously, without excluding any economically viable option. It is necessary to look more extensively into areas such as emission reduction opportunities in industrial waste heat recovery. Climate-sustainable business activities ought to be supported more effectively, making sustainable entrepreneurship more attractive than engaging in business that is detrimental to the climate. Change in emission reductions may be faster than suggested, but this requires substantial investments in energy production infrastructure and runs the risk of a significant decline in energy efficiency.

Climate labelling should also be mandatory for imports in all product categories. The potential for increasing bioenergy use should not be overestimated. Moving forward, the use of biomass should be directed towards applications capable of creating more added value than energy use (including liquid fuels). Resource-efficient biomass use should therefore be adopted as a key criterion for granting investment support, for example.

Respondents also mentioned topics such as the mandatory nature of climate labels in all product categories; switching to a plant-based diet; promoting wood construction; deployment of small modular reactor (SMR) plants; and the potential of geothermal energy.

Question 3:

The land use sector will remain a net sink under all of the scenarios; in other words, the sector's greenhouse gas removals exceed emissions, increasing its carbon stocks. What measures do you consider the most important in the long term to strengthen carbon sinks and stocks and to reduce emissions in the land use sector (land use, land-use change and forestry) in Finland?

<u>Summary of responses:</u>

The key point is to keep forests healthy and in good condition by means of active forest management. In the forest sector, it makes no sense to consider solutions over a period of less than 50 years. Especially with forestry carbon sinks, we should reach a situation where sinks would not be completely dependent on demand for wood and variations in harvesting levels. Since the forest growth rate is an important variable in terms of the GHG balance, any policy measures relevant to growth (ensuring and increasing growth by means such as ash fertilisation) are also important.

The means suggested by respondents also included the following: afforestation of scrublands; abandoning the use of peat fields and peatland clearance in agriculture; intensifying the capacity of croplands as carbon sinks; establishing new nature conservation areas; and keeping to smaller forest harvesting quotas, favouring the principle of continuous growth, thus also improving biodiversity protection. In addition, the harvesting cycle of production forests should be extended. The safest way to sequester carbon is to protect and restore forests and mires.

The land use sector requires stronger steering instruments to cut down on forest clearance. Emissions could be reduced by curtailing deforestation with regard to both clearance of fields and construction activity – the steering instruments suggested for this purpose include fees payable for land-use change – or by developing the use of forests so as to maximise climate benefits, i.e. by directing the structure of production towards wood products with stronger emission-reducing effects.

Furthermore, it is advisable to curb deforestation due to construction and agriculture and to increase forest cover by afforestation where it will make a difference. Any agricultural and forestry subsidies should be revised to be based on environmentally-related criteria, which would also cover encouraging land owners to contribute to protecting and strengthening carbon stocks and sinks.

It is imperative to keep the importance of a socially just/fair transition in mind. As Finland is moving its economy away from the use of fossil fuels, such as peat, it is necessary to ensure that the measures involved are just and respectful of everyone's fundamental and human rights.

Question 4:

Do you have any other comments concerning the long-term strategy?

Summary of responses:

The strategy should be based on creating incentives for a just climate change by all possible means. The strategy should not be isolated from measures being carried out in other sectors or administrative branches. The focus should be on what to support, not on what to ban or restrict. The use of agricultural and industrial subsidies should be supervised and directed towards uses where each specific solution would be of most benefit in concrete terms. Strategy implementation should also be considered in a broader context beyond our own country, as the decisions taken by any Nordic country will also affect the others in any case.

Attention must be paid to communications in order for changes to seem justified and positive in terms of their impacts on both human wellbeing and the economy. So far, not everyone has been engaged in the joint effort by means such as the media. There is still work to be done to ensure that responsibility is fairly divided between everyone.

It is important to consider whether Finnish energy and industrial production will bear international comparison and avoid harmful leakages (investment, carbon and harvest leakages). The development of technology and innovations plays a key role in terms of implementing the long-term strategy. Finland is especially well positioned in energy and low-carbon technologies, not only domestically, but also on international markets. Successful domestic demonstrations provide valuable references for the Finnish technology industry on international markets and in developing new business. At the same time, however, the business community perceives the unpredictability of legislation to be the main factor slowing down climate action.

The strategy development work was criticised, among other things, by pointing out that the existing political steering instruments had failed to embed a science-based overall picture in central government and as part of preparatory work. The direction is right, but the pace is still hopelessly too slow. The strategy pays less attention to analysis of global impacts and dependencies.

The central government is also obliged to ensure that climate action is in line with its human rights obligations and will reduce rather than increase inequality. It is therefore necessary to incorporate assessment of fundamental and human rights into legislation and strategies as well as their drafting and application.

When the strategy is specified, it is advisable to pay varied attention to the kinds of effects that different options will have on people’s everyday lives. Among other things, it is necessary to better identify vulnerable groups most affected by environmental changes and measures to combat these.

Responses from the Sámi Parliament

The following passages present the responses to the public consultation on Finland's long-term strategy given by the Sámi Parliament, which represents the Sámi people, the only indigenous people within the European Union, and expresses their official positions. The Sámi Parliament's responses are provided in full without summarising.

Question 1:

The 2050 emission reduction target for greenhouse gases (excl. the land use sector) is set at 87.5% under the Continuous Growth scenario and at 90% under the Savings scenario compared to 1990 levels. Both of the low-emission scenarios also achieve the 2035 carbon neutrality target.

The Sámi Parliamentary Council (SPC) is the cooperation body for the Sámi Parliaments of the Nordic countries. In its climate policy strategy of 14 April 2010, the SPC demanded significant cuts in emissions. Comparing emission levels to a single year, 1990, treats different states unequally, making it possible for some states to basically not have to make any emission reductions at all. The SPC proposed that the average emissions of states between 1990 and 2000 be adopted as the point of reference. The SPC demanded that states reduce their greenhouse gas emissions from this average by 40% by 2020 and by 90% by 2050.

Question 2:

Cf. responses to 'any other comments' below.

Question 3:

The planning and implementation of emission reductions should be examined in a broader context: Continuous environmental loading and increased exploitation of natural resources will make it difficult for Sámi people to adapt to climate change and the same will also apply to adaptation of Sámi livelihoods, way of life and subsistence to changing climate conditions. Measures to strengthen carbon sinks and stocks must be carried out so as to avoid any negative effects on the indigenous Sámi people's health and livelihoods. The best way for the Sámi community to adapt to climate change is to reduce vulnerability while also contributing to preservation of people, animals and nature's carrying capacity in Sámiland.

Question 4:

Finland's long-term strategy development should take account of the Sámi people's rights as an indigenous people as well as the specific issues based on the Arctic location of the Sámi homeland and the above-mentioned rights of indigenous peoples. The Sámi Parliament represents the Sámi people in national and international contexts. The long-term strategy does not consider the transition to a low-emission society from the perspective of regional or social justice; instead, its underlying calculations are based on the premise that emission reduction costs will be minimised across the country.

The Sámi Parliament considers it important that Finland's long-term strategy to be submitted to the European Commission recognise the special obligations created by the Sámi people's status as an indigenous people at the national and EU levels. Although the strategy does not specify the allocation of emission reductions, its scenarios are based on qualitative and quantitative assumptions for different sectors. The Sámi Parliament stresses that the special characteristics of the Sámi homeland should be taken into account in each sector from the outset. As they now stand, the modelled scenarios seem to include assumptions that, if realised, would likely produce even quite extensive impacts from the perspectives of the Sámi people's traditional livelihoods and rights as an indigenous people. These may cover assumptions relating to biofuels, battery minerals and electric vehicles, wind power generation, as well as forest growth and roundwood removals. Wind power must not cause more than insignificant impediment to the Sámi people's traditional livelihoods, such as reindeer herding. The assumptions on forestry rest on the existing Best Practices for Sustainable Forest Management, the effectiveness of which for the Sámi homeland can justifiably be called into question. According to the Government Programme, "Emissions reduction measures will be carried out in a way that is fair from a social and regional perspective and that involves all sectors of society."

Carbon neutrality must be pursued with due consideration for the language of the Paris Agreement's Article 2.1(b), which provides that the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development should be increased in a manner that does not threaten food production. From the Sámi people's perspective, food security applies to ensuring the utilisation of natural resources – fish stocks, berries and game – at least as essentially as to securing the commercial supply of food. The Sámi people's traditional livelihoods play an essential role in safeguarding their food security and their pursuit is based on traditional wisdom and knowledge of nature. In terms of adaptation to climate change and Sámi people's food autonomy, it is also necessary to examine the means to promote practices of sustainable resource management based on traditional wisdom. Reindeer play a demonstrably important role in mitigating climate change in fell environments.

As the impacts of climate change are already visible in the Sámi homeland, the Sámi Parliament wishes to underline the importance of creating a mechanism for Sámi people's adaptation measures (such as a Sámi climate change panel). It is of the utmost importance to provide earmarked operational funds in order to enable Sámi people's own climate change adaptation and monitoring efforts based on their traditional wisdom and the observations and problem-solving methods of those pursuing traditional livelihoods, Sámi research, as well as their civic knowledge and representation. Furthermore, projects to improve the energy efficiency of snowmobiles and ATVs should be launched urgently. These vehicles are necessary in Sámi people's traditional livelihoods, but they should be developed to release less emissions while ATVs, in particular, should be developed to improve safety and reduce rutting. In its 2014 recommendations to Finland (E/C.12/FIN/CO/6), the UN Committee on Economic, Social and Cultural Rights stressed the need to mitigate the adverse effect of climate change on the Sámi people and the Sámi homeland's natural resources.

Balance between GHG emissions and removals under different scenarios

GHG emissions balance under the WEM scenario (excl. LULUCF).

Gg (CO_2-eq) Emission category	2010	2015	2020	2030	2035	2040	2050
1A Emissions from fuel combustion	60,095	40,715	39,992	33,802	31,428	26,062	15,244
1A1 Energy industries	30,947	17,766	16,875	12,899	12,352	9,422	5,757
1A2 Manufacturing industries and construction	10,250	6,949	8,522	8,204	8,054	7,996	3,838
1A3 Transport	12,712	11,109	11,090	9,832	8,542	6,447	3,900
1A4 Other sectors	4,982	3,803	2,413	1,821	1,460	1,207	822
1A5 Other fuel use	1,204	1,088	1,092	1,047	1,019	989	927
1B Fugitive emissions from fuels	142	146	141	129	123	120	118
2 Industrial processes and product use	6,147	5,861	6,350	6,161	4,849	4,647	4,412
2A Mineral industry	1,167	964	1,171	1,183	1,029	1,044	1,125
2B Chemical industry	1,016	1,170	1,340	1,375	387	351	221
2C Metal industry	2,439	2,142	2,446	2,724	2,740	2,737	2,608
2D Non-energy use	85	104	95	100	102	104	107
2F F-gases	1,438	1,480	1,298	778	591	410	351
3 Agriculture	6,630	6,491	6,571	6,548	6,491	6,455	6,342
3A Enteric fermentation	2,099	2,117	2,078	2,046	2,008	1,970	1,864
3B Manure management	748	751	819	788	743	719	662
3D Agricultural soils	3,502	3,439	3,448	3,486	3,513	3,539	3,589
3F Field burning of agricultural residues	2	3	3	3	3	3	3
3G Liming	277	180	222	222	222	222	222
3H Urea application	2	2	2	2	2	2	2
5 Waste management	2,583	2,134	1,644	1,041	793	629	452
5 Waste disposal	2,194	1,766	1,268	699	455	295	126
5B Biological treatment of waste	144	113	100	100	100	100	100
5D Wastewater treatment and discharge	246	254	276	242	238	235	225
Indirect CO_2 emissions	68	53	76	76	76	76	76
Emissions without LULUCF	**75,664**	**55,400**	**54,774**	**47,757**	**43,759**	**37,989**	**26,644**

NB! Agricultural emission results do not correspond exactly to those provided by the Natural Resources Institute Finland (Luke). Luke's estimates are presented in a Finnish-language report available at: https://www.vtt.fi/inf/pdf/technology/2020/T366.pdf.

GHG emissions balance under the Continuous Growth scenario (excl. LULUCF).

Gg (CO_2-eq) **Emission category**	**2010**	**2015**	**2020**	**2030**	**2035**	**2040**	**2050**
1A Emissions from fuel combustion	60,095	40,715	38,292	23,595	14,307	7,473	3,340
1A1 Energy industries	30,947	17,766	17,098	9,137	5,875	4,267	2,524
1A2 Manufacturing industries and construction	10,250	6,949	7,569	6,356	4,170	1,589	32
1A3 Transport	12,712	11,109	10,091	5,668	2,498	1,069	351
1A4 Other sectors	4,982	3,803	2,442	1,387	745	332	265
1A5 Other fuel use	1,204	1,088	1,092	1,047	1,019	215	168
1B Fugitive emissions from fuels	142	146	136	123	82	73	53
2 Industrial processes and product use	6,147	5,861	6,328	5,797	3,410	3,223	1,664
2A Mineral industry	1,167	964	1,090	1,113	1,187	1,257	1,263
2B Chemical industry	1,016	1,170	1,340	1,375	387	351	220
2C Metal industry	2,439	2,142	2,412	2,596	1,304	1,350	0
2D Non-energy use	85	104	95	100	101	103	107
2F F-gases	1,438	1,480	1,391	612	430	161	75
3 Agriculture	6,630	6,491	6,358	5,158	4,629	4,132	3,436
3A Enteric fermentation	2,099	2,117	1,989	1,537	1,375	1,256	1,105
3B Manure management	748	751	764	629	568	467	378
3D Agricultural soils	3,502	3,439	3,395	2,826	2,529	2,261	1,816
3F Field burning of agricultural residues	2	3	3	3	3	3	3
3G Liming	277	180	207	162	153	143	132
3H Urea application	2	2	2	2	2	2	2
5 Waste management	2,583	2,134	1,643	1,004	711	540	346
5 Waste disposal	2,194	1,766	1,266	662	462	304	133
5B Biological treatment of waste	144	113	100	100	100	100	100
5D Wastewater treatment and discharge	246	254	276	242	149	137	113
Indirect CO_2 emissions	68	53	62	62	62	62	62
Emissions without LULUCF	75,664	55,400	52,819	35,738	23,200	15,503	8,900

NB! Agricultural emission results do not correspond exactly to those provided by the Natural Resources Institute Finland (Luke). Luke's estimates are presented in a Finnish-language report available at: https://www.vtt.fi/inf/pdf/technology/2020/T366.pdf.

GHG emissions balance under the Savings scenario (excl. LULUCF).

Gg (CO_2-eq) **Emission category**	**2010**	**2015**	**2020**	**2030**	**2035**	**2040**	**2050**
1A Emissions from fuel combustion	60,095	40,715	39,623	25,423	4,416	-6	-7,834
1A1 Energy industries	30,947	17,766	17,572	8,501	-1,371	-3,120	- 11,467
1A2 Manufacturing industries and construction	10,250	6,949	7,887	8,739	2,080	349	1,436
1A3 Transport	12,712	11,109	10,660	6,959	3,053	2,242	1,777
1A4 Other sectors	4,982	3,803	2,412	612	403	301	252
1A5 Other fuel use	1,204	1,088	1,092	612	250	222	168
1B Fugitive emissions from fuels	142	146	139	145	90	84	67
2 Industrial processes and product use	6,147	5,861	6,438	5,655	3,546	3,379	1,796
2A Mineral industry	1,167	964	1,095	926	772	772	848
2B Chemical industry	1,016	1,170	1,350	1,375	1,124	1,082	758
2C Metal industry	2,439	2,142	2,506	2,642	1,239	1,261	0
2D Non-energy use	85	104	95	100	101	103	107
2F F-gases	1,438	1,480	1,391	612	310	161	83
3 Agriculture	6,630	6,491	6,316	5,299	4,877	4,441	4,043
3A Enteric fermentation	2,099	2,117	1,979	1,654	1,526	1,399	1,295
3B Manure management	748	751	735	609	616	495	532
3D Agricultural soils	3,502	3,439	3,395	2,856	2,559	2,375	2,052
3F Field burning of agricultural residues	2	3	3	3	3	3	3
3G Liming	277	180	202	175	171	167	160
3H Urea application	2	2	2	2	2	2	2
5 Waste management	2,583	2,134	1,646	1,023	710	539	348
5 Waste disposal	2,194	1,766	1,270	681	461	303	135
5B Biological treatment of waste	144	113	100	100	100	100	100
5D Wastewater treatment and discharge	246	254	276	242	149	137	113
Indirect CO_2 emissions	68	53	62	62	62	62	62
Emissions without LULUCF	75,664	55,400	54,223	37,606	13,700	8,500	-1,518

NB! Agricultural emission results do not correspond exactly to those provided by the Natural Resources Institute Finland (Luke). Luke's estimates are presented in a Finnish-language report available at: https://www.vtt.fi/inf/pdf/technology/2020/T366.pdf.

Estimated trends in emissions and removals in the LULUCF sector under different scenarios.

Table 1. Historical emissions and removals in the LULUCF sector by land use category and for harvested wood products for 2010 and 2015 and their trends by 2050 under the WEM scenario (Mt CO_2-eq).

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Forest land	-32.20	-28.29	-30.64	-28.16	-25.00	-26.66	-28.01	-31.20	-34.43
Cropland	7.66	7.11	6.72	7.38	7.59	7.65	7.68	7.76	7.88
Grassland	0.75	0.67	0.88	1.12	1.25	1.31	1.28	1.28	1.28
Wetlands	2.11	2.21	2.07	1.95	1.87	1.86	1.85	1.78	1.70
Settlements	1.73	0.97	1.31	1.30	1.27	1.18	1.11	1.02	0.92
Harvested wood products	-2.20	-2.73	-3.81	-3.64	-3.50	-3.29	-3.16	-3.08	-2.98
Total	-22.15	-20.07	-23.46	-20.05	-16.52	-17.94	-19.25	-22.44	-25.63

Table 2. Historical emissions and removals in the LULUCF sector by land use category and for harvested wood products for 2010 and 2015 and their trends by 2050 under the Continuous Growth scenario (Mt CO_2-eq).

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Forest land	-32.20	-28.29	-26.29	-25.09	-23.53	-27.48	-31.34	-36.56	-42.17
Cropland	7.66	7.11	6.63	5.92	5.11	4.23	3.31	2.44	1.59
Grassland	0.75	0.67	0.74	0.86	1.02	1.19	1.35	1.37	1.40
Wetlands	2.11	2.21	1.86	1.85	1.86	1.91	1.93	2.16	2.40
Settlements	1.73	0.97	1.32	1.34	1.32	1.25	1.17	1.08	0.99
Harvested wood products	-2.20	-2.73	-3.81	-3.94	-4.09	-3.95	-3.99	-4.12	-4.21
Total	-22.15	-20.07	-19.55	-19.05	-18.31	-22.84	-27.56	-33.62	-40.02

Table 3. Historical emissions and removals in the LULUCF sector by land use category and for harvested wood products for 2010 and 2015 and their trends by 2050 under the Savings scenario (Mt CO_2-eq).

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Forest land	-32.20	-28.29	-25.89	-21.40	-16.14	-14.77	-13.01	-14.45	-15.85
Cropland	7.66	7.11	6.64	6.09	5.47	4.77	4.02	3.31	2.63
Grassland	0.75	0.67	0.74	0.78	0.85	0.93	1.00	1.07	1.13
Wetlands	2.11	2.21	2.07	1.86	1.68	1.49	1.30	1.30	1.30
Settlements	1.73	0.97	1.32	1.30	1.24	1.16	1.06	0.93	0.82
Harvested wood products	-2.20	-2.73	-3.90	-4.32	-4.67	-5.32	-5.95	-6.19	-6.42
Total	-22.15	-20.07	-19.03	-15.70	-11.58	-11.75	-11.58	-14.03	-16.39

Descriptions of scenario modelling processes

The scenarios were modelled using the following calculation models:

- the TIMES-VTT model: energy production and energy systems, including production scenarios for harvested wood products;
- the REMA model: energy consumption of the building stock;
- the DREMFIA model: agriculture;
- the MELA software: development of forest resources;
- the FINAGE model: economic trends.

These models and other methods used in modelling are described below.

Description of the TIMES-VTT model and its database

A key tool used to model and analyse the scenarios is the broad TIMES-VTT energy system model developed by VTT Technical Research Centre of Finland Ltd, which covers global energy production and consumption as well as greenhouse gas emissions. The model is based on the global ETSAP TIAM model (Loulou 2008, Loulou & Labriet 2008), which was developed through international cooperation, building on the IEA ETSAP TIMES modelling system (Loulou et al. 2016). The TIMES-VTT model describes energy systems in Finland, the Nordic countries and the rest of Europe. Methodologically, it is a so-called partial equilibrium model, which maximises the total economic surplus of consumers and producers. The model includes detailed descriptions of both the current system of energy production and consumption and future technologies in terms of several different investment options.

The TIMES-VTT model's extensive database contains a detailed description of the current energy system, including the energy production and distribution system, building stock, energy uses in housing and services, stock of cars and other vehicles, processes and plants for manufacturing energy-intensive industrial products, other industrial energy end uses, as well as energy use in agriculture and forestry. The model database also covers estimates of energy system removals, such as removals from energy production plants, buildings and vehicles. However, the largest part of the database naturally consists of technological descriptions of investment options in future energy systems, including estimated trends in their costs and technical performance (energy production efficiencies, service life, usability, etc.). The model also depicts regional technical potential of energy commodities, the global fuel trade, emissions trading (incl. trade in CO_2 transport and storage services). The TIMES-VTT model and its databases have been discussed in several scientific articles (Koljonen et al. 2009, Koljonen & Lehtilä 2015, Lehtilä & Koljonen 2018).

The energy system model's solution is based on maximising the producer and consumer surplus and the resulting energy supply and end use system therefore satisfies the demand for useful energy as cost-efficiently as possible, taking account of factors such as taxes, subsidies and return on investment requirements in different sectors of the economy. The model also allows a wide variety of limitations to be set on the system's development. By way of example, several forms of energy production have been assigned upper or lower limits for production, capacity or market share, which the solution must accommodate. The model examines energy consumption and production on the basis of consistent principles, so as to account for the interaction between production investments and the opportunities to enhance energy efficiency.

The TIMES-VTT model covers all of the GHG emissions under the Kyoto Protocol and their reduction technologies and/or methods. Consequently, the low-emission scenarios assume that emission reductions will be carried out in all sectors generating GHG emissions (excluding the LULUCF sector) in the order of cost. Another example of limitations set for the scenarios is the emission cap set for effort sharing sectors. The model examines energy consumption and production on the basis of identical principles, so as to account for the interaction between production investments and the opportunities to enhance energy efficiency.

The level of energy consumption and trend in emissions calculated in the TIMES-VTT model depend on several factors provided as baseline data. The key baseline data used by the model includes:

- trends in different economic sectors, including industrial sectors, households, services, agriculture and forestry, and extractive industries;
- trends in production of different products in energy-intensive industrial sectors;
- the existing stock of cars and other vehicles and trends in mobility and transport needs by mode of transport;
- the existing building stock and trends in inhabitable surface area by type of building;
- existing energy and climate policy steering instruments, incl. energy and emission taxes, subsidies, and regulations, legal statutes and other such instruments adopted to increase energy efficiency;
- quantitative removals from the plant and equipment base in the current energy system and the assumed development of available technological options in all sectors both in terms of technical parameters and costs.

The energy system model produces a trajectory for an energy supply and end use system that can satisfy the demand for useful energy as cost-efficiently as possible, taking account of factors such as taxes, subsidies and return on investment requirements of parties operating in different sectors. The results produced by the model cover the annual flows of all of the energy commodities, materials and emissions described in the model from production, import and inventories to end use, export, storage and disposal or recycling. The results for the levels of GHG emissions can be broken down by sector and emission type and, where necessary, by process. The results also include details such as the capacities, investment costs and operating costs for all of the production plants and technologies described in the model. The model further produces results for energy commodity prices, which represent long-term equilibrium prices.

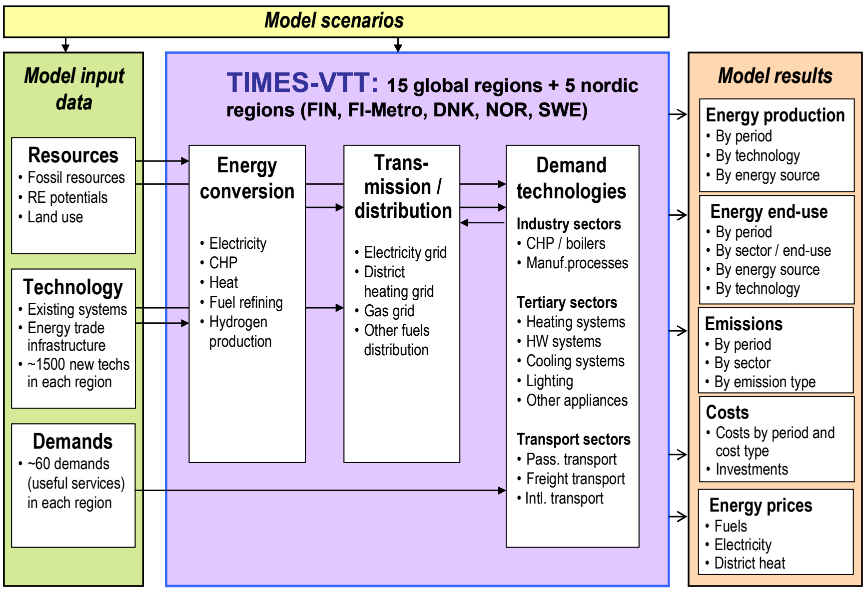

Figure 1. The TIMES model components and a simplified structure diagram for one region. The diagram describes trade in key energy commodities between regions.

The TIMES-VTT model allows the user to freely choose an analysis interval all the way up to 2150, but its current version sets the base year at 2010. The model is calibrated to the detailed energy balances of the International Energy Agency (IEA) for all countries in 2010 and 2015. For Finland, these are based on the statistics submitted to the IEA by Statistics Finland, but the calculation method is slightly different from national energy statistics.

The REMA model for energy consumption of the building stock

The energy consumption of the building stock was calculated using the REMA model developed by VTT Technical Research Centre of Finland Ltd. The REMA model is a bottom-up model for calculating the energy consumption of the building stock, which is based on the use of representative standard buildings. Future trends in energy consumption were calculated on the basis of the volumes of new construction, renovations and annual removals projected for each category of intended use and age. The model divides the entire building stock based on the following intended uses:

- one-dwelling houses;
- terraced houses and residential blocks of flats;
- commercial and public buildings;
- free-time residences.

The ‘commercial and public buildings’ include the following types of buildings used by Statistics Finland: commercial buildings, office buildings, transport and communications buildings, buildings for institutional care, assembly buildings, and educational buildings. Each type of building stock classified by intended use is further divided into age groups by year of completion. The age groups were determined with a view to taking account of developments in energy performance requirements as follows:

- completed prior to 1959;
- completed in 1960–1979;
- completed in 1980–2009;
- completed in 2010–2018;
- forecast for 2019–2024;
- forecast for 2025–2050.

In each building category, energy for heating the facilities was modelled separately from heat losses due to ventilation and envelope (U-value and tightness). In addition to heating, the calculation includes energy required for domestic hot water, as well as real estate electricity and other electricity consumed by users.

The REMA model allows the energy consumption levels of standard buildings to be derived from statistical data, estimated or obtained from simulated buildings. In this case, the modelling was based on data from Statistics Finland (2018) and prior studies (e.g. Tuominen et al. 2012 and Tuominen et al. 2013) for the existing building stock and on the baseline scenario for energy consumption in buildings published by the Finnish Environment Institute (Mattinen et al. 2016) for new buildings. The resulting baseline scenario, in turn, was used to derive the other scenarios by adapting these to each scenario narrative. A more detailed description of the REMA model is publicly available in Finnish (Tuominen et al. 2014).

The DREMFIA partial equilibrium model for agriculture

The DREMFIA model (Dynamic multiREgional sector Model of FInnish Agriculture; Lehtonen 2001, 2015) is an economic partial equilibrium model covering the main production sectors, arable land use, domestic demand and foreign trade in Finnish agriculture within the following four major regions: Southern Finland, Inland Finland, Ostrobothnia and Northern Finland (Lehtonen 2015). The major regions are divided into smaller production areas based on the division into aid zones, providing quite a precise description of aid policy. The DREMFIA model does not include reindeer, horse and sheep husbandry and the agricultural scenario analyses assume the numbers of these animals to remain close to 2018 levels through to 2050. Fur farming and horticultural production are also excluded from the model. Nevertheless, the model covers over 95% of agricultural land use.

Structural development in Finnish agriculture was modelled endogenously, allowing for the growth observed in the number of dairy cows in the largest farm size categories and in Finland's main production areas, which is taken into account in arable land use. The model was validated so as to more or less match actual developments in total livestock production volumes and arable land use in 1995–2018. At the same time, the model takes account of the domestic consumption of Finnish agricultural products in parallel to changes in imports and exports. Domestic consumption may be satisfied with domestic production or competing imported products. Consumption for the 2019–2050 period follows actual developments between 1995 and 2018 and consumption in 2018, unless otherwise determined in specific scenarios, as shown below.

The model assumes that Finland is completely dependent on the input and product prices formed at EU and global levels. However, the price levels of domestic agricultural products may differ slightly from average EU prices. Product-specific deviations in the producer prices of milk and meat, for example, are realised in the model such that domestic and foreign products are treated as imperfect substitutes. In other words, they can substitute for each other to quite a large – yet limited – extent, being different in terms of quality. By way of example, Finland partially imports and exports different types of meat (different carcass parts) and different dairy products (of which the model includes 18 different kinds).

Animal feed consumption may adjust to different levels of output, guided by price ratios, within the framework of feed recommendations. Livestock production has a major impact on feed production and arable land use. Developments in surface areas used for different crops are also influenced by agricultural support and the prices of fertilisers and agricultural products. Consequently, the DREMFIA model broadly replicates the 1995–2018 developments in Finland's agricultural production and land use, including the key variables required to assess agricultural trajectories and trends in GHG emissions from agriculture through to 2050.

The agricultural trajectory covers annual developments through to 2050. The model was originally designed and implemented so as to specifically enable the assessment of agricultural support payments under the EU Common Agricultural Policy (CAP), including the terms of support, and the effects of Finland's national agricultural policy measures on the volume and placement of agricultural production and agricultural income in Finland. The most recent study on this subject was published by Lehtonen & Niemi (2018). The DREMFIA model was also applied when assessing the impacts of market changes, the agri-environmental scheme (Lehtonen & Rankinen 2015) and changing climate (Lehtonen 2015) on agricultural production, arable land use and income. The population projections by Statistics Finland (Tilastokeskus 2015) and trends in energy prices forecast up until the mid-century are taken into account in DREMFIA modelling, which produces the inputs required to calculate greenhouse gases, also taking account of the numbers of reindeer, sheep, horses and fur animals.

The DREMFIA sector model allows inclusion of changes determined in different scenarios for crop yields, agricultural productivity, input use and agricultural support, as well as the EU prices of agricultural end products and inputs. By way of example, fertiliser tax – which is not currently levied but can be determined in different scenarios – will have a direct effect on reducing crop fertilisation and yield levels in the model. Fertiliser tax and any possible new or substitute forms of agricultural support for grasslands with low fertiliser levels will encourage the use of nitrogen-fixing grass-clover mixtures. This will be implemented in the model such that silage grass production based on intensive inorganic nitrogen fertilisation will decline and will be partially replaced with grass production with low fertiliser and yield levels (Lehtonen & Niskanen 2016). The effects of biogas production on livestock production may be taken into account by assuming a slight reduction in energy costs in livestock production, but any more precise change in input use will be omitted for the time being, because the model does not include specific details of biogas production.

In this study, the baseline data for GHG calculations produced by the DREMFIA model includes nitrogen contained in chemical fertilisers, arable land use and numbers of animals for the main categories of livestock. Future developments in livestock weight, nitrogen excretion and milk production will continue to follow those reported in the GHG inventory.

Calculations for the land use, land-use change and forestry (LULUCF) sector

The scenarios for the land use, land-use change and forestry (LULUCF) sector were made up of scenarios separately calculated for harvested wood products and for each land use category. The process of drafting the scenarios was divided into four phases. The first phase produced scenarios for the surface areas of land use categories and land-use change categories; surface areas constitute a key baseline data set for LULUCF calculations. Forest development scenarios, mostly focusing on the development of growing stock, formed a separate phase. The production scenarios for harvested wood products were created using the TIMES-VTT model and its results were used as baseline data for calculating changes in the carbon stocks of harvested wood products. The fourth phase consisted of non-forest land use categories and land-use change categories.

Determining surface areas for land use and land-use change

Emissions and removals in the LULUCF sector were calculated in six land use categories covering Finland’s land area and inland waters. Marine waters were excluded from the analysis. Land-use change areas were estimated using a method proposed by Haakana et al. (2015), accounting for each scenario’s underlying assumptions on factors such as wind farms or field afforestation (Kärkkäinen et al. 2019). The land-use change scenarios are premised on the trends calculated from previous changes in land use and averages of annual land-use change areas. These were supplemented with each scenario’s updated assumptions. Historical data is the same as that used in the MALULU project (Aakkula et al. 2019). Furthermore, emission calculations made use of surface area data from Finland’s most recent GHG inventory (Tilastokeskus 2019). The total of Finland’s land area and inland waters was assumed to remain constant at 33.8 million hectares through to 2050. This standardised total area is also used in the GHG inventory, although it is known that there is some change from marine water to land. The use of the standardised area does not have any significant bearing on the scenarios.

In addition to the historical data and calculated trends, developments in settlements under different scenarios were guided by the TIMES-VTT model’s quantitative estimates on trends in solar and wind power under different scenarios and, for transport routes, the railway projects already decided. The area required for a single wind farm was estimated at 2 hectares with the average farm size of 2–5 MW (Niemi 2019, Mikkonen 2019). The area required for a single one-TWh solar power plant built onshore was estimated at 1,000 ha, which was used to convert output figures into hectares (Lehtilä 2019).

Energy peat production was estimated to develop in different alternative scenarios in keeping with the peat energy output (PJ/yr) produced by the TIMES-VTT model. The production area corresponding to energy output was derived by scaling known surface areas and energy use. Environmental peat production was assumed to remain at current levels.

The LULUCF Continuous Growth and Savings scenarios cover assumptions on the growth in the area used for bioenergy crops, on the one hand, and the sharp decline in cropland area. As a result, more croplands will be converted into forest land or grassland than under the WEM scenario.

Using the MELA software to model the development of forest resources

The harvesting projections of the different scenarios that correspond to the use of domestic commercial timber, forest chips and fuel wood and the development of forest resources contingent on these (growing stock volume, biomass, growth) and drain (harvesting and natural drain) were calculated using the MELA2016 software developed by the Finnish Environment Centre (Hirvelä et al. 2017). The results of MELA calculations were used to assess change in the carbon stocks of moorland soil and forested peatlands. Under the WEM scenario, regional roundwood removal targets corresponding to the use of commercial timber and energy wood were determined in keeping with the LULUCF sector’s WEM scenario developed for a report on the development of emissions and sinks in the agricultural and LULUCF sectors until 2050 (Aakkula et al. 2019). The forest industry production volumes calculated under the Continuous Growth and Savings scenarios using the TIMES-VTT model were converted into forest industry wood consumption volumes by means of coefficients. Consumption volumes were estimated taking account of commercial timber imports. These consumption volumes of domestic commercial timber and energy wood under the Continuous Growth and Savings scenarios were further converted into regional roundwood removals, which were used to calculate the MELA cutting removal projections.

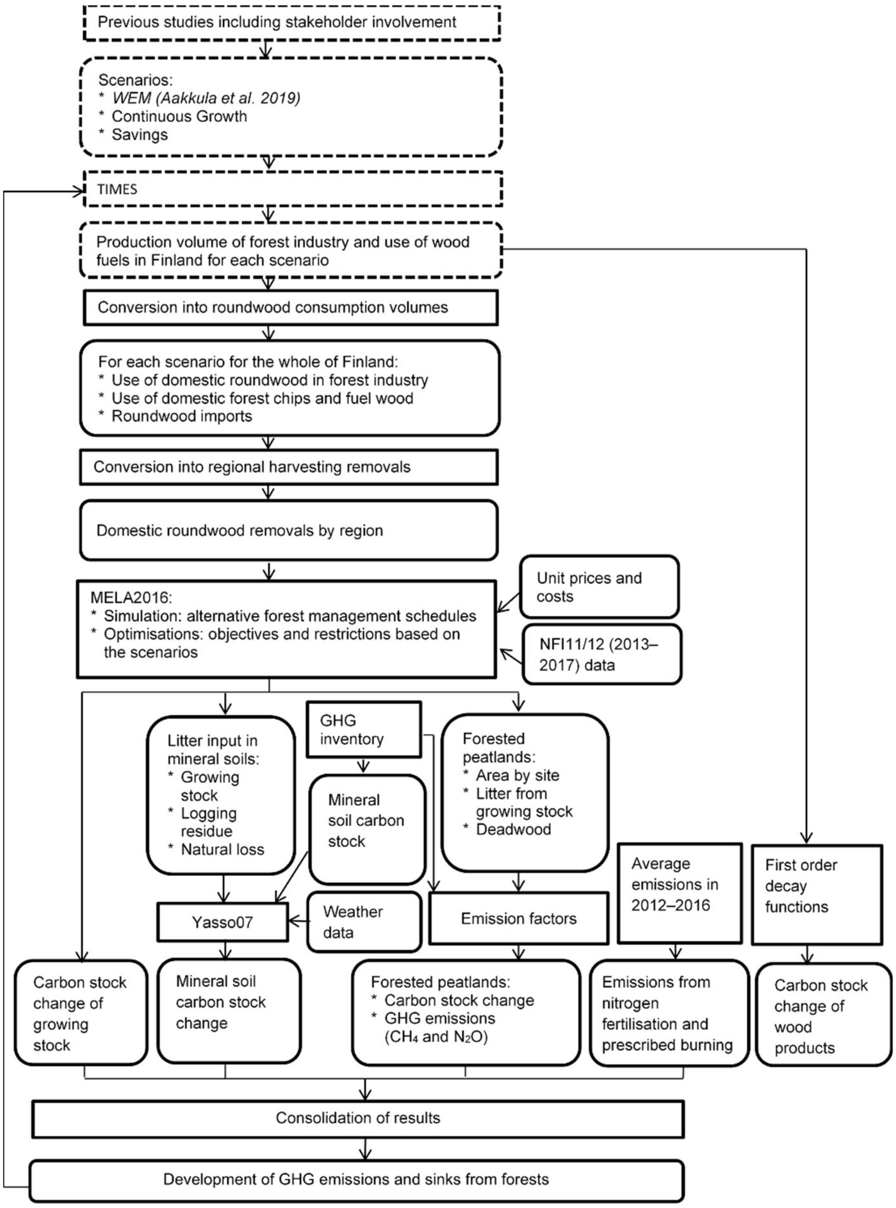

Figure 2. Calculation steps to forecast trends in forest GHG emissions and removals.

The baseline data on forest resources used in the projections consisted of topographic data from the 11th and 12th National Forest Inventories (NFI) covering the 2013–2017 inventory period, with the exception of NFI11 data for Upper Lapland covering a period from 2012 to 2013 (VMI 2013 & 2017). The data consisted of a total of 58,074 management units based on sample plots of forest and scrubland. The management units were divided into three management categories: mainly timber production, limited timber production, and excluded from timber production. The management category sets the parameters for stand-specific forest harvesting and management measures permitted at each specific site. The results on forest resources cover the total of all three categories, although no measures were focused on non-production areas.

The MELA stand simulator automatically produced a number of alternative trajectories for each management unit, comprising natural processes (reproduction, growth and death of trees), forest harvesting and forest management work. Under all of the scenarios, forest management complied with the Best Practices for Sustainable Forest Management by Tapio Ltd (Äijälä et al. 2014, Koistinen et al. 2016).

The harvesting projections were determined in regional optimisation calculations, which used maximum financial performance of timber production at a 4% required rate of return as the target variable and the roundwood removal targets specified in each scenario for different types of timber as constraints. The financial performance of commercial timber production was calculated on the basis of roadside prices, while the figure applied to energy wood was the price paid for chips at the point of use. Roadside prices were derived by adding up statistical stumpage prices and average actual harvesting costs. Point-of-use prices for forest chips followed statistical average prices. Cost calculations were based on statistical unit prices for different types of work and on time consumption levels according to productivity models, allowing for factors such as the effect of harvesting conditions (sturdiness of trees to be removed, drain per hectare, the number of residual trees and soil).

The tree basal-area growth model used in the MELA software was calibrated on the basis of diameter growth measurements in NFI11 data, which had first been indexed to the average 1984–2013 growth level. Furthermore, the volume growth estimate produced by the MELA software was specified in the scenarios by taking account of the effects on the growing stock increment of increases in average temperature and air CO_2 concentration from the mid-year of the calibration period, 1999, to 2017. The volume growth estimate made use of the same method as the report on development of emissions and sinks in the agricultural and LULUCF sectors until 2050 (Aakkula et al. 2019).

This report's WEM scenario assumptions on developments in forestry and its operating environment were the same as those used in the LULUCF-WEM scenario developed by Aakkula et al. (2019). However, the MALUSEPO calculations presented here differed from the MALULU calculations described by Aakkula et al. (2019) in terms such as calculation data and the timeliness of price and cost data, simulated stand-level management operations and residue calculations.

Calculating emissions and removals in the LULUCF sector

The aim was to calculate GHG emissions and removals for the scenarios as consistently as possible with the classifications and methods used in Finland's Greenhouse Gas Inventory (GHG inventory) by Statistics Finland (Tilastokeskus 2019). The inventory classifications and methods are based on the UN Climate Change Convention's reporting guidelines and those drawn up by the Intergovernmental Panel on Climate Change (IPCC). The LULUCF sector calculations comply with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The scenarios' emissions and removals are made up of the living biomass of carbon stocks, deadwood, forest litter and soil changes (CO_2), as well as methane (CH_4) and nitrous oxide (N_2O) emissions. The scenarios neither assume nor take account of changes in climate. In calculations requiring weather data (such as Yasso modelling), the annual weather from 2017 to 2050 is the average of 1980–2017. The carbon content used for matter, such as biomass, is 50%. Carbon was converted into carbon dioxide (CO_2) using the factor of (-44/12). Gases were converted into carbon dioxide equivalents with the global warming potential (GWP) factors of the IPCC Fourth Assessment Report used in the GHG inventory, which are 1 for CO_2, 25 for CH_4, and 298 for N_2O. The land use classification used in the scenarios corresponds to the classification of Finland's Greenhouse Gas Inventory (Tilastokeskus 2019), which is described in the report on development of emissions and sinks in the agricultural and LULUCF sectors until 2050 (Aakkula et al. 2019).

The LULUCF sector comprises six land use categories – forest land, cropland, grassland, wetlands, settlements and other land – as well as harvested wood products. In the scenario calculations, each land use category was further divided into two components such that the emissions/removals for each specific year include: 1) emissions from land-use changes made in the year in question and the emissions and removals of land-use change areas converted over the preceding 19 years; and 2) emissions/removals from areas with no land-use changes within the last 20 years.

Under the scenarios, the land-use and land-use change areas continue a reported time series, which means that the emissions and removals of land-use change areas included in point (1) above may contain emissions/removals from areas converted in 2017 up until 2036. This applies to the WEM scenario, in particular.

Changes in the carbon stocks of growing stock on forest land (that has been forest land for over 20 years) were calculated as the difference between growing stock biomass stocks over 10-yearly periods produced by the MELA modelling process. Soil calculation inputs of forest litter generated by green trees, natural drain and harvesting residue are also MELA results. For afforested lands (that have been forest land for no more than 20 years), change in growing stock carbon stocks was calculated in keeping with the GHG inventory, using estimates for the average growing stock increment and drain of afforested lands based on data from the National Forest Inventory (Tilastokeskus 2019). Changes in mineral soil carbon stocks were estimated using the Yasso07 soil model, while the CO_2, CH_4, N_2O emissions from drained peatlands were calculated with the emission factors of the Greenhouse Gas Inventory (Tilastokeskus 2019). N_2O emissions from nitrogen fertilisation and CH_4 and N_2O emissions from prescribed burning were calculated as an average of actual emissions from 2012 to 2016, as reported, while N_2O emissions from nitrogen mineralisation were also calculated for afforested lands (Tilastokeskus 2019). Area data for various types of forested peatlands was derived as a result of MELA calculations.

Changes in the carbon stocks of cropland mineral soils were estimated using the Yasso07 soil model. Conversely, no changes in mineral soil carbon stocks were assumed for grasslands. The GHG inventory emission factors were used for both cropland and grassland peatlands. Plant biomasses and litter inputs for each plant species were calculated in accordance with the GHG inventory, as were changes in biomass and deadwood carbon stocks and N_2O emissions from nitrogen mineralisation and leaching (Tilastokeskus 2019).

Wetlands are divided into divergent subcategories: peat production areas, sparsely wooded mires reverted from forest land and waters with forest structures. Their emissions were calculated using the methods and factors of the GHG inventory (Tilastokeskus 2019).

The results for settlements only include emissions and removals from land-use change areas. Twenty years after conversion, change areas are moved to the category of areas that have been settlements for at least 20 years, where no carbon stock changes were assumed, in keeping with the GHG inventory (Tilastokeskus 2019).

The impact of harvested wood products was calculated using a production-based approach, where the method was a first order decay function using product half-lives and specific conversion factors for each product group. The main groups of harvested wood products are sawn timber, wood panels, paper and board. The half-lives used were 35 years for sawn timber, 25 years for wood panels and 2 years for paper and board. Each scenario's input assumptions on forest industry production trends were harmonised with different model calculations and wood demand was based on TIMES-VTT modelling results. The low-emission scenarios assumed the forest industry value added to increase, while also including new products. With regard to the mechanical forest industry, these new products were treated as durable products, such that one half of the output was calculated using the half-life and factors for sawn timber while those for wood panels were used for the other half. The applied method is based on the 2006 IPCC Guidelines and it is described in Finland's inventory report (IPCC 2006, Tilastokeskus 2019, Hamberg et al. 2016).

The national economy equilibrium model and source data

The long-term energy and climate policy scenarios were assessed by means of a calculation model depicting Finland's national economy. Under all of the scenarios, the economic description is based on estimated trends in key drivers of the global market and domestic economy.

Assessment of impacts was based on a dynamic general equilibrium model known as FINAGE (formerly VATTAGE). This approach has already been used for a long time to estimate long-term economic development. The model describes economic development in terms of economic activities resulting from decisions made by economic players, including households, enterprises and the public sector. The FINAGE model's scenarios and their interconnections extend both backwards and forwards in years. Historical scenarios make use of actual economic data from statistics and other such sources to identify economic trends and calibrate the calculation model so as to ensure its consistency with history. Future scenarios, in turn, are partially based on historical trends – including assumptions on developments in the parameters of productivity growth and global market changes, as well as certain predictable policy measures. Economic theory creates the frame of reference used in the model to interpret history, whereas historical economic trends and factors such as projected population growth form the framework within which economic players make their decisions. In general terms, such analysis also involves a macroeconomic projection used to match the near-term estimate of the development of the national balance of supply and demand with the estimate used by ministries to plan policies, for example. In terms of domestic economic policy, the scenarios also take account of measures with impacts extending into the next few decades. One of the most important of these is the pension reform, which will mitigate the otherwise looming labour shortage, especially in the 2020s. In addition, the assessment anticipates the impacts of the currently ongoing health and social services reform on labour demand and public finances.

The scenarios produced using the FINAGE model assume that the drivers of economic development will evolve on a 'business-as-usual' basis, whereas the impact of various economic policy objectives or changes in the parameters of the global economy or technologies are assessed in alternative scenarios. This allows the impacts of the phenomena being considered to be isolated from the drivers of economic growth. The scenarios used in this study draw in many respects on a study by Honkatukia, Kohl & Lehtomaa (2018), which gauged the drivers of Finland's long-term economic growth.

Integrated model analyses

The quantitative analyses presented in this report were carried out in an integrated manner, which means that the aim was to harmonise input assumptions used in calculations as far as possible, while some of the results of one model analysis were used as baseline data for another. This resulted in quite a bulky modelling system, which was used to perform the quantitative analyses of carbon neutrality trajectories; moreover, the approach was iterative. A rough overview of the modelling system as a whole is provided below.

The agricultural DREMFIA modelling process produces baseline data for calculating GHG emissions from agriculture as well as for TIMES-VTT modelling related to agricultural production volumes (cereals, livestock farming, biogas potential from agricultural side streams, required arable area). The TIMES-VTT modelling process, in turn, produces baseline data relevant to demand for industrial and energy wood, which is used as baseline data for MELA modelling to estimate domestic forest harvesting trends. The TIMES-VTT model also produces baseline data for FINAGE modelling of the national economy relating to the demand for and prices of energy commodities and needs to invest in the energy system, etc. The marginal cost calculated by the TIMES-VTT model for GHG emission reductions is also included in the essential baseline data for FINAGE modelling. Both MELA and TIMES-VTT calculations provide baseline data for LULUCF calculations. MELA produces harvesting levels and a forest development estimate. TIMES-VTT results are used to estimate land-use developments from the perspective of the energy sector (peat production, wind power, etc.). The net balance between land-use GHG emission and removal trends produced by LULUCF calculations, in turn, functions as baseline data for TIMES-VTT modelling when determining the 2035 GHG emission target and the cost-optimal pathway towards this target.

The schedule and resources assigned to the projects did not allow an in-depth iterative analysis, which would have involved running all of the modelling processes several times. Nevertheless, the TIMES-VTT model calculations were performed twice and it was only during the second round that it was possible to specify the GHG emission target that would allow Finland to achieve carbon neutrality by 2035. Furthermore, the FINAGE results were presented using the results of both TIMES-VTT calculation rounds as baseline data for economic calculations, such that one of the cases would not achieve the carbon neutrality target while the other one would ('net-zero calculation case'). Conversely, LULUCF calculations were not updated with the 'final' TIMES-VTT baseline data and results, but their effects on the LULUCF sector's GHG balance will in all likelihood be insignificant.

References

Aakkula, J., Asikainen, A., Kohl, J., Lehtonen, A, Lehtonen, A., Ollila, P., Regina, K., Salminen, O., Sievänen, R. & Tuomainen T. 2019. Maatalous- ja LULUCF-sektorien päästö- ja nielukehitys vuoteen 2050 [*Development of emissions and sinks in the agricultural and LULUCF sectors until 2050*]. Valtioneuvoston selvitys- ja tutkimustoiminnan julkaisusarja [*Publications of the Government's analysis, assessment and research activities*] 20/2019. 70 p. Available in Finnish (English abstract) at: http://urn.fi/URN:ISBN:978-952-287-650-8.

Haakana, M., Ollila, P., Regina, K., Riihimäki, H. & Tuomainen, T. 2015. Menetelmä maankäytön kehityksen ennustamiseen: Pinta-alojen kehitys ja kasvihuonekaasupäästöt vuoteen 2040 [*Methodology for forecasting land use developments: Developments in surface areas and greenhouse gas emissions by 2040*]. Luonnonvara- ja biotalouden tutkimus [*Natural Resources and Bioeconomy Studies*] 51/2015.

Hamberg, L., Henttonen, H. & Tuomainen, T. 2016. Puusta valmistettujen tuotteiden hiilivaraston muutoksen laskenta kasvihuonekaasuinventaariossa – Menetelmäkehitys Suomen kasvihuonekaasuinventaarioon [*Calculating change in the carbon stock of harvested wood products in the greenhouse gas inventory – Methods development for Finland's Greenhouse Gas Inventory*]. Luonnonvara- ja biotalouden tutkimus [*Natural Resources and Bioeconomy Studies*] 73/2016. Available in Finnish at: https://jukuri.luke.fi/bitstream/handle/10024/537716/luke-luobio_73_2016.pdf?sequence=1&isAllowed=y.

Hirvelä, H., Härkönen, K., Lempinen, R. & Salminen, O. 2017. MELA2016 Reference Manual. Natural resources and bioeconomy studies 7/2017. 547 p. ISBN 978-952-326-1 (Online).

Honkatukia, J., Kohl, J. ja Lehtomaa, J. 2018. Uutta, vanhaa ja sinivalkoista – Suomi 2040 [*Something old, something new – Finland 2040*]. VTT Technology 327. Available in Finnish (English abstract) at: https://www.vtt.fi/inf/pdf/technology/2018/T327.pdf.

IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds.). Published: IGES, Japan. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Koistinen, A., Luiro, J-P. & Vanhatalo, K. (eds.). 2016. Metsänhoidon suositukset energiapuun korjuuseen, työopas [*Best Practices for Sustainable Forest Management: Energy wood harvesting, work guide book*]. Tapion julkaisuja [*Tapio publications*]. Available in Finnish at: https://tapio.fi/wp-content/uploads/2015/06/MHS-Energiapuun-korjuun-suositukset_verkkojulkaisu2.pdf.

Koljonen, T., Flyktman, M., Lehtilä, A., Pahkala, K., Peltola, E & Savolainen, I. 2009. The role of CCS and renewables in tackling climate change. Energy Procedia 1:4323–4330.

Koljonen, T. & Lehtilä, A. 2015. Modelling Pathways to a Low Carbon Economy for Finland. In: Giannakidis G et al. (eds.). Informing Energy and Climate Policies Using Energy Systems Models, Lecture Notes in Energy, vol. 30. Springer, Cham.

Kärkkäinen, L., Haakana, M., Heikkinen, J., Helin, J., Hirvelä, H., Jauhiainen, L., Laturi, J., Lehtonen, H., Lintunen, J., Niskanen, O., Ollila, P., Peltonen-Sainio, P., Regina, K., Salminen, O., Tuomainen, T., Uusivuori, J., Wall, A. & Packalen, T. 2019. Maankäyttösektorin toimien mahdollisuudet ilmastotavoitteiden saavuttamiseksi [*Potential of land use measures in climate change mitigation*]. Valtioneuvoston kanslia [*Prime Minister's Office*]. Valtioneuvoston selvitys- ja tutkimustoiminnan julkaisusarja [*Publications of the Government's analysis, assessment and research activities*] 67/2018. 75 p. Available in Finnish (English abstract) at: http://urn.fi/URN:ISBN:978-952-287-618-8.

Lehtilä, A. 2019. Asiantuntija-arvio [*Expert assessment*]. VTT [*VTT Technical Research Centre of Finland*]. Email on 28 October 2019.

Lehtilä, Antti & Koljonen, Tiina. 2018. Pathways to Post-fossil Economy in a Well Below 2 °C World. In: Lect. Notes Energy, Vol. 64, George Giannakidis et al. (eds.). Limiting Global Warming to Well Below 2 °C: Energy System Modelling and Policy Development.

Lehtonen, H. 2015. Evaluating adaptation and the production development of Finnish agriculture in climate and global change. Agricultural and Food Science 24: 219–234.

Lehtonen, H. & Rankinen, K. 2015. Impacts of agri-environmental policy on land use and nitrogen leaching in Finland. Environmental Science and Policy 50: 130–144. doi:10.1016/j.envsci.2015.02.001.

Lehtonen, H. & Niskanen, O. 2016. Promoting clover-grass: Implications for agricultural land use in Finland. Land Use Policy 59: 310–319.

Lehtonen, H., & Niemi, J. 2018. Effects of reducing EU agricultural support payments on production and farm income in Finland. Agricultural and Food Science, 27(2), 124–137.

Loulou R. 2008. ETSAP-TIAM: the TIMES integrated assessment model. Part II: Mathematical formulation. Computational Management Science, 5(1–2):41–66.

Loulou R., Labriet M. 2008. ETSAP-TIAM: the TIMES integrated assessment model. Part I: Model structure. Computational Management Science 5(1–2): 7–40.

Loulou R., Remme U., Kanudia A., Lehtilä A., Goldstein G. 2016. Documentation for the TIMES Model. Energy Technology Systems Analysis Programme (ETSAP). Available at: https://iea-etsap.org/docs/Documentation_for_the_TIMES_Model-Part-I_July-2016.pdf.

Mattinen, M. Heljo, J. & Savolahti, M. 2016. Rakennusten energiankulutuksen perusskenaario Suomessa 2015–2050 [*Baseline scenario for energy consumption of the building stock in Finland 2015–2050*]. Suomen ympäristökeskuksen raportteja [*Reports of the Finnish Environment Institute*] 35/2016.

Mikkonen, A. 2019. Suomen tuulivoimayhdistys [*Finnish Wind Power Association*]. Email on 30 October 2019.

Niemi, P. 2019. Asiantuntija-arvio, tuulivoima-asiantuntija [*Expert assessment, wind power expert*]. Metsähallitus [*Finnish Agency for Forests*]. Email on 10 January 2019.

Tilastokeskus [*Statistics Finland*]. 2015. Väestöennuste 2015–2065 [*Population projection 2015–2065*]. Suomen virallinen tilasto (SVT) [*Official Statistics of Finland (OSF)*]. 10 p. Available in English at: https://tilastokeskus.fi/til/vaenn/2015/vaenn_2015_2015-10-30_en.pdf.

Tilastokeskus [*Statistics Finland*]. 2018. Energian hankinta ja kulutus [*Energy supply and consumption*]. Available in English at: https://www.stat.fi/til/ehk/index_en.html.

Tilastokeskus [*Statistics Finland*]. 2019. Greenhouse gas emissions in Finland 1990 to 2017. National inventory report under the UNFCCC and the Kyoto Protocol. 15 April 2019. Available at: http://www.stat.fi/static/media/uploads/tup/khkinv/fi_eu_nir_2017_2019-03-15.pdf.

Tuominen, P., Klobut, K., Tolman, A., Adjei, A., De Best-Waldhober, M. 2012. Energy savings potential in buildings and overcoming market barriers in member states of the European Union. Energy and Buildings 51, pp. 48–55.

Tuominen, P., Forsström, J., Honkatukia, J. 2013. Economic effects of energy efficiency improvements in the Finnish building stock. Energy Policy 52, pp. 181–189.

Tuominen, P., Holopainen, R., Eskola, L., Jokisalo, J., Airaksinen, M. 2014. Calculation method and tool for assessing energy consumption in the building stock. Building and Environment 75, pp. 153–160.

VMI [*NFI*]. Valtakunnan metsien 11. inventointi (VMI11) [*11th National Forest Inventory (NFI11)*]. 2013. Maastotyön ohjeet [*Field instructions*] 2013. Koko Suomi ml. Ahvenanmaa [*All of Finland incl. Åland Islands*]. Metsäntutkimuslaitos [*Finnish Forest Research Institute*]. Moniste [*Handout*]. 191 p.

VMI [*NFI*]. Valtakunnan metsien 12. inventointi (VMI12) [*12th National Forest Inventory (NFI12)*]. 2017. Maastotyön ohjeet [*Field instructions*] 2017. Luonnonvarakeskus [*Natural Resources Institute Finland*]. Moniste [*Handout*]. 164 p.

Äijälä, O., Koistinen, A., Sved, J., Vanhatalo, K., & Väisänen, P. (eds.) 2014. Metsänhoidon suositukset [*Best Practices for Sustainable Forest Management*]. Metsätalouden kehittämiskeskus Tapion julkaisuja [*Publications of Forestry Development Centre Tapio*]. Available in Finnish at: http://tapio.fi/wp-content/uploads/2015/06/Metsanhoidon_suositukset_ver3_netti_1709141.pdf.