low carbon finland 2050

VTT clean energy technology strategies for society

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Low Carbon Finland 2050

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Foreword

The main drivers of the global energy system are the growth in energy demand due to increasing population and economic output and, on the other hand, challenges linked to energy security and the mitigation of environmental impacts, especially climate change. Globally, the annual growth in primary energy use was on average above 2% at the beginning of the 21st century. The energy sector is presently the largest source of greenhouse gas emissions on a global scale. The stabilisation of the atmospheric greenhouse gas concentrations at a safe level requires very deep emission reductions in the long term. In addition, global CO_2 emissions should peak before 2020, i.e. start declining within the next few years at the latest. Revolutionary changes are needed in the energy sector in order to cope with future challenges. In 2009 the foresight report by the Finnish Government reviewed and outlined climate and energy policy in the long-term aimed at reducing Finland's GHG emissions by 80% by 2050 compared to the 1990 level.

In 2009 VTT Technical Research Centre of Finland published a global study, "Energy Visions 2050". In this new study the focus is on the national energy economy in Finland assuming deep greenhouse gas reductions by 2050. The main emphasis in the "Low Carbon Finland 2050" work done and financed by VTT is on measures enabled by new technology and service solutions, but changes in the structure of consumption are also dealt with as regards industries and communities. More efficient technologies with regards to energy conversion and end-use should be intensively developed, and carbon-neutral and low-carbon energy sources (renewable energy sources and nuclear energy) as well as carbon capture and storage (CCS) technologies need to be favoured to enable a cost-efficient transition to a low carbon society. Transition management with scenario assessment and system understanding is crucial for analysing the market potentials of new technologies for high efficiency energy generation and energy use in buildings, transport, and industries. VTT's analysis methodologies, including modelling of future energy systems and markets, are developed and reviewed with the activities of the international scientific community and top organizations such as the Intergovernmental Panel on Climate Change (IPCC), the International Institute for Applied Systems Analysis (IIASA), the International Energy Agency (IEA) and EU frame work programmes. The application assessment tools include processing of information for regional, national, market segments and technology which lead to a better understanding of future markets and business effects. The analyses and scenarios combine both energy resources, energy generation and all end-use sectors including the overall infrastructure. Various policy instruments, such as emissions trading and taxation, are also considered in the assessments. Carbon and material foot prints increasingly control the behaviour of consumers and leading companies.

The European Commission has recently indicated in "A Roadmap for moving to a competitive low carbon economy in 2050" that massive investments of around €270 billion annually are needed for the next 40 years. This represents an additional investment of 1.5% of the EU GDP per annum but, on the other hand, this would also reduce the EU's average fuel costs by €175–320 billion per year. In 2050 the EU's total primary energy consumption could be about 30% below 2005 levels. Without actions oil and gas imports to the EU could double compared today. The EU SET-Plan (Strategic Energy Technology Plan) will activate energy technology development in public-private partnerships and market introductions of new technology supported by industrial initiatives and EERA (European Energy Research Alliance) collaboration.

VTT offers support for policy makers, industrial actors and research community by energy system modelling and scenario work in order to find cost efficient measures and implementation plans to fulfil the new energy and climate targets. VTT's leading edge "Low Carbon and Smart Energy" enables new solutions with a demonstration that is the first of its kind in Finland, and the introduction of e new energy technology onto national and global markets. VTT's multidisciplinary expertise and networking in the energy value chains are crucial to the success stories.

The analysis shown in this publication has been carried out as a broadly based collaborative effort at VTT. In addition to VTT, Research Director Juha Honkatukia from the Government Institute for Economic Research (VATT) has contributed to the project to give a wider perspective on low carbon economies in Finland. The views expressed do not reflect the views of Finnish policy making or individual stakeholders. We would like to express our warm thanks to all researchers, graphic designers, and editors who have contributed to the project. Hopefully the publication will stimulate enlightening and multidisciplinary discussions on low carbon futures of Finland.

November 2012

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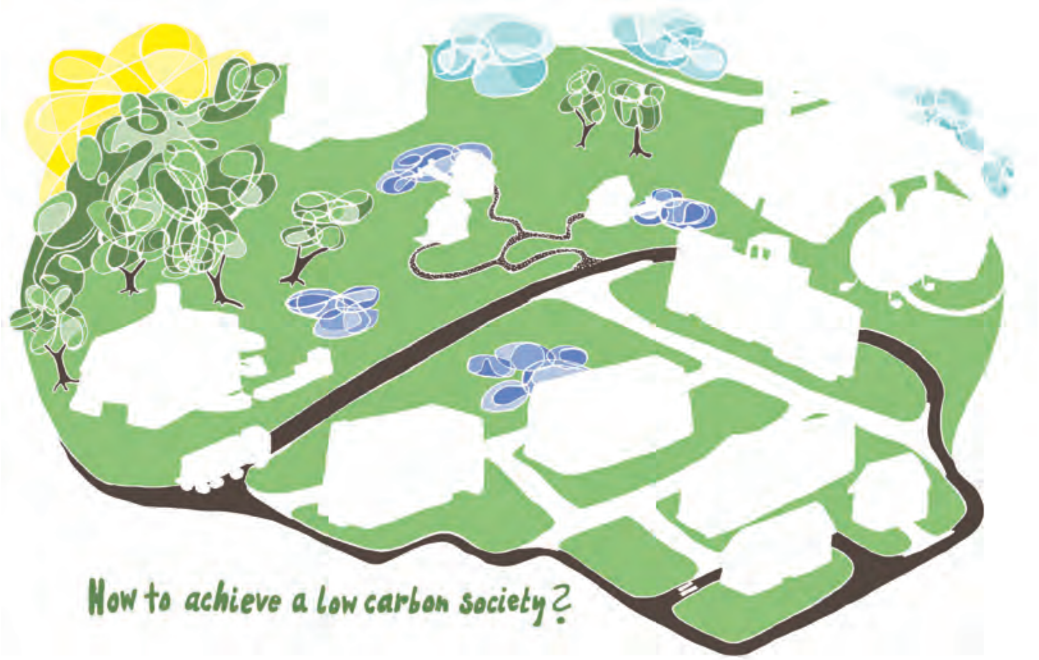

Contents

List of symbols

BECCS	Bioenergy with Carbon Capture and Storage
billion	1000 million, 10^9
BTL	Biomass-to-liquid
CCS	Carbon capture and storage
CHP	Combined heat and power, Co-generation of heat and power
CO_2	Carbon dioxide
CO_2 eq.	Carbon dioxide equivalent
DH	District heating
EU	European Union
FB	Fluidised bed
FBC	Fluidised-bed combustion
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoule, 10^9 joules
IEA	International Energy Agency of the OECD
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hour
LULUCF	Land Use, Land-Use Change and Foresty
MES	Microbial electrosynthesis
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
NO_x	Nitrogen oxides
NPP	Nuclear power plant
OECD	Organisation for Economic Co-operation and Development
PCC	Precipitated calcium carbonate
PFBC	Pressurised fluidised-bed combustion
PJ	Petajoule, 10^{15} joules
PV	Photovoltaic
R&D	Research and Development
RD&D	Research, Development and Demonstration
RES	Renewable energy sources
SNG	Synthetic natural gas
SOFC	Solid oxide fuel cell
TIMES	The Integrated MARKAL-EFOM System
TWh	Terawatt hour, 10^{12} watt hours
UNFCCC	United Nations' Framework Convention on Climate Change
VATT	Government Institute for Economic Research
VTT	VTT Technical Research Centre of Finland

1 Introduction

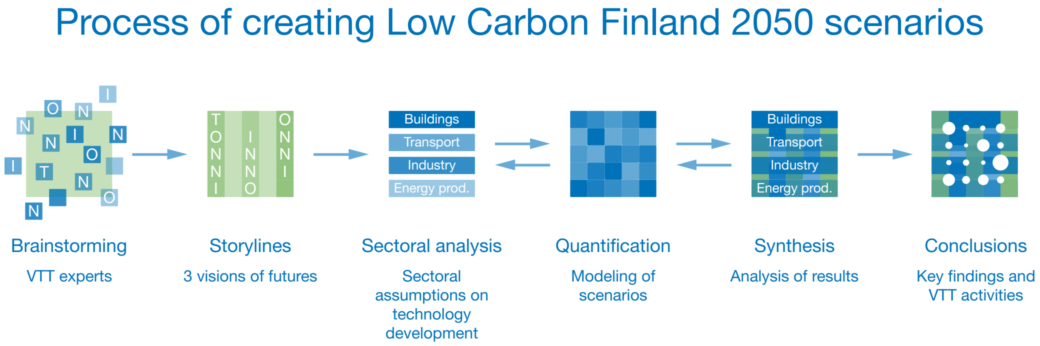

FIGURE 1. A chart describing a process of creating quantitative scenarios for Low Carbon Finland 2050 in this project. About fifty VTT researchers have been involved in the project and have contributed in formulating alternative pathways to low carbon energy systems. The techno-economic viewpoint is emphasized in the process and in the results.

In October 2009, the Government of Finland adopted the Foresight Report on Long-term Climate and Energy Policy. Setting a target to reduce Finland's greenhouse gas emissions by at least 80% from the 1990 level by 2050 as part of an international effort, the report marks out the road to a low-carbon Finland in 2050. The Foresight report stimulated intensive development work on a new generation of VTT's energy system toolbox to better model and analyse the systemic change needed throughout the energy chain. In 2010, VTT started a strategic project "Low Carbon Finland 2050", which gathered together VTT's technology experts in clean energy production, smart energy infrastructures, transport, buildings, and industrial systems as well as experts in energy system modelling and foresight. The project has been successful in supporting VTT's own long-term strategy making and in increasing the cross sectoral understanding of low carbon energy systems and the role of clean and smart energy technologies in low carbon futures. Figure 1 describes the process of creating storylines and analysing the transition to low carbon societies. The main emphasis of the project was to analyse how the clean technology progress enables the low carbon transition cost-effectively.

In March 2011, during VTT's low carbon project, the European Commission published a roadmap for moving to a low-carbon economy in 2050[1]. In December 2011, the European Commission adopted the Communication "Energy Roadmap 2050"[2], which is the basis for developing a long-term European framework together with all stakeholders. In this study we also assume that the EU's targets to reduce its own greenhouse gas emissions from the 1990

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[1] See e.g. http://ec.europa.eu/clima/policies/roadmap/index_en.htm

[2] See e.g. http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm

Fact box: Finnish energy sector today in European context

- Primary energy consumption of Finland was 284 GJ (6.79 toe) per capita in 2010. The World average is 78 GJ (1.86 toe) per capita, whereas the average in industrialised OECD countries is 184 GJ (4.39 toe), and in Sweden, the figure is 229 GJ (5.47 toe) per capita[3].
- The share of imported fossil fuels of primary energy consumption was 47% in 2010.
- Final energy consumption in Finland in 2010 was 1151 PJ or 27.5 Mtoe. By sectors, 45% was used in industry, 17% in transport, 26% for space heating and 13% in others.
- Total greenhouse gas emissions in 2010 amounted to 74.6 million tonnes of carbon dioxide equivalent (t CO_2 eq.) (without LULUCF sector). The energy sector is the largest source of greenhouse gases emissions in Finland with a share of 81%.
- The energy sector's emissions include emissions from energy industries (41.0% of the total in 2010), transport (18.2%), manufacturing industries and construction (13.3%), and other uses of energy (8.9% including heating of buildings, other fuel use in agriculture, forestry and fisheries, other fuel use and fugitive emissions from fuels). The emissions from the energy sector consist almost entirely of CO_2. Excluding the energy sector, other important GHG emitting sectors include industrial processes, agriculture and waste management[4].
- The share of bioenergy-based electricity (13% in 2010) is the highest in the world.
- The EU has introduced so called 20–20–20 goals for the year 2020, that have a great effect on the development of the Finnish energy sector. The EU's and Finland's targets for 2020 can be seen below.

Targets for the EU

- GHG reduction 20% by 2020 (a), (b)
- Energy end use reduction 20%
- Share of renewable energy 7% → 20% (a), (b)
- Renewable energy in transport 10% (b)

Targets for Finland

- GHG reduction 16% in the non-ETS sector by 2020 (a), (b)
- Share of renewables 28.5% → 38% (a), (b)
- Renewable energy in transport 20%

(a) reference year 2005, (b) binding target

- Additionally, sectoral targets for energy efficiency or emission reduction are set for energy production, industry, transportation and buildings.

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[3] IEA Figures for 2010

[4] Statistics Finland

level by at least 80% by 2050 have been realised and that globally it has been agreed to tackle climate change to 2 degrees.

The transition to a low carbon future is a great challenge, which requires paradigm change by way of developing and implementing clean energy technologies and systems as well as restructuring the way we live, move and work. Also, changes to the whole society would be needed, such as changes in industrial structures and human behaviour. This publication is a summary of VTT's findings on the role of new technologies in moving Finland sustainably towards a low carbon economy. The analysis has been contributed by creating three different low carbon storylines, "Tonni" and "Inno" and "Onni" for Finland[5]. Based on narrative storylines, the analysis includes systematic modelling and assessments of the whole energy chain, including fuel and energy production, energy infrastructures and end use in buildings, transportation, and industries. The Government Institute for Economic Research (VATT) has also contributed to the project by analysing the changes in Finland's economic structure and welfare by 2050 in the "Tonni" and "Inno" low-carbon futures. Quantitative low-carbon scenarios of the future are compared to the business-as-usual scenario.

The "Inno" scenario focuses on the most radical technological breakthroughs by 2050. On the other hand, the "Onni" scenario includes more non-technical behavioural and consumption-related factors in the analysis, such as environmental awareness, regional development and its implications. In-depth multidisciplinary research, however, is increasingly needed in order to integrate the techno-economic and socio-economic scenarios.

The drivers of Finland's energy system reflect global megatrends. Different storylines, in which different developments for the drivers and associated reflections for Finland are assumed, are described in Chapter 2. The main assumptions behind sectoral developments and discussion of associated technological changes are described in Chapter 3. The fact boxes throughout the text describe Finland's peculiarities from global and EU perspectives. Additionally, several "wild cards" are shown to present technologies that are at very early stage of development but whose impact might be significant. Due to lack of any cost or technology data, these wild cards are not included in the scenario assessments. A more detailed description of the data and assumptions can be found from the project's www-pages (www.vtt.fi/lowcfin). Chapter 4 describes the pathways to a low carbon society in Finland by 2050 and their implications on Finland's energy systems and economical structures. The contents of Chapter 4 – i.e. the quantitative scenarios – are based on the results of techno-economic and economic model analysis at VTT and VATT. Chapter 5 summarises the major findings of the whole work and gives a shortlist of VTT's activities, which could stimulate Finland's green growth and foster low carbon development.

It is clear that moving Finland to a low carbon society would be driven by the Grand Challenges declared by the EU, such as climate change mitigation and limited natural resources, and requires not only political consensus but also the commitment of all the stakeholders. On the other hand, multidisciplinary research as well as intensive technology development and deployment would be required to accelerate low carbon transition sustainably. Therefore, this publication shows the first steps in VTT's efforts to create a better understanding of the RD&D needs including the challenges and opportunities for Finland's green growth, and the work continues in several national and international efforts.

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[5] The names "Tonni", "Inno" and "Onni" are words in the Finnish language intended to describe key characteristics of the scenarios. "Tonni" means tonne (ton); "Inno" is derived from a word meaning "Innovation", whereas "Onni" means happiness.

2 Drivers towards low carbon societies

2.1 KEY MEGATRENDS

The driving force or driver is considered to be a major external (or internal) phenomenon that influences decision-making and thereby shapes the future development. The energy sector (consisting of energy use, energy production, transmission and distribution) can globally be seen to be driven by the factors illustrated in Figure 2 in the next few decades.

Scenarios presented in this study produce systematic descriptions of plausible, considered Low Carbon society in Finland in the future. By making assumptions on the development of the central energy sector drivers, storylines for scenarios can be built. Table 1 presents a set-up for how the drivers have been assumed to vary between the scenarios in this study. Each of the scenarios Tonni, Inno and Onni aim at 80% GHG reduction by 2050 compared to 1990 across the EU, including Finland. In the scenarios, the EU level of emissions trading is allowed for all the greenhouse gases and by all the sectors. Additionally, it is assumed that the 2 degree target would be fulfilled globally during this century.

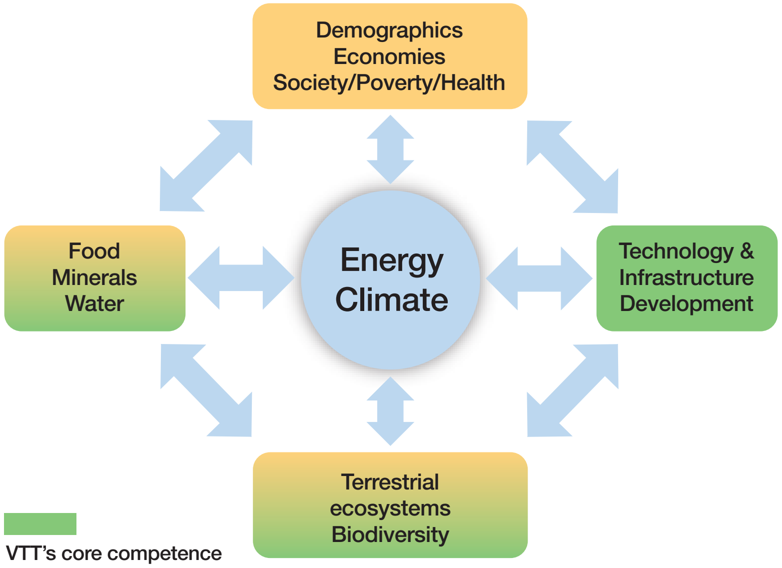

FIGURE 2. Energy and climate change: system issues – not a single issue problem.

TABLE 1. Key drivers of the energy sector and their assumed long-term development between the scenarios. In each scenario, an 80% GHG reduction by 2050 is aimed for.

	Tonni -80%	Inno -80%	Onni -80%
Global and EU development	Linear development	Increasing globalisation, technology-oriented	Increasing global environmental awareness, global information society
Research, development and introduction of technology	Moderate	Very high	Moderate to high
Structure of the economy of Finland	Heavy industries with growing production volumes.	New export products of Finnish industries Digital world	Growing significance of service sector and service exports Small-scale industry

Taking into account assumptions of global drivers presented in Table 1, a more detailed picture can be drawn of the development of the energy end-use sectors – buildings, industry and transportation – and energy production in Finland. The sectoral analysis is presented in Chapter 3. As a result of the analysis, key numerical figures are obtained describing technology and the economy in the scenarios by sectors.

Demographic development globally is a key factor affecting economic growth and structure. For this study, the demographic development of Finland is most significant and it is assumed to be common to all the scenarios (see Figure 3).

The results of scenarios presented in Chapter 4 are based on techno-economic and economic model analysis at VTT and VATT. The TIMES model of VTT is used for the energy system analysis, and the VATTAGE model of VATT for the economic analysis. These models produce development paths for a future in which a 80% GHG reduction is aimed for by 2050. Such a reduction calls for significant changes in energy production and use.

The input data of the models is largely based on expert assessments carried out in sectoral analysis (Chapter 3). As assumptions on technology and global drivers are different, variations in modes and technology of buildings, transportation, industries and energy production are also seen between the scenarios in the results. The scenarios should not be considered to represent forecasts or predictions of reality, but rather as optimal trajectories indicating the most cost-efficient decisions of producers and consumers while satisfying all the demand projections and other constraints.

2.2 THREE LOW CARBON STORYLINES FOR FINLAND

Key characteristics of the Tonni, Inno and Onni storylines are visually presented in the following spreads, providing narrative descriptions of the scenarios. In addition to these, the “Baseline” or “Base” scenario is produced as a reference. It describes the future assuming a continuation of current trends and policies. The baseline scenario includes Finland’s 2020 targets set by the EU and the energy policy measures in use. Three alternative scenarios are presented of an energy 80% GHG emission reduction by 2050, demonstrating alternative pathways to achieve it. These scenarios also take into account the policy measures implemented hitherto.

1. **The “Tonni” scenario** aims at an 80% emission reduction in an environment where

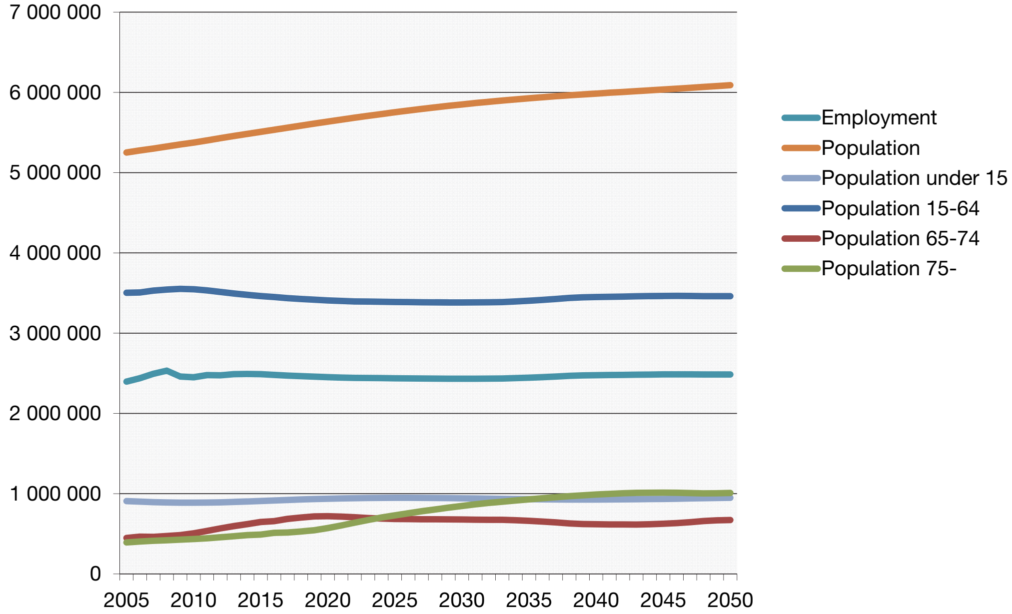

FIGURE 3. Assumption of demographic development in Finland used in all the scenarios[6].

industrial structure and production volumes are assumed in the future to grow largely according to historical trends. Assumptions of technological developments are more conservative than in the "Inno" and "Onni" scenarios, which implies that emission reduction is largely achieved through today's commercial technology and through technologies that are in the demonstration phase. As in industrial structure, no significant changes are assumed in regional and urban form either.

2. **In the "Inno" scenario**, technological development is assumed to be the fastest. New products and production processes are commercialized in many industrial branches, providing a backbone of welfare. The regional and urban form is based on relatively few centres with high population density that provide a promising environment for industrial innovations in ICT and related industry. These regional developments also enable energy-efficient solutions in transportation, such as a wide utilization of public transportation. In energy production technology too, the efficiency, and costs of technologies are assumed to develop most favourably to achieve the targets.
3. **The "Onni" scenario** presents significant changes in industrial structure and in regional and urban form. Industrial production is assumed to move in a less energy-intensive direction. Local, small-scale, especially service enterprises and related innovations are assumed to emerge. The significance of traditional, energy-intensive industrial production decreases. Similarly, in energy technology, the significance of local, distributed technology solutions utilizing renewable energy increases. Regional structure moves in a more decentralized direction. An increase in dwelling area per capita is assumed. This is due to an assumed increase in teleworking and in the total dwelling area of detached houses. As the "Onni" scenario is largely based on the provision of local, renewable solutions and less energy intensive industry, the basis and need for centralized, large scale energy production in this scenario is not as strong as in the other scenarios.

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[6] Statistics Finland

1. THE "TONNI" SCENARIO aims at an 80% emission reduction in an environment where industrial structure and production volumes are assumed in the future to grow largely according to historical trends. Assumptions of technological developments are more conservative than in the "Inno" and "Onni" scenarios, which implies that emission reduction is largely achieved through today's commercial technology and through technologies that are in the demonstration phase. As in industrial structure, no significant changes are assumed in regional and urban form either.


CCS
Service
MALL
Library
SHOP
HOSPITAL
Café
Nursery
-80% GHG emissions
2050
TONNI

2. IN THE "INNO" SCENARIO, technological development is assumed to be the fastest. New products and production processes are commercialized in many industrial branches, providing a backbone of welfare. The regional and urban form is based on relatively few centres with high population density that provide a promising environment for industrial innovations in ICT and related industry. These regional developments also enable energy-efficient solutions in transportation, such as a wide utilization of public transportation. In energy production technology too, the efficiency, and costs of technologies are assumed to develop most favourably to achieve the targets.

-80% GHG emissions

2050

INNO

3. THE "ONNI" SCENARIO presents significant changes in industrial structure and in regional and urban form. Industrial production is assumed to move in a less energy-intensive direction. Local, small-scale, especially service enterprises and related innovations are assumed to emerge. The significance of traditional, energy-intensive industrial production decreases. Similarly, in energy technology, the significance of local, distributed technology solutions utilizing renewable energy increases. Regional structure moves in a more decentralized direction. An increase in dwelling area per capita is assumed. This is due to an assumed increase in teleworking and in the total dwelling area of detached houses. As the "Onni" scenario is largely based on the provision of local, renewable solutions and less energy intensive industry, the basis and need for centralized, large scale energy production in this scenario is not as strong as in the other scenarios.

-80% GHG emissions

2050

ONNI

3 From storylines to alternative assumptions – how we live, move and work?

3.1 THE BUILT ENVIRONMENT BECOMES SMART

3.1.1 The built environment responds to people's needs

The built environment is constructed and shaped to respond to people's social, cultural and economic needs. Inside it, people reside, work, worship, move, consume and enjoy. Its development depends to a large extent on social and economic circumstances. The development of building stock follows rather closely on the needs of the economy, and in relation to that, the needs of their occupants (Table 2). Technologies for producing and operating the built environment are mainly cross-sectoral implementations of the achievements of all sectors of the economy; this technological diffusion depends on socio-economic conditions. In this study, development of the building stock will in the future take different paths, depending on the scenario that society and the economy adopt. One characteristic of future built environment is the increase in embedded sensor and monitoring technologies, which will allow smart technologies to help in people's everyday living.

Fact box: Buildings

In Finland buildings consume 40% of end-use energy[7]. The Finnish building stock is dominated by residential buildings (52%, EU 75%) and the proportion of single-family houses is 27% (EU 65%). Compared to average European levels, both proportions are low.

Due to Finland's northerly location (it is at 60–70 degrees North latitude), heating energy consumption makes up a large proportion of energy use, 22% of final energy use is employed in the heating of buildings. The average energy consumption of new residential buildings is 150 kWh/m^2, and for space heating 70 kWh/m^2; for existing building stock the average is 250 kWh/m^2 and for space heating 160 kWh/m^2. Due to our extreme climate, Finnish buildings are well insulated and all new buildings have heat recovery from ventilation.

VTT's key areas of competence in the energy efficiency of buildings are arctic zero energy concepts, efficient ventilation, heating and building automation technologies, district-level energy networks and solutions for sustainable communities. VTT's strength is in the knowledge chain from sensor technology to measurement, analysis and control technologies.

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[7] Including residential, commercial and industrial buildings

TABLE 2. Key drivers of the assumptions concerning the built environment.

	Tonni	**Inno**	**Onni**
Urban area development	Scattered, urban sprawl increases slightly	Dense urban areas	Urban sprawl increases
Living area m^2 per capita from 2012 → 2050	Slight increase 27.3 → 28.1	Decreasing 27.3 → 24.1	Clear increase 27.3 → 34.0
Average heating kWh/ m^2 in new residential buildings from 2012 → 2050	Decreasing according to given regulations 75 → 43	Clearly decreasing 70 → 40	Clearly decreasing 70 → 40
Living	As today, single-family homes are typical	Increase in apartment and terraced house type living	Single-family homes dominant
Share of non-residential buildings	Decreasing slightly 44% → 42%	Clearly decreasing 44% → 37%	Clearly decreasing 44% → 35%
Building stock	Renewal rate of building stock is the same as in Baseline	Renewal rate of building stock is moderate	High renewal rate, old buildings are replaced by new energy-efficient buildings

For several decades, the capacity of telecommunication systems has usually doubled every year. This is due, for example, to a growth in the optical backbone network. During the last decade, commercial off-the-shelf cameras and displays (TVs) have improved after 20 years of slow development. A similar development can be expected to continue, while augmented and virtual reality technologies will become commonplace. This development will make lifelike telepresence possible well before 2050. If this technology is accepted socially – which might be possible among the Playstation generation – it will affect all aspects of everyday life: work, schools, social life, free time and vacations. Such a disruptive technological change would enable scattered living without increasing traffic congestion and thus, non-travelling could become a desirable thing. Lifelike telepresence capability will remove many of the practical reasons for travelling and might also partially fulfil human beings' natural inclination to travel and see new places.

3.1.2 The importance of electricity will increase in the future

Currently our building stock energy consumption is dominated by space and domestic hot water heating. However, in the future the importance of electricity use will increase. In passive houses, very low energy houses, overall electricity use is between 30–40% of the total energy use of the building. For new buildings, the EU has set the target close to zero energy buildings by 2020. In order to achieve the zero energy building targets, interaction between different parts of the infrastructure is crucial, and communications are needed between energy supply and consumption. In buildings with a need for cooling, the use of solar energy has evidently achieved the perfect match of supply and demand in the Finnish climate. For comfort reasons, the cooling demand might increase in future buildings. On the other hand, advanced material technologies such as phase change materials might provide other alternatives to mechanical cooling.

The Baseline and Tonni scenarios are identical in respect of building stock size (m^2) development and urban form, and these scenarios follow today's expected development. In the Inno scenario, urbanization will be more rapid, and people will live in a more efficiently utilized living space. Traditional industries will be supplanted by service and technology businesses that require less space, resulting in a lower need for commercial and industrial buildings.

In the Onni scenario, people will want more space and nature around them, so urban sprawl will increase. Large single-family houses will become the predominant form of housing, and rapid growth will occur in the residential building stock. People tend to work from home, and some even aim at partial self-sufficiency, with small-scale farming, leading to a smaller size in the industrial and commercial building stocks. Since people are living close to nature, the number of summer cottages or other leisure homes is low compared to Inno and Tonni. In the Onni scenario the assumptions regarding the specific heating energy consumption per building type are close to those in the Inno scenario. In the Onni scenario, the high renewal rate of single-family houses is achieved via upgrading by replacing old building stock by new very energy-efficient buildings. Single-family houses are consuming roughly 30% of the energy of the building stock; thus, changes in that particular building type also lead to changes in the energy efficiency of the entire building stock. As a result of the high number of new buildings, the energy efficiency of the building stock increases (Table 3).

The scenario paths are summarized in Figure 4, showing the sizes of the residential building stock and the combined commercial, industrial and public building stock in all three scenarios.

3.1.3 Building stock has a lifetime of 50 to 100 years

In the year 2050 half of our building stock will have been built or re-built as a result of major renovation after 2010. Thus, the specific energy consumption in space heating will decrease but, due to an increasing housing area per person, absolute consumption will not drop that rapidly. On the other hand, electricity consumption will increase slightly due to an increased number of appliances and devices, even though the specific electricity consumption per device will have decreased dramatically.

In the Baseline scenario, heat consumption is thought to represent fairly accurately a continuation of the present situation into perpetuity. In the Tonni scenario, the present mode of building improves at a relatively slow pace. Old buildings are renovated and their energy efficiency is improved at a modest pace. These developments are representative of a reasonable extrapolation of past developments.

In the Inno and Onni scenarios, a faster pace of improvement is anticipated. In the Inno scenario, this is due to the focus on technological development, whereas in Onni it is due more to a heightened environmental awareness. It should be borne in mind that a large part of the improvement in the average consumption by the building stock is due to the removal of the oldest buildings from the stock rather than to renovations.

TABLE 3. Heating energy consumption of single-family houses and assumptions used in the scenarios.

Single-family house, heating energy (kWh/m^2)				
	New		Existing	
	2012	2050	2012	2050
Baseline	80	70	170	138
Tonni	75	55	170	129
Inno	70	40	170	80
Onni	70	40	170	75

3.1.4 Interaction between smart buildings and energy networks

Renewable localized energy production technologies could considerably alter the futures envisioned

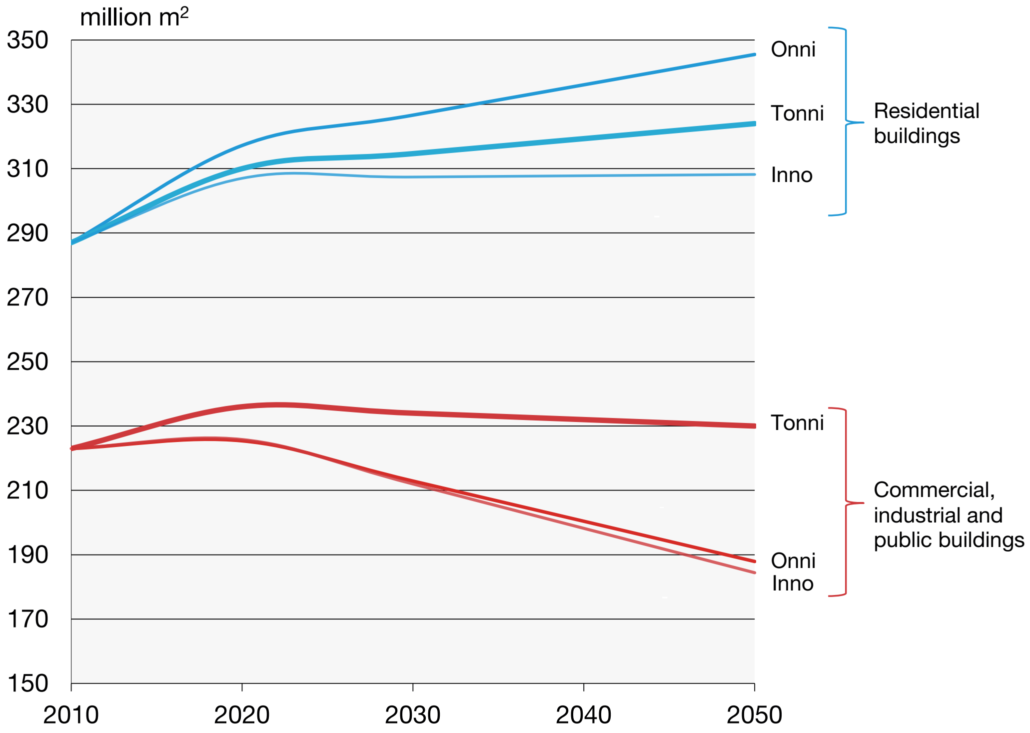


FIGURE 4. The development of the building stock in the three scenarios in terms of built floor area (millions of m^2). Residential buildings also include summer cottages.

here. Hitherto, local power generation in our cold climate has been limited by a number of factors: the efficiency of local power generation tends to be lower than that achieved in large power plants, and our present distribution networks cannot manage the situations that may be produced by large scale local power generation. This may not, however, be the case in the long term. Smarter distribution grids, control and monitoring technologies, energy storage and improvements in small-scale renewable energy technologies can improve the efficiency of local power generation at district and building levels. In addition, water heating systems with energy storage may be a valuable asset in the future, because in Europe controllable electricity consumption will have increased in value due to a price volatility caused by an increased share of variable wind and solar power generation. In addition, heating and cooling systems which can use waste heat and cooling sources (low exergy) might become very attractive in energy-efficient buildings and also benefit the energy network. If these technologies are accepted socially and viable business models can be created, this has a potential to profoundly change our ways of producing and consuming energy.

3.2. LOW CARBON AND SMART MOBILITY

3.2.1 Society and the economy set the pace for transport and traffic

While looking into the future, we need to remember that transport is a derived utility serving society and the economy, not a necessity in itself. Therefore, the trend-setting factors depend heavily on social and societal structures, as well as the structure of the economy and the state of technical development (Table 4).

Broadly speaking, we can say that land use and structure of the community has the closest correlation with the amount of passenger transport needed. The denser the structure, the less transport is needed, especially motorised transport.

TABLE 4. Key drivers of the assumptions concerning transport and transportation systems.

Main drivers	Tonni	Inno	Onni
Source of GDP / structure of economy	Heavy manufacturing industry	New and innovative "virtual" products	New and innovative "virtual" products
Freight transport volumes	Maintain high (BASE)	Low	Medium
Regional structure	Similar to existing	Urban, centralised	Decentralised
Passenger transport	Maintain high (as today)	Low	Moderate
Technical development and implementation of low carbon transport systems	Moderate	High	Moderate to high

Fact box: Transportation

- In 2012 car density in Finland was 482 cars per 1,000 inhabitants, and the average annual kilometres travelled by an active car was approx. 17,600 km/year. In all, the age of the car fleet is fairly high as well as is the average annual mileage by car.
- A substantial proportion of the population lives in sparsely populated areas, thus limiting the opportunities for cost-efficient public transport.

Furthermore, dense structure provides a greater opportunity for effective public transport systems. In addition, an intense use of ICT (teleworking, telepresence, e-business, etc.) reduces the need for physical travel. On the other hand, an increase in spare time as well as living in urban neighbourhoods may cause an increase in longer leisure trips that cannot be provided by public transport, especially trips to summer cottages which increasingly are used as second homes. (See Figure 5.)

The amount of freight transport is also related to the regional structure and population density, but perhaps more to the framework of the economy, business and industry. Traditional heavy manufacturing industry generates high transport volumes, whereas the new economy emphasises more contents-based, virtual products in favour of material-based products. Virtual products can be distributed via the Internet rather than by traditional freight-carrying systems. On the other hand, growing e-commerce over the Internet has generated an increasing amount of parcel-level freight, when people shop for small consumer products from all ends of the world and have these shipped to their post boxes. Harnessing these thin material flows into more effective bulk is a challenge.

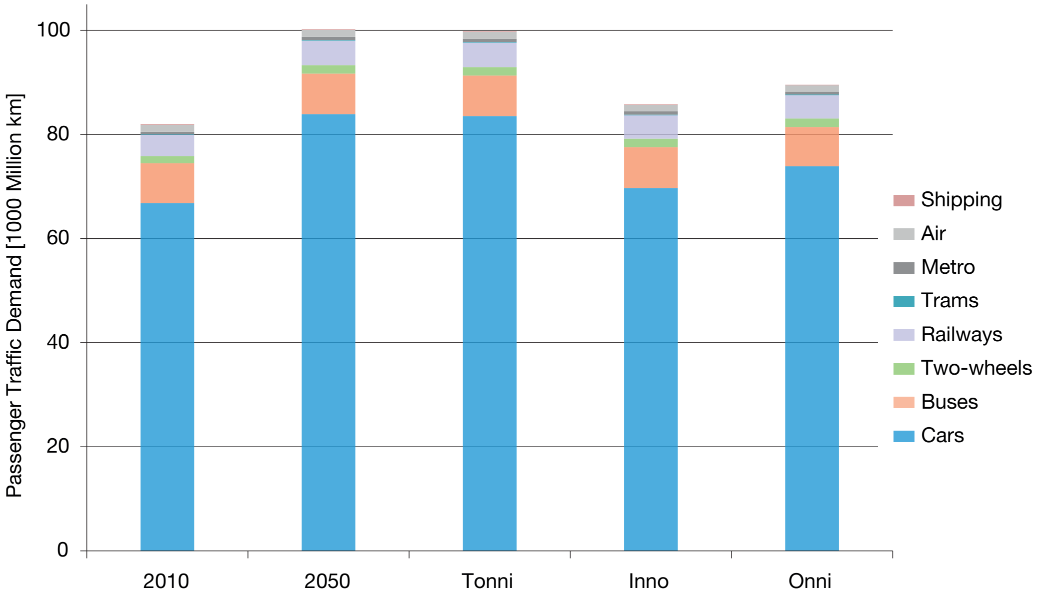


FIGURE 5. Assumed development of passenger transport. The baseline forecast for passenger transport is based on statistics and existing forecasts, and has been extended to the target year 2050 using linear trend lines. The assumed development in the scenarios reflects changes in the total amount of domestic travel by trip purpose, changes in travel patterns and trip lengths as well as changes in efficiency.

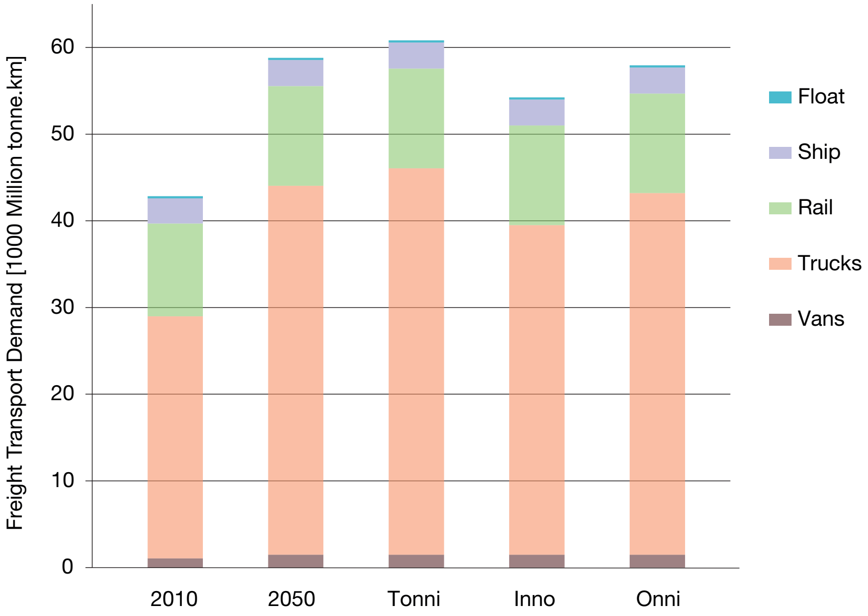


FIGURE 6. Assumed development of freight transport. The baseline forecast for freight transport is based on statistics and existing forecasts, and extended to the target year 2050 using trend lines. The assumed development in the scenarios reflects changes in the total amount of domestic freight transport by mode, volume and trip length.

Even if the traditional industry-based freight transport volumes diminish, there are other sectors that should remain to generate a significant demand for freight transport. Land use development, construction of houses and infrastructure often necessitate the movement of large volumes and masses. Likewise, food supply and other daily services even today generate freight transport at the same level as industry. If we increase our dependence on imported food, freight volumes will increase accordingly. (See Figure 6.)

3.2.2 New and innovative technology needs investments

The other half of the equation regarding energy use and the environmental impacts of transport is the technology of vehicles and other systems that are used to fulfil the demand. An increasing market price of crude oil plays a crucial role as the third important key parameter in bringing forward new, innovative technologies and more advanced solutions for vehicles and their energy services, and even all-new transportation systems for both people and goods. Furthermore, the intensity of the development including the renewal rate of the vehicle fleets and implementation of low carbon and smart transport systems is dependent on economic welfare, regulation and also our behaviour and values.

However, apart from ships, all other vehicles – cars, trucks, buses, trains and aircraft – are almost exclusively developed by large international companies, and Finnish industry has a very limited input into this work. The Finnish market for vehicles is so small that it does not justify manufacturers in considering products specific to the Finnish or even the Nordic market. Therefore, we need to carefully monitor developments and try to choose those vehicle technologies that best suit our conditions.

3.2.3 Improving the energy efficiency of engines and vehicles

Mating the combustion engine with an electric drivetrain will offer further possibilities for engine optimization. In this kind of hybrid configuration we can also expect even to see a novel type of combustion cycle, which cannot be run on a mechanical-only powertrain. An example of such a cycle is homogeneous-charge compression ignition (HCCI), which may offer low-temperature combustion with good efficiency and low NO_x emissions. Already many of today's hybrids use less traditional combustion principles for greater efficiency.

Progress is also possible by lowering the energy demand of the vehicles. Cutting down mass and making improvement in aerodynamics help the vehicles to move with less energy. A growing use of advanced materials and the increased power of design software should support the already promising outlook towards lightweight but safe cars. This is a combination that has not been achieved yet, because traditionally increased safety has also meant a higher mass of the vehicle. Energy use of comfort-related systems should be rationalised.

3.2.4 Decarbonising the transport energy supply is a huge effort

The efforts to cut down CO_2 emissions have led to decarbonising the energy contents of transport fuels. Using sustainable biofuels is one prime candidate in this effort, as their carbon is derived from renewable biomass, and will again be trapped by growing vegetation. However, there is considerable debate on the sustainability issues of biofuels produced from crops such as maize, corn or palm oil, due to their indirect impacts on food security and land use emissions.

Replacing the fuel-burning combustion engine with an electric-only drivetrain can offer much better odds. However, the greatest challenge regarding the use of electricity in vehicles is storage technology. Even the best battery technologies can only store a fraction of the energy contents that liquid fuels offer. Batteries also carry a high cost penalty. Therefore, the car industry has a keen eye on hydrogen – the ultimate end of the decarbonising effort. It is also quite a flexible energy carrier, as production possibilities are very versatile.

When hydrogen fuels a fuel cell, it produces electricity and water and no other gaseous or

Fact box: Industry

- The proportion of the industrial sector in final energy consumption is high in Finland. In 2009, its share was 42%, whereas the average for the EU27 was 24%.
- Industry is the largest energy end-use sector in Finland. The pulp and paper industry, the metal industry and the chemical industry are the main industrial energy consumers in Finland.
- The energy use of the industrial sector is a major reason for the high energy intensity of the Finnish economy compared with other industrial countries. In 2010, the total primary energy supply/GDP ratio was nearly 30% higher in Finland than in OECD countries on average.
- The share of CHP in the energy production of industry is high by international comparison.
- The high volume of pulp and paper industry in Finland has enabled a high proportion of bio-based fuels and CHP production in industry. This has been a major contributor to the internationally low proportion of fossil-based energy used in the industry in Finland.

particulate emissions. With hydrogen, we can obtain enough energy on-board to run for more than 500 km. What is more, refuelling does not take any more time than refuelling with present-day liquid fuels. This fact, and the uncertainty and high cost penalty associated with battery technology, has led the global automotive industry to favour the hydrogen fuel cell as their future option. Top manufacturers are all planning to start mass production over the next couple of years, and the anticipated number of vehicles exceeds the forecast for battery-electric cars at least for the next decade. However, the great challenge is in the roll-out of a hydrogen refuelling infrastructure. It will be more expensive than supplying electricity for battery recharge, as even today electricity is almost everywhere. We need only to build a suitable interface to the main grid. Secondly, hydrogen is not a primary energy source as such, but has to be produced from other energy sources. Therefore, it should be borne in mind that the hydrogen production process should also produce no or only a small amount of greenhouse gases.

3.2.5 Heavy-duty vehicles look to biofuels

As regards heavy trucks in long-range transportation, so much power and range are needed that none of the new power options for cars are viable. Even if liquid hydrogen offers a fairly high energy density, the fuel cell that can deliver 300 to 500 kW of power is too large and heavy, unless the power density of a fuel cell can be increased by a factor of 10 or so. Therefore, on-road freight transport will continue to run predominantly on diesel engines, but the fuel will increasingly be bio-based products. Nevertheless, in urban public transport hydrogen fuel cell or even battery-electricity can offer a very good low carbon solution.

3.3 INDUSTRIAL RENEWAL DRIVEN BY GLOBAL MEGATRENDS AND LOCAL RESOURCES

In 2010 the proportion of energy used by industry in Finland was around 50%, which is among the highest in the OECD nations, mainly due to energy-intensive metal and forest industries. As a result of

TABLE 5. Key drivers of the assumptions concerning forest industry.

	Tonni	Inno	Onni
Main drivers	Growing global demand of traditional industrial products, high cost efficiency of traditional Finnish products	Need to re-invent forest industry, high material and energy efficiency	Decreased international trade, reduced opportunity for paper exports
Innovation	Low	High	High
Investments	Low	Moderate	Moderate
Added value of products of forest industries	Moderate	High	Moderate

globalization and growing markets for industrial products in developing economies, the production of traditional products has been moved closer to the growing markets, where production costs are usually also lower than in industrialized economies. Therefore, energy-intensive industries in Finland are facing new challenges, and there are already signs of a renewal of the Finnish industrial sector. Because of the important role of the industrial sector in Finland's energy system, it is very clear that changes in industrial structures and energy demand would have a great impact on the development of the whole energy system. In this study, we have focused on forest industries, as these are now already in the process of renewal, and they are steering their strategies more towards the energy business.

The three scenarios present different paths regarding product portfolio and volumes, which affect industrial energy consumption and intensity. One has to bear in mind that the future paths of the forest industries also affect energy production, since they are a major producer of bio-based CHP. All the scenarios include deployment of energy efficiency technology and measures.

3.3.1 Renewing forest industry – new opportunities in high value products

The main assumptions regarding the forest industry in the three scenarios are included in Table 5.

The Tonni scenario can be seen as a linear extrapolation of the current situation regarding production volumes and product assortment (see Figure 7). As global demand for existing products is estimated to remain strong and production costs remain competitive, there is little incentive to develop new products. The only addition to the product portfolio is production of liquid biofuels. They are introduced by 2020, and the minimum production rate is 200 kt/year.

In the Inno scenario the world looks quite different – demand for traditional products is not growing and their production has been increasingly moved closer to markets (see Figure 8). The production volume of traditional products is substantially lower than in the Tonni scenario. However, there is a growing demand for new fibre products such as composites, biochemicals and biofuel components, and the forest industry has been able to introduce these new products into global markets, thus compensating for the decline. Compared to Tonni there is an additional 200 kt liquid biofuel capacity by 2030.

The Onni scenario differs from the Inno in the aspect of seeing a quicker decline in the production of traditional paper products and larger portion of board products in the product portfolio (Figure 9). There is still innovation in new products, but they are clearly less energy-intensive than the ones in the Inno scenario. Biofuels are introduced as in the Tonni scenario.

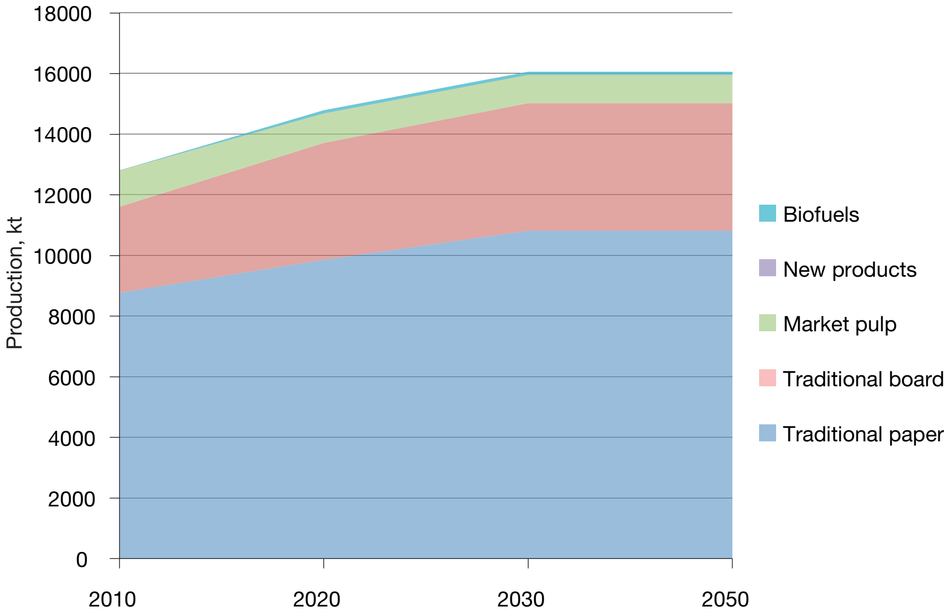


FIGURE 7. The Tonni scenario – more of the same with improved technology. The production of biofuels is introduced by 2020, and for the scenarios, a minimum production rate of 200 kt/year is set and this is shown in the Figure. In addition to the assumed minimum production, market-based production is possible in the scenario results, see e.g. Figure 22 (p. 51).

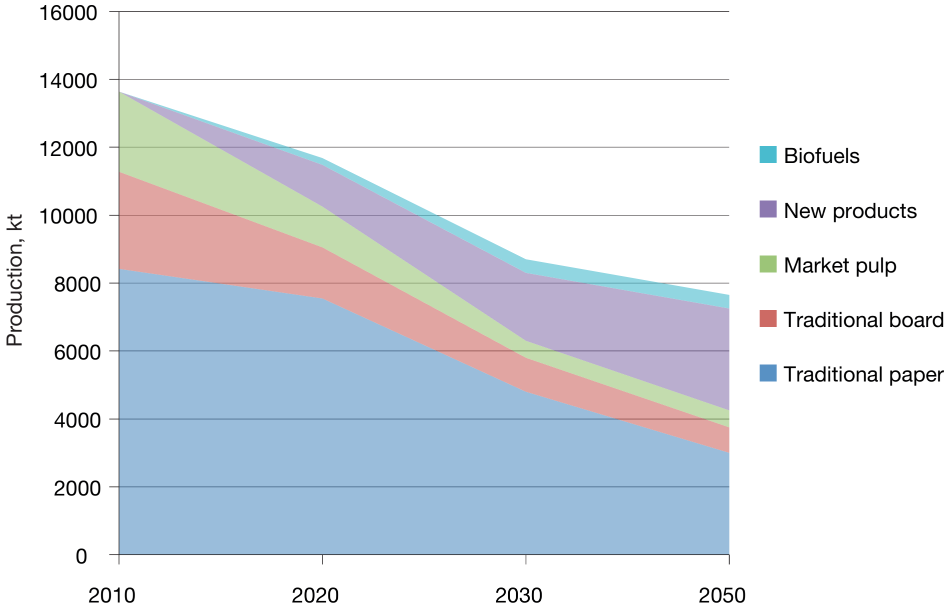


FIGURE 8. Inno – new products with lower volumes but high value. For the scenarios, a minimum production rate for biofuels, 200 kt/year in 2020, and additional 200 kt/year in 2030 are set and shown in the Figure. In addition to the assumed minimum production, market-based production is possible in the scenario results, see e.g. Figure 22 (p. 51).

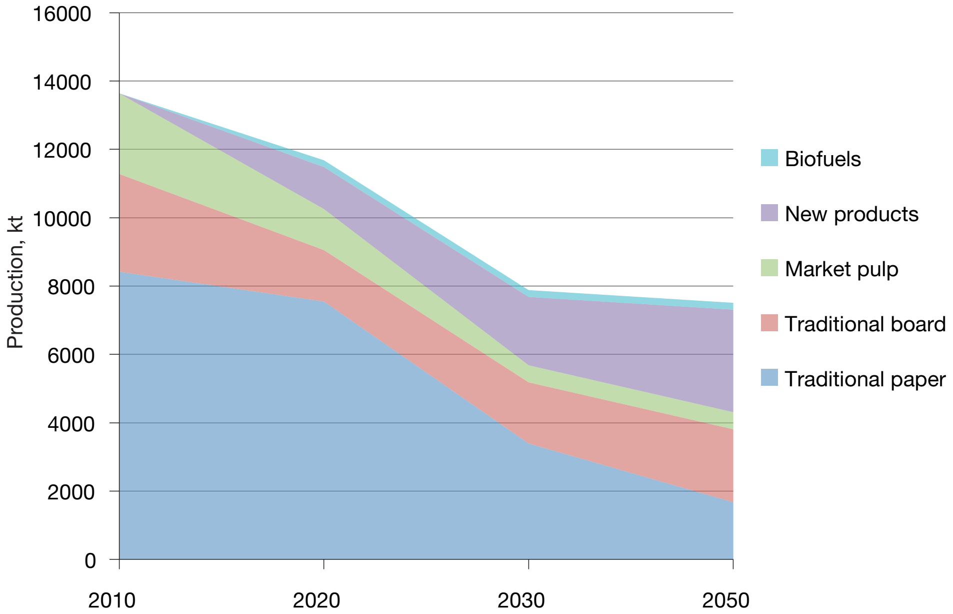


FIGURE 9. Onni – new products with moderate value and reduced energy intensity. Biofuels are introduced as in the Tonni scenario. In addition to the assumed minimum production, market-based production is possible in the scenario results, see e.g. Figure 22 (p. 51).

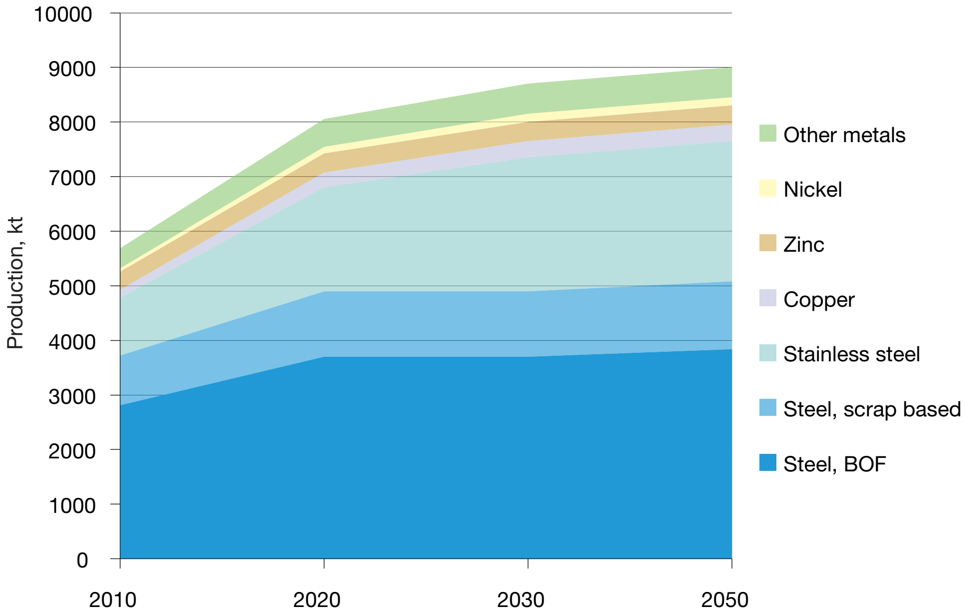


FIGURE 10. Metals – a steady increase in production. The production volume of ferrous and non-ferrous metals is expected to increase on average by 58% between 2010 and 2050 in all scenarios.

Fact box: Energy production

- Versatile structure of energy production (Figure 11) with high efficiency: one third of electricity from CHP.
- Indigenous energy sources cover only one third of energy demand; the share of renewable energy sources (RES) is high, over 25% from primary energy supply.
- Energy-intensive industry covers half of energy demand.
- Finland joined Nordic electricity markets in 1998.
- CO_2 tax on fuels introduced as early as in 1990's.
- Wood fuels are planned to cover half of the RES increase by 2020.
- Two Decisions-in-Principle were accepted by Parliament in 2010 for new nuclear investments, which makes nuclear energy a viable option for base load also in the long term.

When making decisions on energy production investments, three major criteria are weighted for the whole 20–60 year life-cycle of the plant: cost-efficiency, fulfilling present and future environmental and other legislative constrains, and security of energy supply.

Finland has compensated for its dependence on imported energy by choosing an exceptionally versatile combination of energy sources and production technologies.

Finland has been a forerunner in the introduction of new fluidised bed (FB) combustion and gasification technologies, especially for CHP (combined heat and power), since large heat loads exist in cities and process industry, and in the use of biomass as fuel, since biomass has been the most important indigenous fuel resource. The world's leading FB vendors, forest machinery and wood handling companies and their R&D activities are located in Finland, which creates a lucrative operating environment also in the future for the introduction of new technologies connected to new business models.

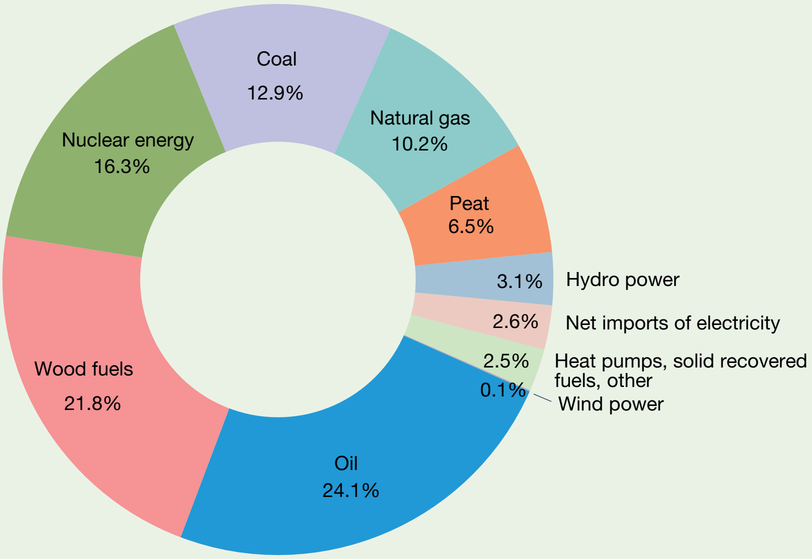


FIGURE 11. Total primary energy of Finland by energy source in 2010, 1464 PJ.

TABLE 6. The main drivers regarding assumptions on energy production in the three scenarios.

	Tonni	Inno	Onni
Main drivers	Growing demand of energy, cost efficiency	Integrated concepts and radical technology development for all renewable resources, especially biomass, solar and wind. New technologies for both small and large scale energy production.	Decreased international trade, reduced opportunity for paper exports
Innovation	Low	High	High
Investments	Nuclear power plants as a backbone complemented with renewable energy and carbon capture	High in advanced combined heat and power (CHP), renewable energy and carbon capture	High in distributed energy production based on renewable energy

3.3.2 Favourable conditions for other energy-intensive industries make steady growth possible

The production volume of ferrous and non-ferrous metals is expected to increase on average by 58% between 2010 and 2050 in all scenarios (Figure 10, p. 35). The production shown follows the basic assumptions by the Ministry of Employment and the Economy of Finland (forthcoming in VATT Publication Series). In the scenarios, production technology is incrementally improved to increase energy efficiency.

Apart from pulp and paper, mechanical wood processing and basic metals manufacturing sectors, growth in the other industrial branches was to a small extent varied according to the general characteristics of the scenarios. For example, growth in the manufacture of electrical equipment and electronic products was assumed to be highest in the Inno scenario, while growth in the manufacture of food products and construction was assumed to be highest in the Onni scenario. The energy consumption of other industries comprises mainly electricity, i.e. the greenhouse gas emissions are not so remarkable compared to basic metal or forest industries.

3.4 RENEWAL OF ENERGY PRODUCTION, TRANSMISSION AND DISTRIBUTION NEEDED

3.4.1 Reflections on the changing demand for energy services

Energy production in different scenarios reflects the demand of energy services in the scenarios. In the Tonni and Inno scenarios, the high demand for process heat and base load electricity in industry makes nuclear power and combined heat and power (CHP) plants especially lucrative. In all scenarios, renewable energy is an increasingly important source, and integrated use of biomass to biomass-based products and energy is one of the most competitive solutions. The main drivers regarding assumptions on energy production in the three scenarios are included in Table 6. A new option for reaching the low carbon economy is carbon capture and storage (CCS), which is estimated to be feasible with the highest greenhouse gas reduction costs. There are still great uncertainties related to implementation of CCS in Finland, and therefore we have also carried out a sensitivity analysis, in which CCS is not included in

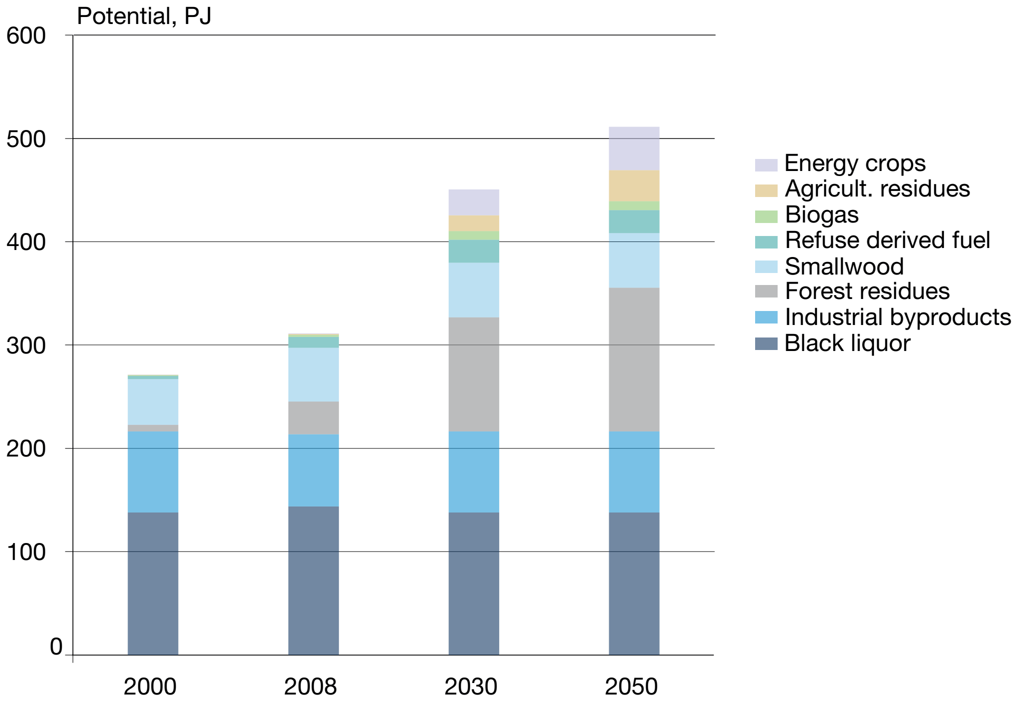


FIGURE 12. Assumed technical potentials of bioenergy: wood-based biomass dominates biomass supply in the future as well, but energy crops, agriculture residues and biogas could offer increasing potentials.

the future technology portfolio of greenhouse gas reduction. On the other hand, we have included bio-CCS option from 2030 in the Tonni, Inno and Onni scenarios, which increases the CCS potential in Finland.

Increased R&D inputs in the Inno scenario do not only improve efficiency and decrease the investment costs of energy production, but new high efficiency technologies are additionally commercialized. The Onni scenario relies on a more distributed energy production.

3.2.2 Large scale mobilisation of sustainable biomass is crucial

Most increases in the biomass fuel supply in all the scenarios studied will be based on wood-based biomass (Figure 12). Wood residues and black liquor from the wood products industry forms the largest share of wood fuel in all the scenarios. But an increasing amount will be harvested from thinnings or collected as harvesting residues – branches, tops and stumps, and both of these major alternatives are integrated with industrial wood raw material procurement. A small fraction of wood fuels will be from intensive production of energy wood stands.

Increased use of biomass for energy purposes requires smarter forest biomass supply chains to reduce costs at each step of the logistical chain: harvesting or collection, transportation, storing, fuel handling at plants. Learning machines can improve productivity by improving machine performance and efficiency. In addition to wood residues, source-separated waste from municipalities and industry, and agricultural residues and perennial agrobiomass could be utilised.

In the scenarios, stemwood use for purely energy purposes is limited to thinnings of young forests and sapwood chips from sawmills. In Finland, additional use of forest growth for energy would increase the technical potentials of bioenergy considerably, but further research is needed to study the impacts on Finland's total carbon balance.

Securing and verification of sustainability of each cubic metre of biomass supply will also probably be required by EU legislation in order for biomass to receive the status of renewable energy. Economic, social and environmental sustainability will be analysed for the whole fuel chain, which will be extremely challenging.

3.4.3 Bioenergy carriers for longer transportation distances and long-term storage

Biomass availability has both geographical and seasonal variations that can be eliminated largely by means of solid, gaseous or solid energy carriers with a higher energy content per volume unit than loose wood or wood chips.

Megawatt-scale CHP plants are designed to utilise several types of solid fuels chosen according to their seasonal economy and availability. Fluidised bed technology, utilised both in boilers and gasifiers, enables a wide variety of not only solid, but also liquid and gaseous biomass fuels. Most of the largest plants are also equipped with the possibilities for using coal, which makes possible large scale fuel storage for several years. Most CHP plants are equipped with additional condensing turbines to provide electricity without dependence on heat demand. These are replacing ageing coal fired condensing plants.

3.4.4 An increasing amount of electricity from CHP plants at all scales

A reduction in heat demand in buildings and an increased use of electricity compared to process heat in industry both require an increase in the power-to-heat ratios of CHP-plants.

In Nordic DH-systems the maximum outgoing temperature is 115°C in winter and 80°C in summer. In the Inno scenario, district heating systems will be transformed to only 60°C outgoing temperature, and CHP plants will produce significantly more electricity. CHP plants can also be designed to provide cooling, called a Trigeneration Plant.

The Integrated Gasification Combined Cycle with a pressurised gasifier connected to both gas and steam turbines (IGCC) and once through boilers with supercritical steam values (OTU) are multifuel concepts for over 100 MW (thermal), taking a significant market share well before 2050. In closer to 2050, IGCC plants combined with large-scale SOFC (solid oxide fuel cell) plants will provide a CHP plant option with a high electrical efficiency. Gasifiers connected to gas engines, gas turbines and fuel cells are examples of smaller MW-scale market entrants. The smallest CHP plants will be based on the utilisation of liquid and

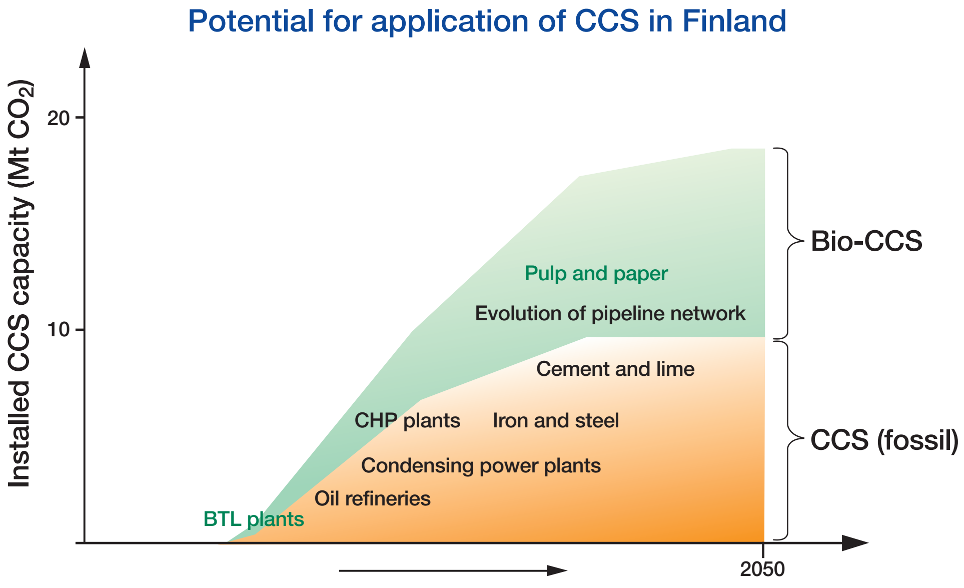


FIGURE 13. Potential for application of CCS in Finland.

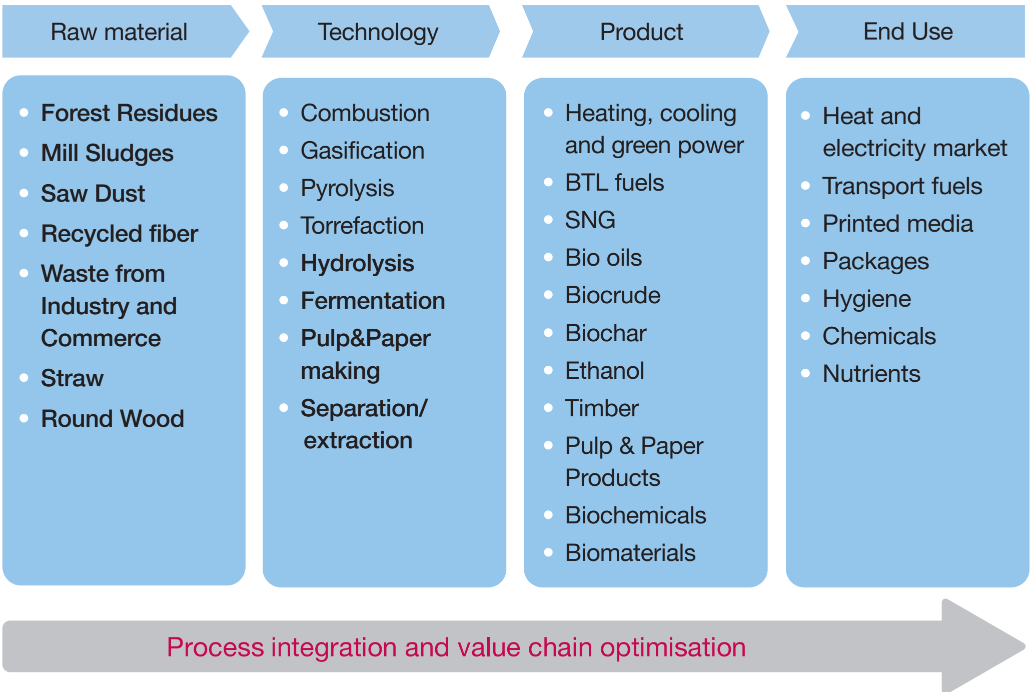
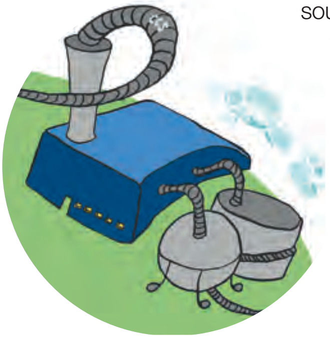


FIGURE 14. Several new high-value, renewable products, and also new raw materials, will be introduced in the forest and other process industry value chains in the near future.

gaseous fuels that can be processed from biomass or from different residues and waste from industry and municipalities.

3.4.5 Carbon capture and storage (CCS) – significant opportunities related to implementation in Finland

Finland's location is not favourable for large scale CCS (carbon capture and storage), because feasible underground storages have not been identified in near-by locations. The most cost-efficient applications for Finland are connected to capturing CO_2 from syngas-based biofuel (BTL) production (sizes of emission sources 0.3–1 Mton CO_2 per year), oxy-fuel boilers and IGCC plants (sizes of emission sources 1–5 Mt CO_2 per year) (Figure 13). In addition to the primary large scale solution of transportation of CO_2 to geological storages outside Finland, the life cycle of utilisation of carbon could be extended by using carbon dioxide as a raw material for PCC (precipitated calcium carbonate) (size of single sink 40 ktons of CO_2 per year) and organic chemicals.



Bio-CCS is the only large-scale technology that can remove CO_2 from the atmosphere. Bio-CCS may be defined as processes in which CO_2 originating from biomass is captured and stored. When biogenic CO_2 from processes is captured and permanently stored in underground formations, this would result in a net removal of CO_2 from the atmosphere, as biomass binds carbon from the atmosphere as it grows.

3.4.6 New integrated processes – energy products, chemicals, materials

In the future there will be a range of biorefineries in different size scales utilising several types of biomass feedstock and various technology options. Different technologies, e.g. thermochemical, chemical and biochemical conversion processes, will be used to provide optimal process concepts for each feedstock and product. In the near future,

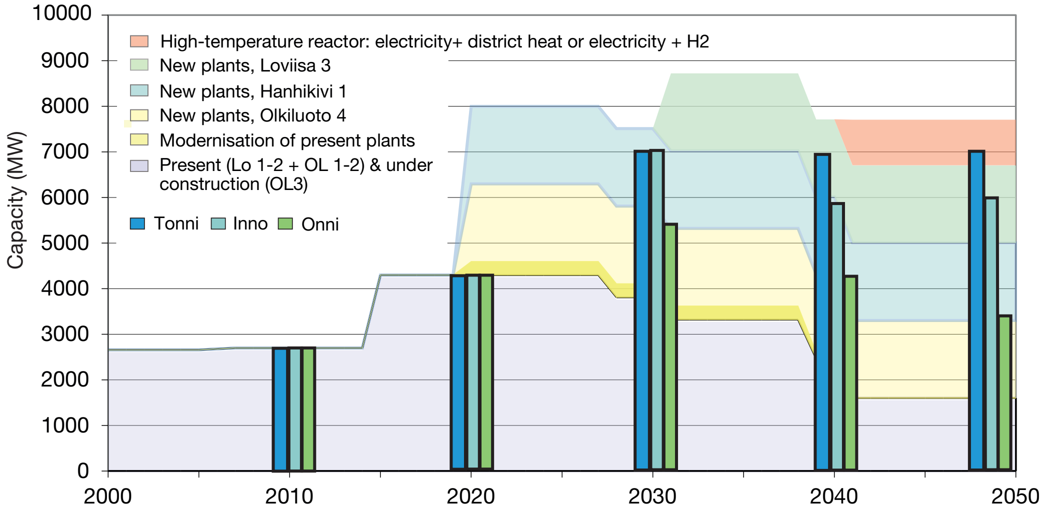


FIGURE 15. Development of Finnish nuclear power capacity is based on the plants currently in operation and the plant under construction (Olkiluoto 3), as well as the two plants for which Decisions-in-Principle were accepted by Parliament in 2010. In addition, a new reactor unit in Loviisa and a potential CHP plant based on high-temperature reactor technology are included. The assumptions used in the Low Carbon Finland scenarios are included in the bar chart, representing the maximum amount of nuclear power in the scenarios. In the scenarios, the investment decisions and operation of the nuclear plants are the results of cost optimization of the whole energy system.

Fact box: Wind energy

Several different wind turbine components are manufactured in Finland including gearboxes, generators, power electronics, towers, blade materials and offshore foundations. Cold climate and blade heating RD&D is especially strong in Finland. There are also two companies offering MW-class wind turbine designs and manufacturing. Despite the domestic R&D and industry, there is relatively little wind power in Finland, and even the current plans are modest by comparison with Europe. Finnish power generation already has quite low CO_2 emissions and therefore the pressure for emission reductions is more in other GHG emitting sectors.

Many different climates experience icing conditions from time to time. In Finland this happens relatively often. There are two major impacts from ice accretion on the wind turbine blades: electricity production losses and increased loads on the turbine components. Both of these can be prevented with state-of-the-art ice prevention systems. In many places increased yield alone can cover the additional cost of the ice prevention equipment, but the true value may lie in the lower maintenance and replacement costs and increased lifetime of the turbines.

Finland is peculiar due to the mostly forested landscape. Hence, land-based wind power has an additional obstacle due to the lower wind speeds and increased turbulence. Therefore, higher towers with low-wind speed turbines capable of withstanding increased turbulence levels are needed to tap most of the Finnish wind power potential. On the other hand, the shoreline facing the prevailing winds from the west is long.

integration of advanced gasification or pyrolysis to a conventional energy production plant, for example, enables a more efficient and profitable utilisation of biomass.

In Finland, the focus will be on biorefineries utilising forest biomass. In these biorefineries, different kind of biomass-based chemicals and materials can be produced, in addition to several energy products: power, heat, solid and liquid biofuels of different qualities (Figure 14).

3.4.7 Nuclear power as the backbone of low carbon electricity production

The Tonni, Inno, and Onni scenarios include alternative developments of the Finnish nuclear power capacity based on plants currently in operation, the plant under construction (Olkiluoto 3), the two plants for which Decisions-in-Principle were accepted by Parliament in 2010, and different scenarios for additional nuclear plants (Figure 15). In the scenarios, only maximum nuclear capacities are given, and the investment decisions and operation of nuclear plants are the results of cost optimization of the whole energy system in each calculation year. Therefore, the scenario assessments do not indicate site-specifically which plants will be built

In the development of fourth generation nuclear plants, it is planned to increase the scope of application of NPPs to cover in addition to power production also the production of process and district heat as well as that of hydrogen. These types of advanced plants could be feasible in the period when the presently operating plants are decommissioned. Furthermore, preliminary plans have been presented to include the possibility of district heat production in the new Loviisa reactor units for the needs of the municipal area of Finland.

Technology developments for nuclear power in Finland have concentrated on the further development on nuclear safety and spent fuel management and disposal. In the case of third generation nuclear power plants, such as the Olkiluoto 3 reactor unit, even more extensive efforts have been devoted to further increasing the safety of NPPs. Examples of additional safety measures include the core catcher for severe accident management and strong secondary containment to mitigate the consequences of potential aircraft impacts. Additional safety

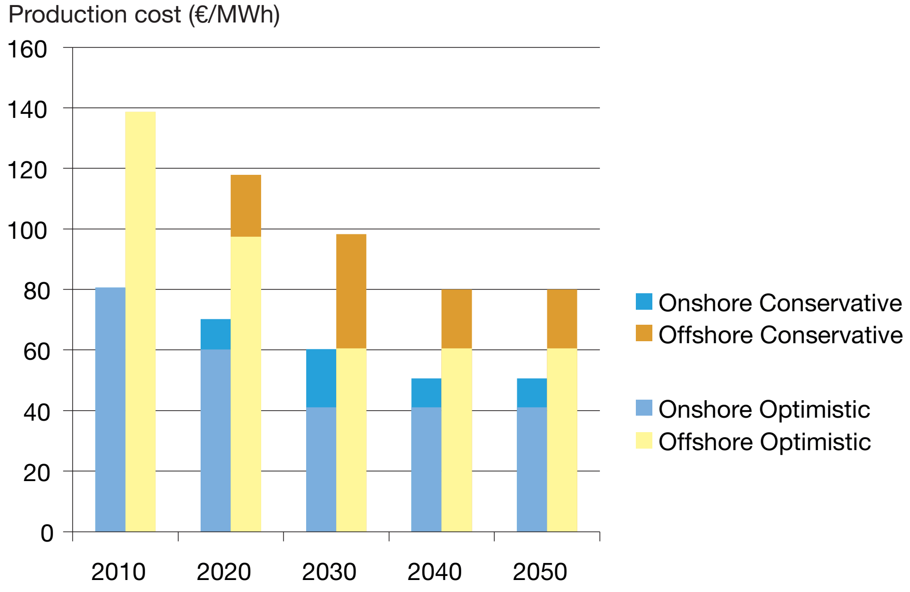


FIGURE 16. Assumed wind power production costs in conservative and optimistic pathways. Onshore wind power is assumed to have a 30% capacity factor at a height of 125 metres. Offshore wind power is assumed to have a 40% capacity factor at a height of 100 metres. A 10% return on investment is assumed.

improvements will be included in the final design of the new NPP units planned to be built in Olkiluoto and Hanhikivi.

3.4.8 Wind power – different site conditions require different turbines

Two different wind power cost development pathways were created. One is more conservative and the other is more optimistic about technological development (see Figure 16). The conservative pathway was used in the Tonni scenario, since in this future conventional power generation is assumed to remain highly competitive. The same pathway was also used in the Onni scenario, since technological progress was assumed to be slower there. The Inno scenario commits more resources to R&D and as a result the more optimistic cost pathway for wind power is assumed.

The differences between the scenarios can be explained by considerable uncertainty regarding future progress in wind power technology. It is likely to remain relatively rapid and includes multiple sources of uncertainty. The current R&D emphasis is less about reducing investment costs per MW and more about increasing yields, reliability, and optimising O&M. Higher yields are pursued with higher towers and larger rotors, both of which impose challenges to the secure management of loads and resonances in the blades, towers, bearings, gearboxes, and generators. At the same time, new materials are bringing new opportunities in making the turbines lighter and larger. Another trend is that turbine characteristics are adapted to suit site characteristics – e.g. offshore, low-wind speed, high turbulence and cold climate wind turbines. In the longer term these developments are likely to continue. The differences between the conservative and optimistic scenarios stem from different success rates in achieving better performance with the possible developments.

Technological leaps are also possible, although they have not been assumed in the scenarios. Current technology is able to access only a small fraction of the potential wind energy in the troposphere. Kite turbines could access much larger and more stable resource. They are currently in the demonstration phase, and it is too early to say whether they could lead to competitive power generation. Similarly, floating turbines are currently being demonstrated and these would provide access to great offshore potential in deeper waters, which is unavailable for the current technology.

3.4.9 Solar radiation with large seasonal variations call for innovations

The amount of annual solar radiation is about the same in Finland as in Central Europe, but most of the solar radiation (1170 kWh/m^2 per year) is generated in the southern part of Finland during May to August.

As a rapidly developing technology, assumptions about solar PV technology include significant reductions in investment costs. In the most optimistic cost development path, used in the Inno scenario, investment costs for PV systems are estimated to drop by 60% by 2020 compared to a cost level for 2010 of €5/W. Additionally, the investment costs in 2050 end up at a level of €0.25/W in 2050. In more conservative cost development path, investment cost for PV systems are estimated to drop by 40% by 2020, and the investment costs in 2050 end up at a level of €0.5/W, still 90% lower than the 2010 cost level.

The topic of solar energy includes many options under development, whose influence in investment costs or efficiency might be dramatic. These options are discussed in “Wild card” box on page 47.

A question of critical materials for cells is important in developing solar technology. These materials are, in 1st generation chrystalline silicon (c-Si) technology silver, used for electrical contacts replacing copper. In 2nd generation technology (thin film cells) tellurium (Te), indium (In), gallium (Ga) and germanium (Ge); and in 3rd generation technologies ruthenium (dye sensitised solar cells) and silver (CSP concentrating solar power), are considered critical.

3.4.10 Integrating large amounts of variable power generation requires flexibility

While variable power generation in Finland remains relatively low in the scenarios analysed, on a European scale wind and solar power generation will be very large by 2050. The associated variability and forecast errors will require more flexibility from all possible directions: operational practices, regulations, market designs, thermal power plants, hydro reservoir, pumped hydro power, demand response, heat sector, electric vehicles, transmission and distribution.

New transmission lines can mitigate variability and prediction errors by smoothing variability, decreasing overall forecast errors and sharing flexibility resources between regions. For example, more connections from central Europe to Norway and Sweden would help to utilise the existing flexibility of Nordic hydro power in central Europe.

Distribution grids will also face challenges if large amounts of PV and possibly wind generation are connected to them. For the most part, distribution grids have been designed for one-way power from the higher voltage levels to the lower voltage levels for the electricity consumers. The distribution grids will need increased monitoring, controllability, and protection in order to cope with the generation injections. They may also need to be strengthened, although it may be more cost-effective to prevent too high a generation in distribution grids. Controllability and grid compliance of small-scale generation will also be a required feature at high levels of variable generation. Otherwise system stability may be threatened.

Many of the issues above are abstracted away in a global energy model like TIMES used in this study out of necessity. Therefore, it has been assumed that the developments described, at least to a large extent, can and will take place when the share of variable generation increases to high levels.

4 Scenarios – pathways to an 80% emission reduction by 2050

The quantitative Tonni, Inno and Onni scenarios are presented in this Chapter. The scenarios are model based estimates of cost-efficient pathways for achieving the at least an 80% GHG emission target in Finland in assumed operational environments by 2050. The results of the scenarios show 80–90% GHG emission reductions for Finland by 2050, compared to the 1990 level (Figure 17). The 90% GHG reduction is achieved in the Inno scenario, where Finland is able to sell emission allowances to EU, which was assumed to have the same 80% GHG reduction target. The implications of deep emission cuts on sectors of buildings, transport, industry and energy production, as well as on economic structures are discussed in the Sections 4.1–4.3.

4.1 RESULTS AND COMPARISONS OF SCENARIOS

4.1.1 Energy production may become 100% carbon-free by 2050

Historically, energy production has been the most significant source of greenhouse gas emissions in most countries. In Finland, energy production accounted for 32–44% of total annual emissions

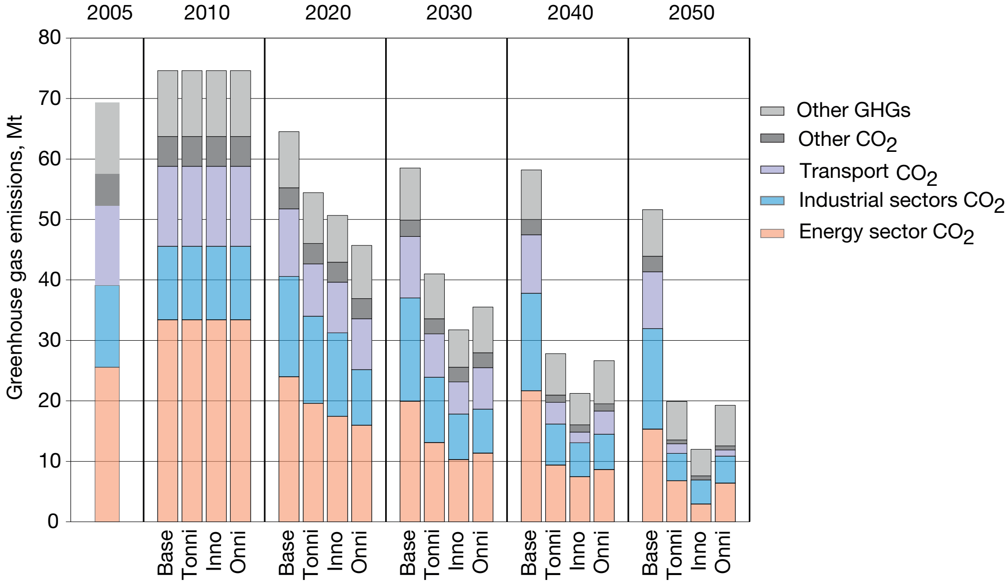


FIGURE 17. Development of greenhouse gas emissions. Innovation, development and deployment of clean technology can make the low carbon economy feasible.

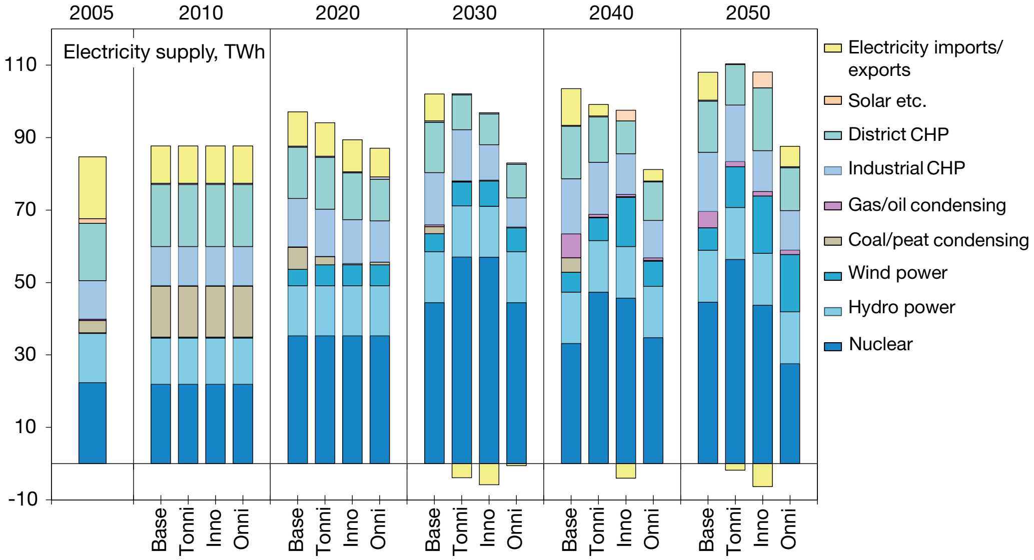


FIGURE 18. Development of electricity supply in Finland. Diversity of electricity supply remains high even in the low-carbon future. Negative values indicate electricity export from Finland.

during 2000–2010. However, the results from the scenarios indicate that the energy sector is not among the most difficult sectors with respect to decarbonising the economy. In fact it appears that, in line with the ambitious targets set by some other countries, energy production could become practically 100% carbon-free by 2050 also in Finland.

The most important options for increasing carbon-free energy production in Finland appear to be nuclear power, wind power, biomass-based generation as well as solar power (Figure 18). In accordance with the assumptions of the Tonni, Inno and Onni scenarios, nuclear power would account for 31–52% of the total supply by 2050. The combined share of wind and solar power may reach about 20% of the total supply, as realized in the Inno scenario. The remaining additional potential for hydro power is relatively limited in Finland, although climate change by itself has been estimated to bring about considerable gains from the increasing annual inflows.

The Base scenario results correspond to a total electricity supply of about 102 TWh in 2030. Consequently, the overall assumptions used in the low-carbon scenarios appear to be in good agreement with the view of the Ministry of Empoyment and the Economy.

Within the energy supply sector, abandoning the use of fossil fuels completely would appear to be most difficult in the combined heat and power production of large community energy systems, because in large-scale demand centres extensive reliance on biofuels and other renewables would become difficult not only technically but also logistically and economically. However, as an alternative route to carbon-free production, CCS is expected to become an economically viable option in large-scale thermal generation, including CHP applications. In the scenario results, a number of large new CHP plants were equipped with CCS by 2050, including oxyfuel-FBC extraction turbine plants as well as biomass-fuelled IGCC plants.

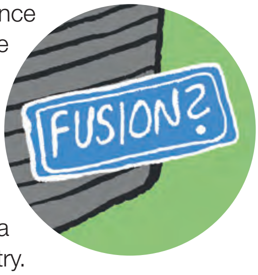
In addition to the options of carbon-neutral energy sources and CCS, the penetration of advanced technologies with higher power-to-heat ratios will be important for CHP to maintain its competitive position in the low-carbon economy. The results indicate that, with the combination of biofuels, new technologies and, where applicable, CCS, the role of CHP would continue to be high in Finland, despite declining heat demands. In particular, in the Inno scenario the introduction of low-temperature district heat systems would both accelerate the penetration of high power-to-heat CHP technologies and improve the overall energy efficiencies of district heat systems.

In the low-carbon futures depicted for Finland, the use of biomass for energy not only

Nuclear fusion energy – a wild card?

Energy from the fusion of heavy hydrogen fuel (deuterium, tritium) is being actively pursued as a long-term, almost inexhaustible supply of energy. The scientific feasibility of fusion energy has already been proven, but its technical feasibility remains to be demonstrated in experimental facilities. A major international effort, the international thermonuclear experimental reactor (ITER) aims at demonstrating magnetic containment of sustained, self-heated plasma under fusion temperatures. This extensive pilot plant is being built in France, and it is intended to resolve the remaining scientific and engineering challenges requiring resolution. Upon successful demonstration of fusion power production, commercialisation of fusion is contemplated to begin at the earliest in about 2050.

Finland has been participating in European fusion research since 1995. Finland focuses its technological development on those areas which, in addition to strengthening fusion technology know-how, promote the position of local industry in fusion reactor projects, and which also have applications beyond fusion technology. Presently, the technology work related to the European fusion research programme is carried out at VTT, Aalto University, Tampere University of Technology and Lappeenranta University of Technology in close collaboration with Finnish industry.



Solar energy – wild cards?

In the future, solar energy may produce both electricity and heat in the same cell (multijunction cells). Traditional concentrating solar collectors can be used in co-operation with biomass connected to hot water or steam boilers in combined heat and power (CHP) production. Printed thin film technology for daylight use in outdoor and artificial light indoor locations is an interesting possibility. Also, infrared light in the electromagnetic spectrum is a possible way of extending the daily utilisation time of solar cell.

Significant viewpoints related to technology development and the future of solar energy are listed in the following.

- Thin film solar cells (R2R); the life-cycle in outdoor use must be longer; thin-film wallpaper for artificial light
- Energy storage at northerly latitudes will be solved. Advanced batteries, hydrogen, compressed air storage (CAES), etc. could be the answer to electricity storage
- Solar cell CHP material development is needed
- Solar energy improves process efficiency and economy in traditional CHP plant Solar cooling technology applications
- Solar technology integrated into building envelope elements and rapid connection
- Solar microbial-electro-synthesis (MES) processes for energy production

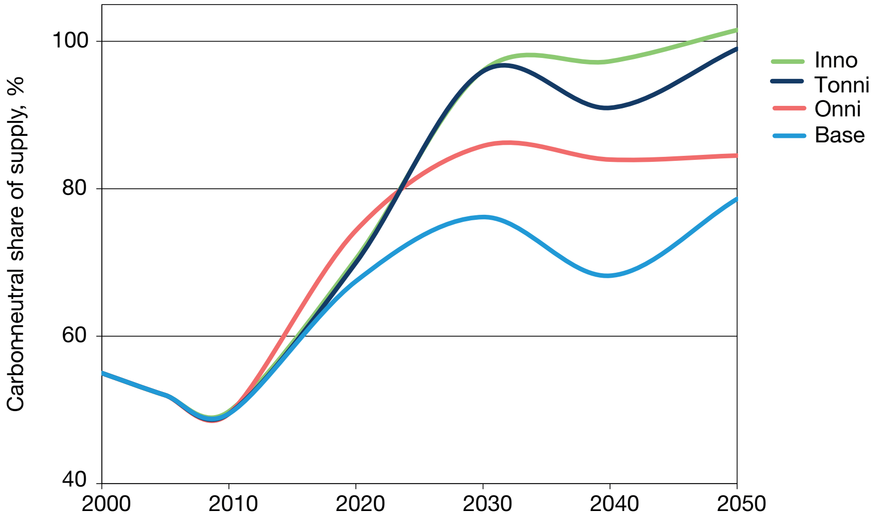


FIGURE 19. Carbon-neutral electricity production as a percentage of total domestic electricity supply. Essentially 100% carbon-free supply may be reached by 2050.

increases in power and heat generation but also in all end-use sectors. Most of the additional biofuel supply would still be forest biomass, and this implies that the biomass supply and logistics chain need to be continuously enhanced. In addition to forest residues, agricultural residues and energy crops would be utilized to a much greater extent than today. As it is foreseeable that in the future the true sustainability of the biomass supply will also need to be verifiable, the extensive use of biofuels, which also appears to be highly important in Finland's future low-carbon energy supply, may involve adopting more detailed accounting procedures.

Of the scenarios analysed, the Inno scenario would lead to the highest share of carbon-free electricity production, reaching 100% of the domestic supply by 2050 and even more for exports (Figure 19). Through the high nuclear power expansion programme, levels close to 100% could be reached also in the Tonni scenario, whereas the Onni scenario shows the share of carbon-free generation stabilizing at a level around 85% between 2030 and 2050. In the figure, the "negative" emissions with bio-CCS have not been taken into account, meaning that the Onni scenario could also reach 100% of carbon-free electricity if we compensate fossil emissions with bio-CCS. The dip in 2040 shows the impact of phasing out old nuclear – it takes some time before new low-carbon investments will have compensated for the loss in nuclear generation.

On the European level, the transition to a low-carbon economy is estimated to increase total electricity consumption, because of gradual electrification of energy use within all end-use sectors. However, at the European level too the structural changes in European industries may alter the electricity demand growth, but probably not as much as in Finland. On the supply side, decarbonisation is expected to involve very large amounts of renewable generation in the system, which poses additional challenges. Increasing the share of highly variable generation will also change the characteristics of the electricity demand that remains to be met by other generation options, and therefore also the competitive position of those.

According to the scenario results, wind power would become the most significant electricity supply option in Europe by 2040 (Figure 20). Solar power will provide an additional contribution to the variable generation but with a much smaller share. The combined proportion of variable generation from renewable sources would reach about 35% of European supply by 2050. Regarding other low-carbon options, the prospects of increasing nuclear power generation are estimated to be relatively small on the European scale. Moreover, decreasing heat demands are counterbalancing the potential for new combined heat and power production, which is therefore mostly possible only through increasing the power-to-heat ratios. On the other hand, biomass-based power generation may also become quite significant at the European level.

4.1.2 Energy use in industry is largely driven by the competitiveness of energy-intensive industries

Industry accounts for about one third of global energy use and for almost 40% of worldwide CO_2 emissions. Due to the favourable conditions for energy-intensive industries, Finland has long been among the countries with the highest shares of industrial energy use. The percentage share of industry in total final energy consumption has been around 50% in 2000–2010. By far the most significant industrial branch with respect to energy consumption has been the pulp and paper sector. In the scenarios the development of the energy-intensive industries was mostly varied only for the pulp and paper industries, but to a lesser extent also for the chemical industries. However, the projections used for the basic metal industries and non-metallic minerals were essentially the same in all the scenarios, and relatively optimistic in terms of production volumes. Based on these projections, the level of industrial final use of energy would remain quite high in the Base and Tonni scenarios, but would become substantially lower in the Inno and Onni scenarios.

The most important single factor behind the differences between the scenarios is the development of the pulp and paper industry. With the increasing volumes and conventional product mix in the Base and Tonni scenarios, the total industrial use of wood fuels would remain at roughly the present level up to 2050. However, in the Inno and Onni scenarios the black liquor yields from chemical pulp production would diminish considerably, thereby also reducing overall bioenergy consumption.

Fossil fuels currently account for about 70% of global industrial final energy consumption, but due to the large use of biomass in Finland they have played a smaller role. In certain industrial applications such as many basic metal manufacturing processes, fossil fuels may be relatively difficult to replace with renewable fuels or electricity. Consequently, largely due to the assumed growth projections for the basic metal industries, the industrial use of fossil fuels also remains at a high level in the low-carbon scenarios. This would, nonetheless, be compensated for by industrial CCS applications becoming competitive in the largest steel, pulp and cement mills, thereby making large

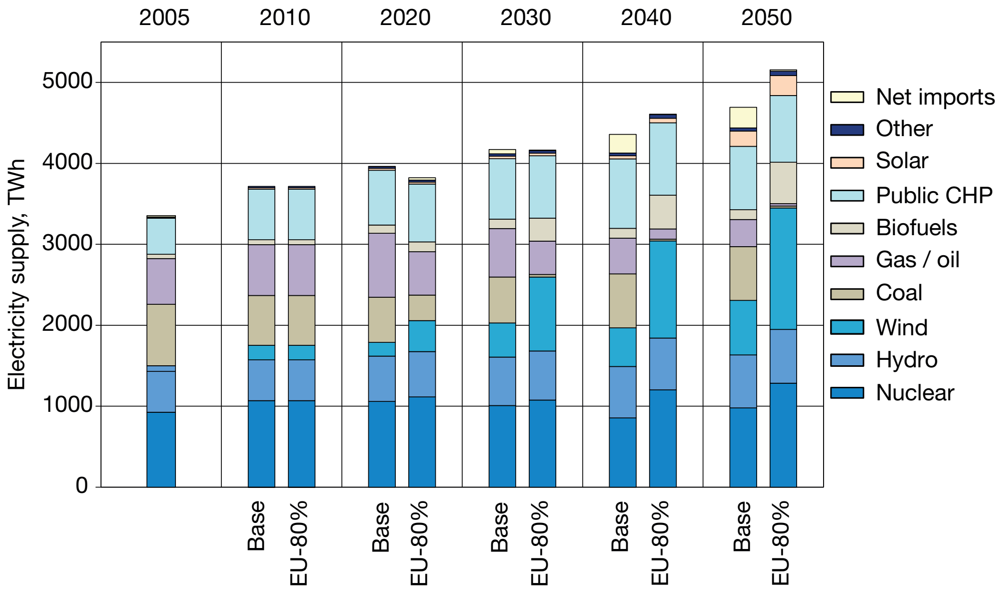


FIGURE 20. Electricity supply in Europe (EEA region + Switzerland + Former Yugoslavia + Albania). Variable renewable generation dominates the low carbon supply in Europe by 2050.

fractions of the fossil fuel use nearly carbon-neutral. The share of carbon-free final energy is highest in the Inno scenario, where it reaches 80% of total final energy consumption by 2050, while in the other low-carbon cases it is around 75% (Figure 21).

Although energy-intensive industries already have a good level of energy-efficiency in Finland, new processes can also bring about further major efficiency improvements in the low-carbon scenarios. These include, for example, high-efficiency mechanical pulping and new generation paper machines in the pulp and paper industry, as well as technologies making increasing use of recycled scrap as a raw material in steel-making. In the Inno scenario in particular, many new processes such as these are adopted between 2030 and 2050. In addition, gradual electrification is also contributing to emission reductions in the low-carbon scenarios.

In international statistics, the production of biofuels for transport is usually accounted for within the transformation sector, i.e. in energy production. However, in Finland these kinds of biorefineries would in many cases be best integrated into pulp and paper plants, where the processes could be optimized together with CHP generation and heat cascading, and therefore they are considered here within the industry. According to an IEA study, biofuels could provide about 30% of global transport fuels by 2050. In particular, the second generation biofuels could replace conventional diesel, kerosene and jet fuel.

In developed countries with the strictest targets for achieving low-carbon economy by 2050, the need for biofuels for transport may become substantial. In our low-carbon scenarios, the demand for transport biofuels would account for up to about 40% of the total final energy in the transport sector. Domestic production in Finland is not projected to be able to meet such a high demand, and a large part of it would have to be met by imports (Figure 22). The results indicate that a domestic production of 30–35 PJ could be achieved by 2050, accounting for 50–65% of the demand in Finland. However, by active measures for accelerating technology deployment and establishing the necessary incentives one could accelerate investments into the biorefineries. Nonetheless, one should note that sustainability of the imported biofuels in the producer countries was also required in the scenarios, through constraints on resource use.

As mentioned earlier, one should bear in mind that the use of stemwood for energy production was restricted in the scenarios and additional technical potential of biomass use could be realized by allowing the use of stemwood. The results indicate that, in comparison to the Tonni scenario, in the Inno and Onni scenarios there might, in fact, be room for some additional use of stemwood in biorefineries, because in these scenarios the total domestic fellings in 2050 remain at level of 6 and 25 Mm^3 lower than in the Tonni scenario, respectively.

4.1.3 Looking ahead to steep efficiency improvements in the building sector

Buildings account for almost a third of total final energy consumption, both globally and in Finland. Due to the cold climate, space heating is particularly important in Finland, but in the future space cooling may also be expected to play a larger role. Nonetheless, along with improving thermal insulation of buildings, specific electricity uses such as lighting and various appliances are becoming more predominant in building energy use.

Industry – perfect reactors as wild cards in technology development?

Being able to control chemical reactions at a molecular level would enable a major reduction in energy consumption in process industries, especially in the chemical industries. Better control of reactions translates to better selectivity and higher reaction rates, which would enable low-temperature processes, minimisation of waste and a reduced need for energy-intensive separation of products.

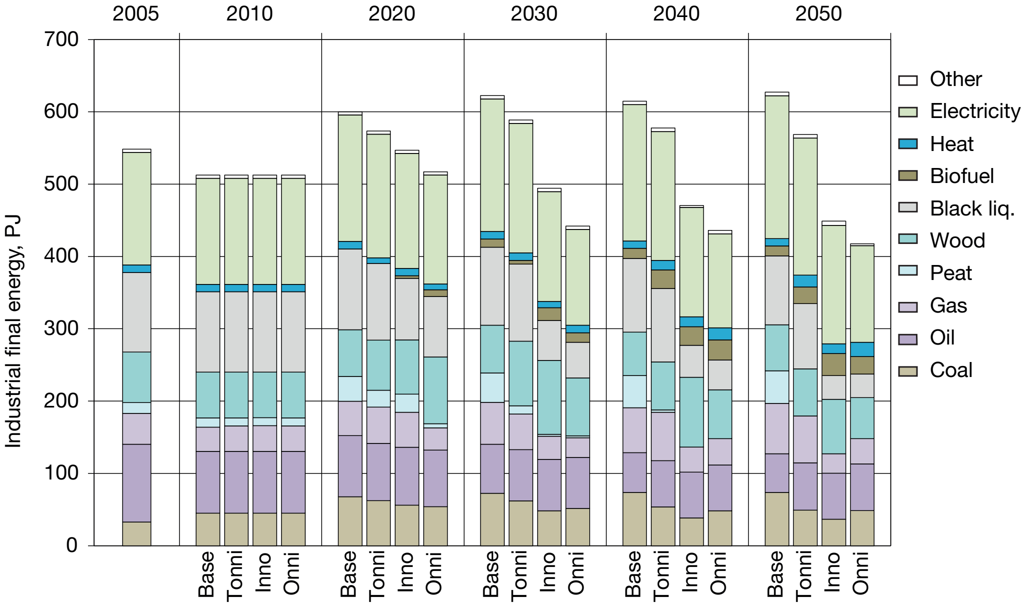


FIGURE 21. Development of final energy consumption in the industrial sectors. Introducing CCS helps decarbonising the industrial use of fossil fuels.

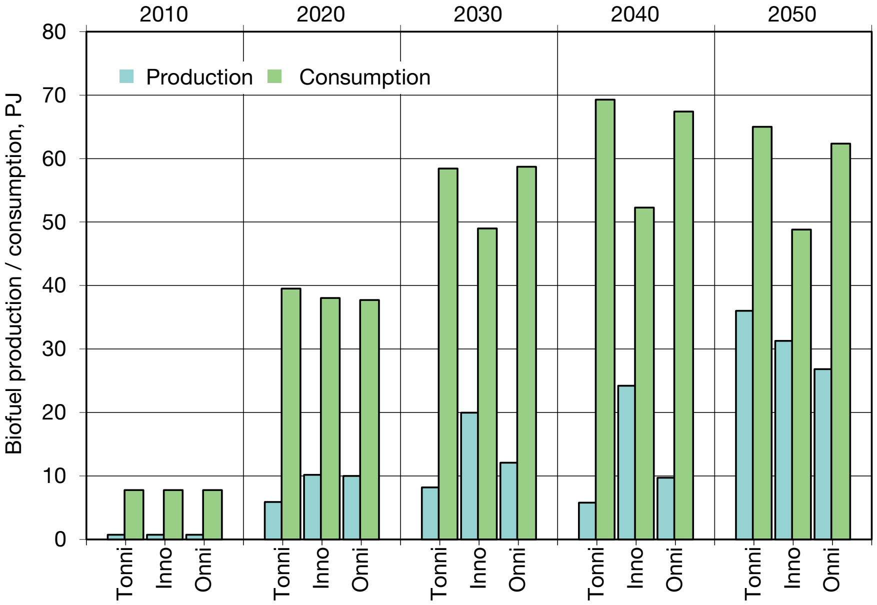


FIGURE 22. Consumption and production of transport biofuels in Finland. Technology push and incentives are needed to accelerate investments in domestic production.

In the low-carbon scenarios, the assumptions concerning the development of the building stock were tailored according to the projected urban structure and density, as well as consumer lifestyles and preferences. These differences are directly reflected in the results for final energy consumption. However, although urban planning does have an impact on energy efficiency, the results indicate that new low-energy building technologies and concepts are

Plus-energy buildings – a wild card?

A plus energy building has a net energy production higher than its consumption over a typical year. This is achieved through reduced energy demand for heat and electrical power, and this reduced demand is met on an annual basis from renewable energy supply. Typically, a plus energy building uses smart control technologies and is connected to district level smart networks. The renewable energy supply can either be integrated into the building design or provided for the specific building, for example as a part of a district renewable energy supply system. Real-time energy management will be an important aspect in matching energy demand and supply. In demand control by load shifting, many energy demand peaks can be delayed or advanced without a comfort penalty. Low exergy systems become very attractive in plus- and zero-energy buildings as they typically use low temperature level (waste heat) heat sources and high temperature cooling sources. Plus- and zero-energy buildings do not compromise a good indoor climate, but use intelligent control technologies to maintain optimum conditions while saving energy.

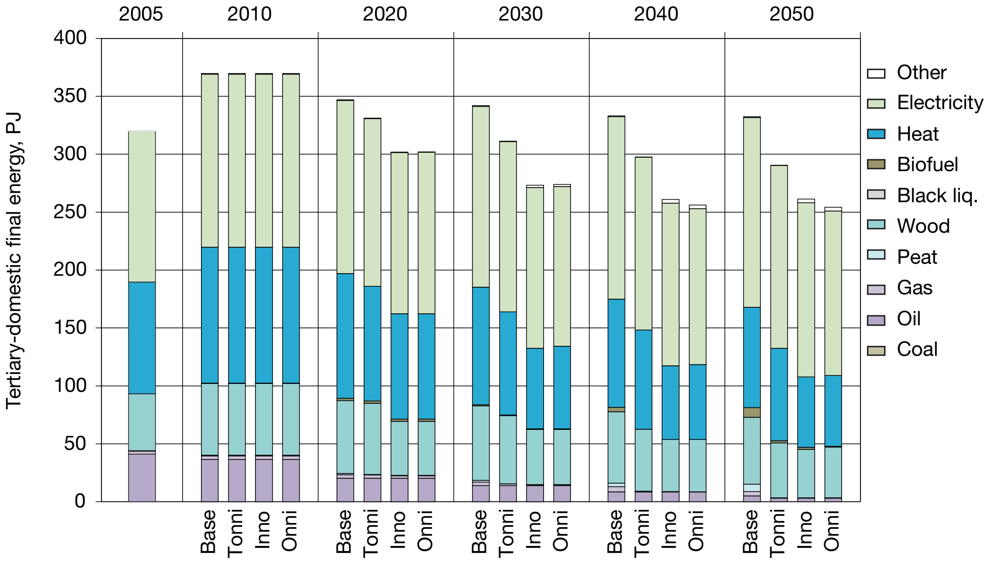


FIGURE 23. Development of final energy consumption in the residential and service sector. Buildings may have nearly 100% carbon-free final energy consumption by 2050.

even more important with respect to future energy consumption.

According to the results in the low-carbon scenarios, the total final energy consumption in buildings would be reduced by 17–30% by the year 2050, and the total demand for heating, including hot water consumption, would be reduced by 25–50% (Figure 23). Almost equally high savings are achieved in both the Inno and Onni scenarios, where the total heating energy requirements are roughly halved by 2050.

Among individual energy sources for heating, the use of mineral oil is practically phased out by 2050. Biomass-derived heating oils could be used as a substitute, but they gain a notable market share only in the Base scenario, and turn out to be less competitive in the low-carbon scenarios. While solid biomass still maintains its share among heating fuels, electrification becomes the most important trend when moving into low-energy housing, combined with supporting solar heat systems where the specific conditions are favourable.

In the Inno scenario, where the deployment of new technologies is most rapid, a wide range of high-efficiency technologies is extensively taken into use, such as LED lamps in residential and commercial lighting, various types of heat-pumps in heating systems, including multi-family houses, advanced district cooling systems and high-efficiency heat-pumps for commercial cooling. In addition, solar energy systems are both integrated into buildings for electricity and heat production as well as into district heating systems. In buildings with notable cooling demand, solar energy production can thus effectively compensate for the peaks in consumption during times of highest cooling loads.

With all the technologies and measures adopted in the low-carbon scenarios, the share of carbon-free energy in the total final energy consumption of buildings increases to 87% in the Onni scenario, to 93% in the Tonni scenario, and to 95% in the Inno scenario. In these figures, the percentage of carbon-free electricity and heat production has been taken into account. Consequently, in the Inno scenario the building sector would be practically carbon-free by 2050, and would locally even have a surplus of renewable energy production.

In terms of specific energy consumption the energy savings achieved in the building sector look even steeper in the low-carbon cases. While in the Tonni scenario the average specific heating energy consumption over the whole building stock still shows only a relatively moderate decrease of 37% between 2010 and 2050, in the Inno and Onni scenarios the average reduction achieved is as high as about 55% (Figure 24). Such major improvements are only possible through extensive renovation of the existing stock by 2050, in addition to the installation of nearly zero-energy new houses. They would also require a wide adoption of smart control technologies. Moreover, one should note that the transition to very low-energy houses also makes many traditional boiler-based heating systems less attractive, and contributes to the further electrification of the building sector, as reflected also by the scenario results.

Even if the building stock and urban sprawl become more marked in the Onni scenario compared to the Inno scenario, due to enhanced environmental awareness, renovations of the old stock were assumed to be even more extensive

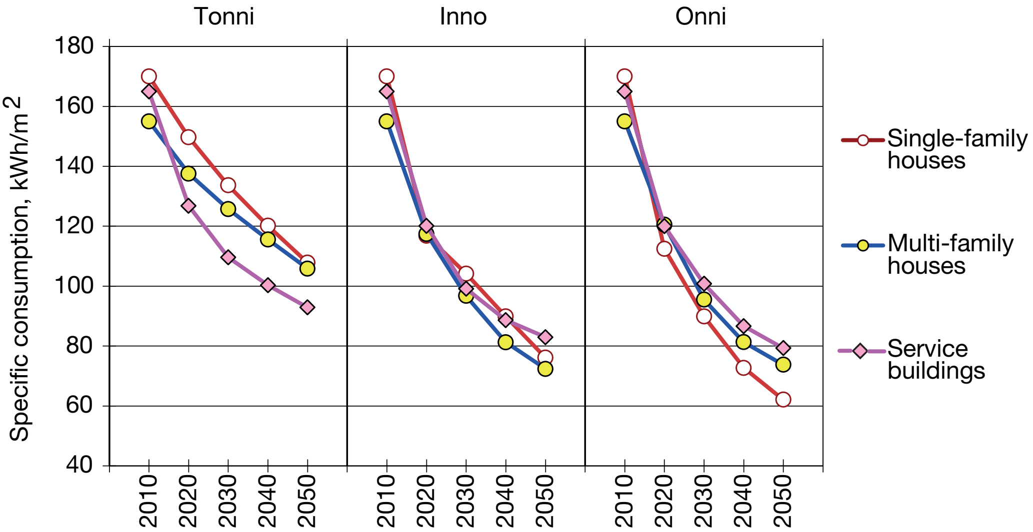


FIGURE 24. Development of the average specific heating energy consumption for space heating and domestic hot water in buildings. Considerable reductions in specific consumption can be realized by low-energy building concepts and smart control technologies.

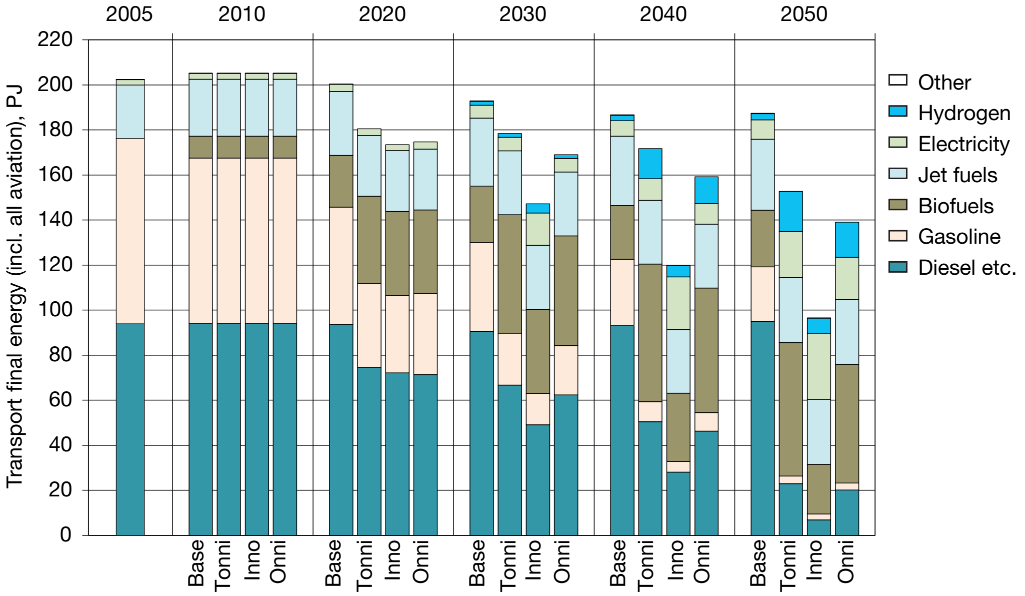


FIGURE 25. Development of final energy consumption in the transport sector. The future entails an increased variety of energy sources for the transport sector, but major uncertainties remain in the deployment of new vehicle technologies.

than in the Inno scenario, leading to roughly equal average consumption levels in both scenarios. In the Tonni scenario, the pace of renovations and new standards for new houses remain at a more moderate level. In addition, the removal of old service buildings occurs at a faster rate in the Inno scenario than in the two other scenarios.

4.1.4 Carbon-neutrality of transport made feasible by biofuels and advanced technologies

Domestic transport accounts globally for about 15% of total greenhouse gas emissions, and in Finland its contribution is currently almost 20%. However, if also international transport is taken into account, the share increases to well over 20% in Finland. In the low-carbon futures depicted, the development of the urban structure was assumed to affect transport volumes. However, only very small changes were assumed to take place in the relative shares of the various transport modes.

For passenger transport, in the Base and Tonni scenarios the overall volumes continue to increase in the future, although more slowly compared to historical growth. In contrast, in both the Inno and Onni scenarios the volumes will stabilize, and even turn into a decreasing trend in the Inno scenario, where the urban spatial structure becomes denser. For freight transport, the growth in volumes is again highest in the Base and Tonni scenarios, while the Inno and Onni scenarios exhibit only modest growth in goods transport. Due to more efficient logistical systems in the Inno scenario, the growth in the volumes levels out after 2030.

An increasing variety in the energy sources in the transport sector is clearly shown in the scenario results as soon as in 2030, and even more prominently by 2050 (Figure 25). Another clear trend is the shift away from petrol in passenger cars, first mainly to both diesel and biofuels, and later also to electricity and even hydrogen. In the low carbon scenarios, the demand for transport biofuels appears to peak around 2040, and thereafter the consumption begins to decrease along with further efficiency improvements and the market shifts towards electric and fuel cell cars.

Technology development and deployment both play major roles in decarbonising the transport sector. In the first phase, the development involves mainly further improvements in the fuel economy of new road vehicles, similar to those that have already been achieved during the 2000s. For example, the average fuel economy of new cars improves by about 50% by 2030 in the Inno

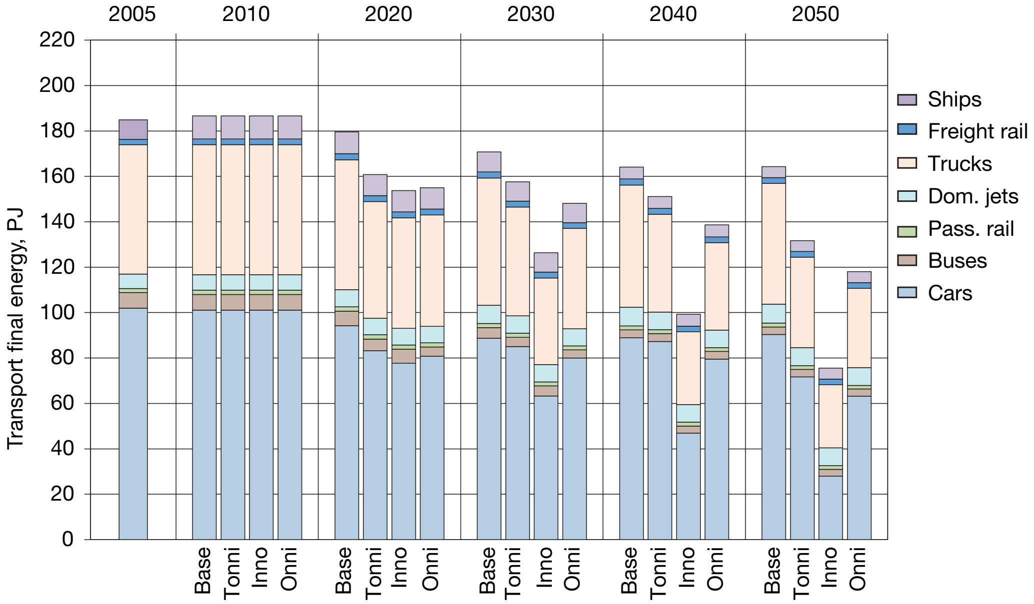
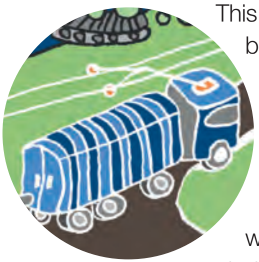


FIGURE 26. Final energy consumption in the transport sector by mode. Heavy transport appears to be the most difficult to decarbonize.

Electric highway (eHighway) – a wild card?

In low-carbon futures, rail transport is widely favoured over road transport, as trains can easily run on carbon-free energy. But what about taking the same kind of electricity feed systems used in trains and building "electrified" e-highways?



This technology is already available at a proof-of-concept level. It is based on a normal truck chassis, powered by a diesel engine, but also fitted with an electric motor and suitable pantographs that can take electricity from overhead contact lines. With their on-board power, trucks can run over crossings and other sections with dense traffic, and powerlines are needed only for extra-urban roads. Given time, it could be possible to replace the ICE with a decent sized buffer battery to keep the truck going over the stretches that do not offer overhead lines.

scenario. The second involves a break-through of new vehicle technologies, such as plug-in hybrid cars, which may even bring further improvements of over 100% by 2050. Consequently, the total improvement in the efficiency of new cars may be 100–200% in the low carbon scenarios, measured by the useful vehicle kilometres produced per unit of energy consumed. Moreover, the average useful energy efficiency of the car stock may also be increased by increasing the useful passenger loads, which was, in fact, assumed to be achieved in the Inno scenario, but not in the other two scenarios (Figure 26).

Looking at the total final energy consumption in the scenarios, the results show a significant reduction in all of the low carbon cases, but the Inno scenario clearly stands out in achieving by far the lowest level of consumption by 2050. The steep

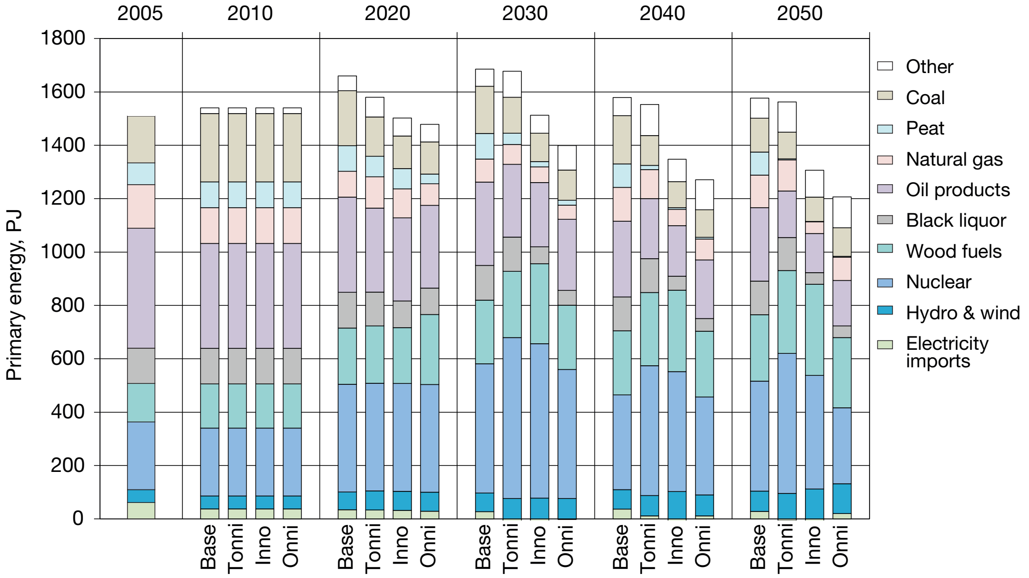


FIGURE 27. Primary energy consumption by main energy source. Dependency on imported fossil fuels will be greatly reduced by 2050. The share of imported fossil fuels of primary energy consumption is 22% in the Tonni scenario, 21% in the Inno scenario, and 27% in the Onni scenario.

Microbial electrosynthesis (MES) – a wild card?

The new emerging technology – microbial electrosynthesis (MES) – offers a possibility of a completely new way of producing fuels and chemicals in the future.

In microbial electrosynthesis, electrons are supplied directly to microbial cells by applying an electric current. The electrons are used by the cells to convert carbon dioxide to value-added chemicals or fuels with great efficiency. The system combines the features of an electrochemical cell and a microbial fermenter. Ideally, the electric current would be produced by a renewable energy source such as solar energy.

improvements in energy efficiency are mostly achieved by large shifts into all-electric cars and advanced hybrid vehicles in heavy transport. As a consequence, by the year 2050 the demand for transport biofuels also ends up being much lower in the Inno scenario compared to the other scenarios.

With respect to decarbonising the economy, transport has often been considered among the most challenging sectors. Notwithstanding this, the results of the scenarios demonstrate that large reductions in both energy use and greenhouse gas emissions are also possible in this sector. As in other sectors, the share of carbon-free energy in the total transport final energy consumption is the highest in the Inno scenario, where it reaches the very impressive level of 80% by 2050. Greenhouse gas emissions from domestic transport are in this case reduced by an even higher percentage, about 90%, because in addition to decarbonisation, the scenario also includes high efficiency improvements. In the other two low-carbon scenarios, Tonni and Onni, the share of carbon-free energy remains at slightly less ambitious levels, and is about 70% by 2050.

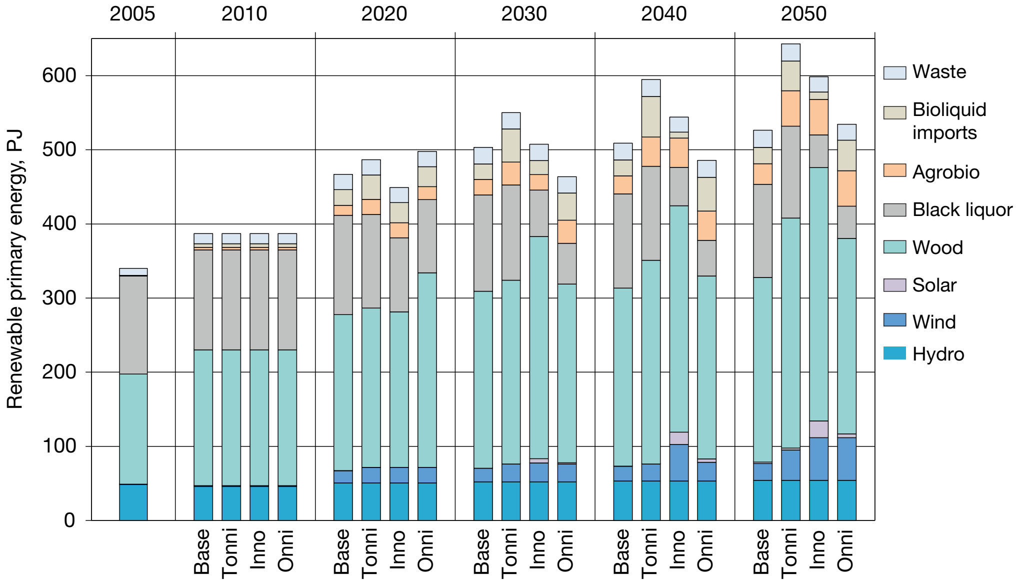


FIGURE 28. Development of renewable primary energy supply in Finland. Close to 50% of primary energy may be renewable by 2050.

Microalgae – a wild card?

Microalgae is a new and interesting biomass feedstock option for bioenergy production and for biorefining.

Microalgae contain lipids, proteins, polysaccharides and other biomolecules. The lipids are extracted and used in the same way as vegetable oils, i.e. in the production of biofuels. The carbohydrates fraction could, for example, be hydrolysed and fermented to ethanol or butanol. Under defined conditions, microalgae can produce hydrogen or ethanol. New efficient process concepts could be built by combining algae cultivation with waste water treatment systems, and utilising waste-derived nutrients and carbon sources together with low-temperature waste heat and CO_2 from flue gases.

However, as the development of future car technologies is by and large determined by the international markets and can be little affected by measures taken in Finland, there remain considerable uncertainties concerning the predominant technologies in the 2050 markets. These could be advanced hybrid cars, all-electric cars, or hydrogen fuel cell cars, or even liquid nitrogen cars. Therefore, one should consider the results as only indicative of the plausible developments in transport technology performance under strict low-carbon economy targets.

As already mentioned above, the relative shares of the various transport modes were assumed to remain rather stable in all of the scenarios (Figure 26). Perhaps most importantly, this implies that passenger transport is assumed to continue to be dominated by car travel, and freight transport continues to be dominated by trucks. These assumptions are reflected in the high shares of car travel and truck transport in the overall final energy consumption by transport mode. Furthermore, one can see that, in the scenario leading to the lowest consumption and

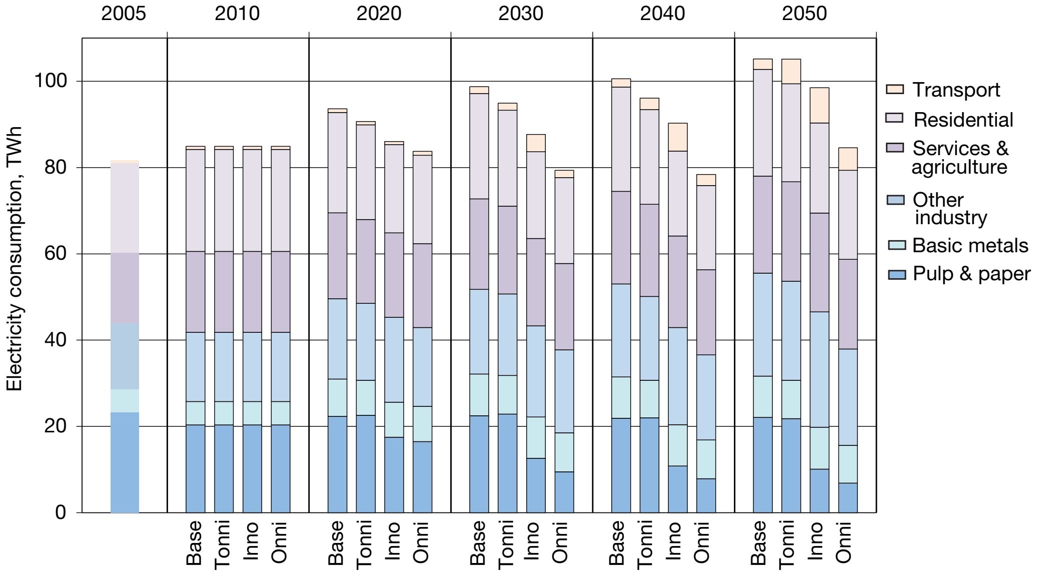


FIGURE 29. Development of electricity consumption in Finland by main sector. Industrial development strongly affects the electricity balance.

emissions, the Inno scenario, heavy transport has a much higher share of the remaining energy consumption compared to its current share. On the basis of the results, heavy transport appears to be the most difficult mode in terms of achieving efficiency improvements and subsequent decarbonisation, although with the extensive use of biofuels even that mode can be made nearly carbon-free. The prospects for applying electric fuel-cell vehicle technologies to heavy transport are fairly poor, because of the relatively low power densities of these technologies. However, a break-through in so-called electric highway technology might change the picture for future heavy transport as well.

4.1.5 The overall energy system is able to comply with low-carbon commitments

In the Base scenario, total primary energy consumption in Finland rises to about 1680 PJ by 2030, but starts to decline thereafter. In the low-carbon scenarios, primary energy requirements are, in general, at a lower level, particularly in the Inno and Onni scenarios (Figure 27). One should note that the rise in primary energy by 2030 is mainly due to the expansion in nuclear power, which has quite high fuel consumption when presented in terms of primary energy. Among fossil fuels, the use of coal and peat are most sensitive to climate change policies, and subsequent prices of emission allowances, and decrease steeply at higher price levels. The remaining use of coal in the low-carbon scenarios occurs mostly in the manufacturing of basic metals and cement, where fuel substitution is much more difficult. The use of oil decreases considerably in all scenarios and already in the short term, but in the longer term the reductions become much more rapid in the low-carbon scenarios, where the consumption may drop by 65% by 2050. For natural gas, the overall trends are similar to those for oil, but the decreases are much more moderate.

Compared to most other countries, the utilization of biomass for energy is already currently at a very high level in Finland. In 2010, bioenergy accounted for about 20% of total primary energy consumption, and most of it is used in industrial scale energy production. In the low-carbon scenarios the use of wood fuels increases further, such that by 2050 it is 50–85% higher than in 2010, when black liquor is not counted. Moreover, the use of both agrobiomass and imported liquid biofuels also play a notable role in 2030–2050. However, in the Inno and Onni scenarios the declining production volumes of the pulp and

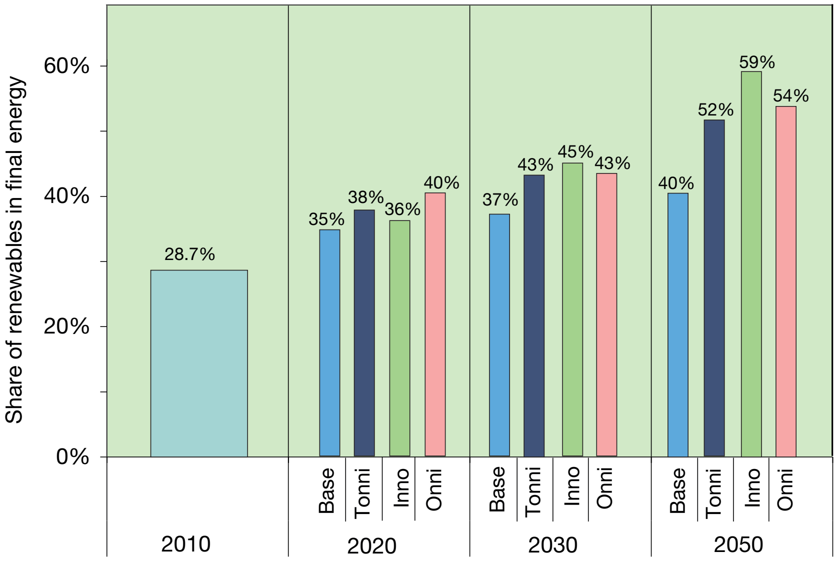
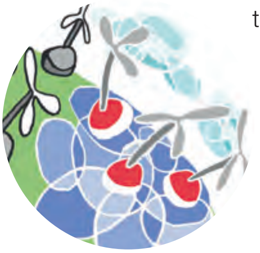


FIGURE 30. Share of renewable energy in final energy consumption in Finland. With some technology push, renewables may account for 60% of final energy by 2050.

Floating offshore turbines and kite turbines – wild cards of wind energy?

Prototypes of floating offshore turbines are currently being tested. If the technology reaches cost-competitiveness, it would tap into a larger potential of offshore wind power in deeper waters than is currently possible. Currently offshore foundations are difficult to construct, partially due to a strong variation in seabed quality. Floating turbines would enable a larger portion of the construction to be unified, which would potentially lead to cost savings



Energy in wind is greatest at heights of more than 1,000 metres above ground level. The resource is also more stable at short time scales as well as longer time scales. Kite turbines are being tested that would be able to use this resource. The cord attached to the kite pulls a generator on the ground when the kite is rising. Then the kite is allowed to drop while the cord is pulled back in. The economics of the design are unclear.

paper industries cause a marked reduction in the use of black liquor for energy, which counterbalances the large growth in other wood biomass utilization. The considerable increase in the use of wood for energy in the Inno scenario would thus not be reflected as an increase in fellings.

Looking at the total contribution from all renewable energy sources (Figure 28), the largest amounts are utilized in the Tonni scenario during 2030–2050. However, if black liquor use is not taken into account, the Inno scenario represents the highest utilization rates of renewable energy. Among the non-biomass renewables, the Inno scenario includes the highest utilization of both wind and solar energy, but a slightly lower utilization of waste for energy. The range of the total

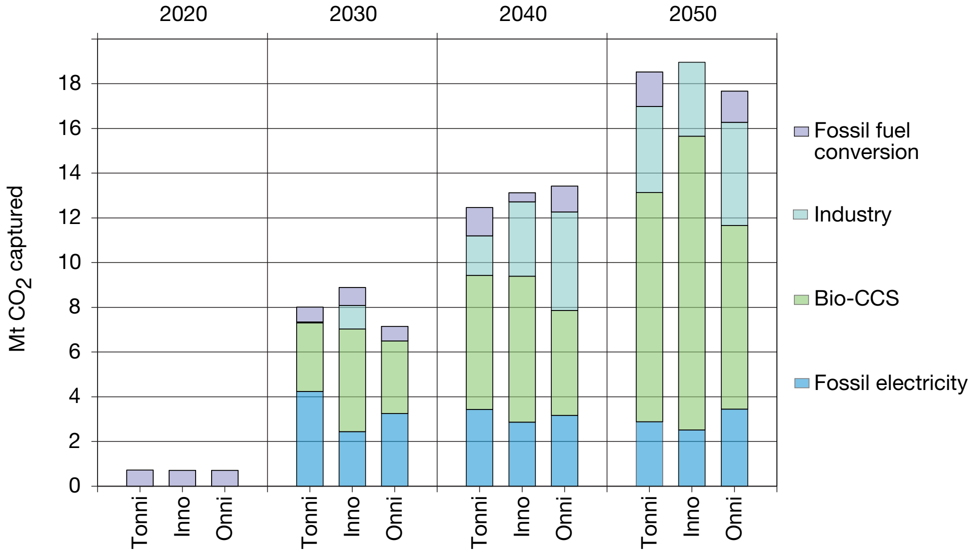


FIGURE 31. Potential application of CCS in Finland. The negative emissions from BECCS appear to have considerable prospects in Finland.

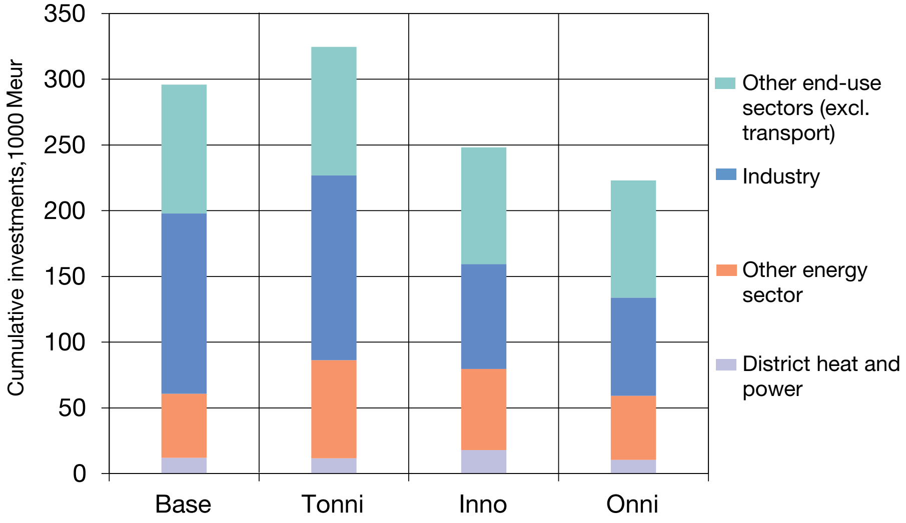


FIGURE 32. Cumulative investments in the energy system, excluding the transport sector. End-use sectors dominate total energy-related investments, and the development of energy-intensive industries has a major impact on overall investments. District heat and power includes CHP plants, heat plants and district heating network.

primary supply of renewable energy in the low carbon scenarios is 540–640 PJ in 2050.

By far the greatest uncertainties in the renewable energy potentials appear to be related to the agrobiomass potentials. Agrobiomass includes both various residues from food-related crop production and the production of dedicated energy crops. Nevertheless, as the estimates used in the scenarios were not taken from the high end of the range of the estimates published, and as the agrobiomass potentials represent a relatively small part of total renewable energy resources, these uncertainties do not have a great impact on the results.

Concerning overall electricity consumption, in 2030 the total consumption is 99 TWh in the

Base scenario but 79–95 TWh in the low carbon scenarios, of which the highest consumption appears in the Tonni scenario and the lowest in the Onni scenario. Accordingly, in the Onni scenario, the total consumption would in 2030 already be less than in 2005. When going further into the future, the increasingly stringent policies start causing additional electrification in the energy economy, which becomes particularly visible in the transport sector by 2050. In the low-carbon scenarios, total electricity consumption amounts to 85–105 TWh in 2050, with the Onni scenario again having the lowest and the Tonni scenario the highest consumption.

The differences in overall electricity consumption between the scenarios (Figure 29) are to a great extent explained by the assumed divergence in the development of energy intensive industries, in particular the pulp and paper industry, which are only to a small degree cancelled out by reverse differences in the growth of light industries in the Inno and Onni scenarios. Consequently, future industrial development may also be considered to be one of the most important uncertainties with regard to the future energy economy of Finland.

In the European Union, directives on renewable energy define national targets for the share of renewable energy in total final energy consumption. The compliance with the targets is measured by detailed calculation rules, which for Finland produce a realised share of 28.7% in 2010, while the target for 2020 has been set at 38%. Using a more or less similar methodology, the development of renewable energy in total final energy consumption has been calculated from the scenario results (Figure 30). According to these calculations, in the Base scenario Finland would not achieve the target for 2020, but would reach it in the Tonni and Onni scenarios. Interestingly, the Inno scenario would still fall short of the target by about 2 percentage points. However, one should note that some of the current national policies were not forced to be fully implemented in the scenarios, such as the promoting of the use of forest chips in the district heat sector, and the sizeable targets for the increase in using heat pumps in buildings. Taking into account these factors, Finland seems to achieve its renewable target for 2020.

Even if lagging somewhat behind the renewable target in 2020, the Inno scenario would rapidly pass the other scenarios after 2020 and achieve the highest renewable shares in 2030–2050. The results indicate that, with accelerated technology deployment and incentives, a renewable share of 60% would be feasible by 2050. All of the three low-carbon scenarios reach a share of 52% or higher in 2050, while the baseline stays at around the 40% level. However, there are great uncertainties related to long term fossil fuel prices, which could have an impact on the rate of renewable deployment. In the TIMES VTT calculations, fossil fuel prices depend on global demand and supply, which both have great uncertainties as well.

Achieving a truly low-carbon economy requires very strict reductions in carbon emissions, which in this work have been simulated by assuming an 80% overall greenhouse gas reduction target by 2050 for Europe as a whole. Such substantial reductions would be very difficult to achieve purely by domestic measures, unless measures to increase carbon sinks are also taken into account. There are several important ways of increasing the sinks, but in the present scenarios only the CCS options, including the BECCS option (Bioenergy with Carbon Capture and Storage), were taken into account for Europe, as they are de facto already accepted in the UNFCCC emission inventory reporting. The current reporting guidelines make no distinction between CO_2 captured from fossil and biomass sources. However, due to geological conditions, there is practically no carbon storage potential in Finland, and therefore applying CCS in Finland would require long transport of the CO_2 captured into suitable disposal sites. Possible disposal locations include Norwegian sites in the North Sea and Barents Sea areas as well as some sites around Denmark. The estimated transport costs to representative sites at comparable distances were included in the scenarios calculations.

According to the results, CCS would indeed become a viable option in Finland, and, due to the extensive industrial scale use of biomass in Finland, particularly the BECCS option. In all three low-carbon scenarios, the total application of CCS would amount to about 18 Mt of CO_2 in 2050, of which BECCS would account for 45–65% (Figure 31). Apart from small-scale pilots, the first CCS-enabled plants would be installed some years before 2030. The CCS plants would include large-scale extraction turbine CHP plants,

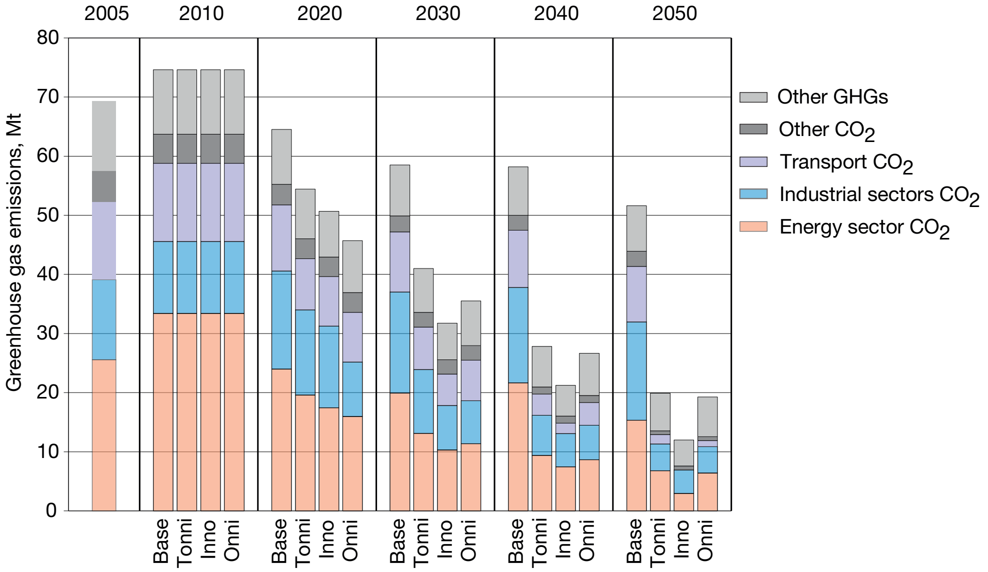


FIGURE 33. Development of greenhouse gas emissions in Finland in the no-CCS cases. With technology deployment and innovation, low carbon economy can be achieved also without CCS, albeit the additional costs will most likely be higher.

biorefineries, steel and pulp mills, and possibly also cement mills. The negative emissions from BECCS would offset the small remaining use of fossil fuels in the energy, industrial and transport sectors, such that in net terms the economy would be practically carbon-free, especially in the Inno scenario. Most of the remaining GHG emissions would then consist of non-CO_2 emissions from non-energy sources, in which substantial reductions may become very costly. However, because the feasibility of large-scale utilization of CCS technologies still involves considerable uncertainties, a sensitivity analysis was carried out, assuming that the CCS option would not be available in Finland (see Section 4.2).

The macroeconomic impacts of the strict policies depicted in the low carbon scenarios have been estimated in Section 4.3. Concerning the direct investments into the energy system, the results indicate that the additional cumulative investments caused by the low carbon policies would be of the order of €300 billion by 2050 (Figure 32). Compared to the overall investments in the whole the energy system, which would have to be made anyway, this burden is not overly large. However, one should point out that a large proportion of the overall investments occur in the end-use sectors, especially industry, and are usually far from purely energy-related investments. Considering only the energy sector proper, the estimated increase in investments would be over 40%, which is already quite substantial.

4.2 SENSITIVITY ANALYSIS HIGHLIGHTS THE ROLE OF TECHNOLOGY DEPLOYMENT

4.2.1 The Case of no CSS in Finland

In order to put the analysis on firmer ground with respect to the viability of CCS in Finland, we also analysed – for all of the low-carbon scenarios – a variant case in which CCS was assumed not to be available in Finland for either political, technical or economic reasons. In these sensitivity analysis cases, it was also assumed that bio-CCS, or BECCS, would not at all be considered acceptable in Europe, for example, due to being suspected of offering incentives to the non-sustainable use of biomass.

The results from these sensitivity analysis scenarios appeared quite encouraging from the perspective of technology deployment: The general target of an 80% greenhouse gas emission reduction by 2050 proved to be still well achievable in the Inno scenario, although the Tonni and

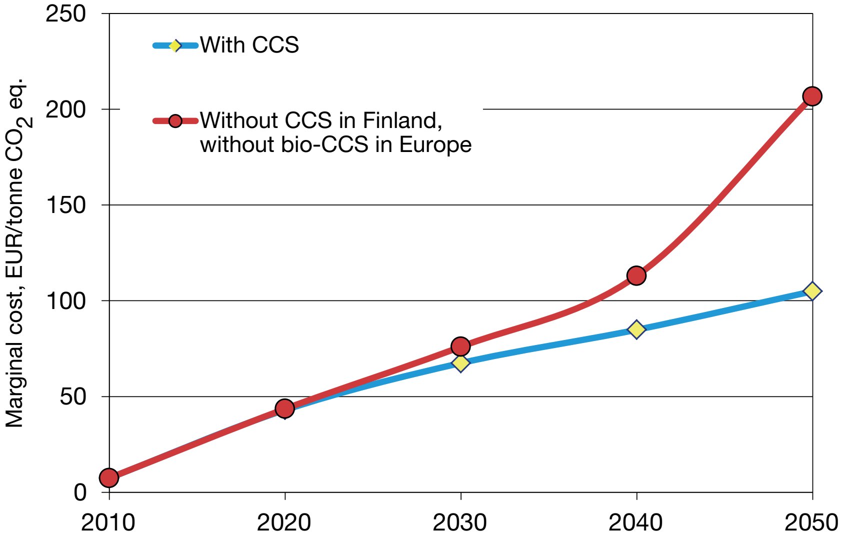


FIGURE 34. Marginal cost of greenhouse gas emission mitigation in Europe. Model results indicate that enabling BECCS may have a considerable impact on marginal costs by 2050.

Smart city – a wild card?

The smart city can be defined as a concept of innovative and interactive design, as well as an intelligent and resilient operation of the whole urban built environment. Urban performance depends not only on the city's infrastructure, but also on the availability and quality of knowledge communication and social infrastructures. Smart cities can be identified by the following main factors: a smart economy, smart mobility, smart environment, smart people, smart living and smart governance. The smart city includes urban, social, and natural systems (including urban form, buildings and infrastructure, energy and material flows, governance and human behaviour) and their intelligent management and control. The intelligent use of systems includes energy, traffic and other infrastructures, governmental and educational systems as well as communications, well-being and leisure activities. Sensor networks and intelligent communication is one of the key technologies that helps create smart cities.

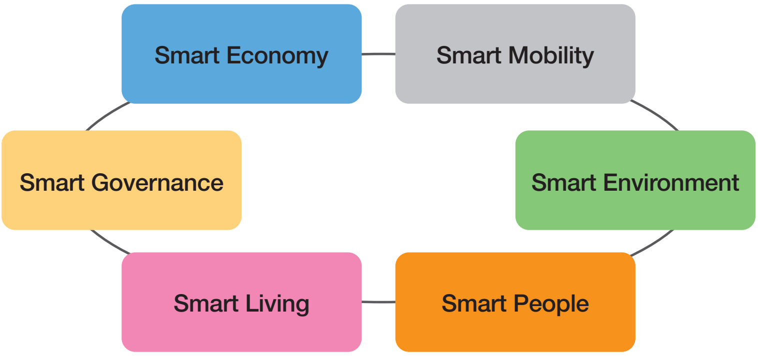


TABLE 7. Assumptions concerning the Smart City analysis case.

Sector	Smart City characteristic	Modelled impacts
Energy distribution	Two-way networks for electricity and heating	Increased capacity credit for variable generation
Dwellings	Telepresence and telecommuting Smart control systems	Modestly increased efficiency in living space usage Added flexibility in consumer loads
Services	Telepresence and telecommuting Smart control systems	Markedly increased efficiency in service space usage Faster renewal rate of the building stock Added flexibility in consumer loads
Transport	Telepresence and telecommuting Smart logistics	Markedly reduced passenger car transport volumes Reduced light goods transport volumes

Onni scenarios were no longer able to comply with the target (Figure 33). In fact, the Inno scenario still reached 85% emission reductions, while in the Tonni and Onni scenarios the reduction was around 75%, i.e. below the criteria set for the low-carbon economy. The most notable differences between the CCS and no-CCS cases occurred in the energy production sector, where practically zero net emissions were reached in the CCS case, but without CCS some of the fossil fuel emissions could not be avoided at a reasonable cost. Similar differences were also noticeable in the industrial sector emissions.

Another interesting result from this sensitivity analysis was related to the marginal costs of decarbonising the economy, measured by the marginal cost of reducing greenhouse gas emissions in Europe. In the base cases, with all CCS options available throughout Europe, the marginal costs increased gradually to approximately the level of €100/tonne by 2050. However, in the sensitivity analysis cases where BECCS was completely disallowed in Europe, the marginal costs started increasing rapidly when approaching 2050 with its very strict emission target (Figure 34). Coincidentally, the resulting marginal cost at the end of the horizon was roughly doubled compared to the base case scenarios. This implies that the reduction target of 80% is, indeed, already on such a stringent level that either BECSS, other carbon sink options, or flexible mechanisms would deserve consideration in addition to the direct emission reduction measures within Europe.

4.2.2 The Smart City Case

As described in the previous sections, the building and transport sectors already reached very high levels of carbon-free energy consumption in the low carbon scenarios. However, in many visions the performance of the urban structure, lifestyles and working styles could be further enhanced towards so-called smart city concepts, in which ICT and local energy production and control systems play a more prominent role. Therefore, we also analysed a Smart City-oriented variant of the Inno scenario in order to see how large the overall impacts of these concepts might be on the energy system in Finland. The characteristics that were considered in the analysis and their direct impacts are described in Table 7.

According to the results from the Smart City exercise, the overall conclusions from the base case analysis would not be significantly affected if a break-through of the Smart City concept were

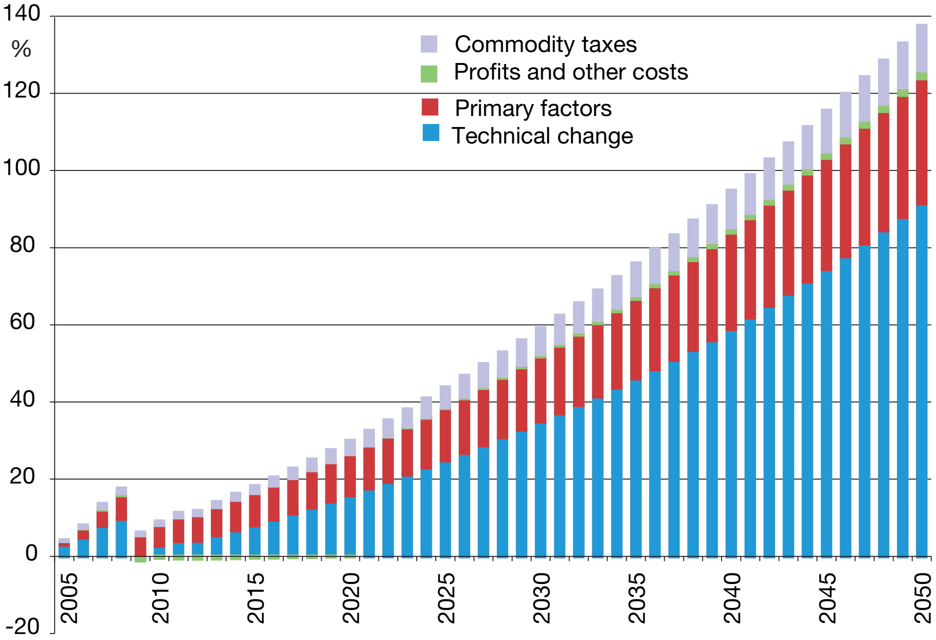


FIGURE 35. GDP growth from 2004 in the base scenario.

to occur. This is mainly due to one of our base scenarios already being the very technology-oriented Inno scenario, which in fact had some of the characteristics of Smart Cities embedded in its assumptions. Nonetheless, the concept did have a notable impact on the final energy consumption of the services and transport sectors, which were both reduced by roughly a further 15% compared to the Inno scenario. As the Smart City concept will thus offer efficiency improvements even beyond the Inno scenario, the results may be viewed as strengthening the conclusions about the feasibility of the Low Carbon vision for Finland through the deployment of new technology.

4.3 ECONOMIC SCENARIOS

The Low Carbon Finland 2050 scenarios involve a huge change in technology over the next half-century or so, but the key drivers of economic growth remain essentially familiar. To generate growth, the economy has to have access to more factors of production and to better ways of using them. Fundamentally, potential GDP growth is thus driven by employment growth and technological change. Taking as a starting point the most recent population forecasts for Finland, our scenarios assume only modest growth in labour supply. Therefore, growth needs to stem from technological change. This is depicted for the Baseline scenario in Figure 35, showing how two thirds of growth stems from technological change, with primary factors – labour and capital – generating most of the rest. The figure also shows the contributions of profits and commodity taxes by their definition.

In all of the Low Carbon Finland 2050 scenarios, real GDP grows by a factor of 2.4 compared to the year 2004, reaching a level of about €540 billion in real terms by 2050. Real GDP per capita attains a level of €88,500 (at 2004 prices) in the baseline, €86,700 in the Tonni scenario, and €87,900 in the Inno scenario. In terms of economic welfare, there is thus not much to choose between the scenarios.

The policy scenarios differ little from the baseline in terms of the fundamental drivers of growth, and by 2050 both the Tonni and Inno scenarios attain nearly the same level of GDP as the baseline. For this to be possible, new technologies discussed elsewhere in this volume need to be developed and utilized on a large scale in order to maintain the same level of overall productivity growth in the economy. To give one example, it would be impossible to attain the baseline levels of technological change without using CCS in many of the heavy industries; to give another, the

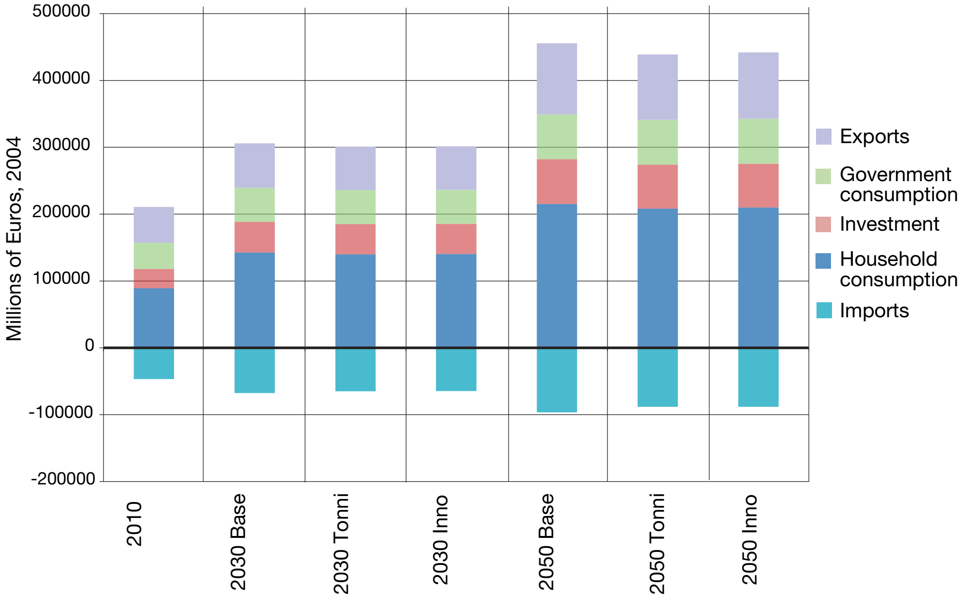


FIGURE 36. Use of GDP in the Low Carbon Finland 2050 scenarios (in millions of Euros, 2004).

functioning of the logistics of the modern economy can only be secured with dramatic advances in fuel efficiency.

Population growth is as important for the development of the demand structure of the economy as it is for the supply of goods and services. The aging of the population affects labour supply, which, over the next decade or so, is likely to decline – but also the patterns of consumption. Older generations tend to consume more services than younger ones, and they constitute the major clientele of many publicly provided services, such as health care. These effects can be seen from Figure 36, which shows the use of GDP in the baseline, and in two of the Low Carbon Finland 2050 scenarios.

In all scenarios, the share of consumption demand is increasing compared to 2010. Finland is thus becoming more of a service economy than in previous decades, which also shows in the declining share of exports in the use of GDP. An important factor contributing to this is also economic growth itself – as consumers become wealthier, they increase their demand for goods and services that previously were seen as non-essential.

Figure 37 shows the value added of major industry aggregates, picking up the major differences between the Low Carbon Finland 2050 scenarios. In the Tonni scenario, heavy industries continue to thrive in the export markets, whereas in the Inno scenario, it is the manufacturing industries that account for a larger share of exports. The drivers of domestic consumption, however, are the same as in the baseline and there is little to choose between the scenarios.

The Low Carbon Finland 2050 scenarios also have very different regional implications, as regional growth depends on the prevalence of growing industries. This is seen from Figure 38, where for example the manufacturing industry-driven growth in the Inno scenario implies markedly higher employment growth compared to 2004 in the Pohjanmaa regions, known for their thriving machine shops and the like, than the Tonni scenario, which benefits in relative terms more those regions that host heavy industries.

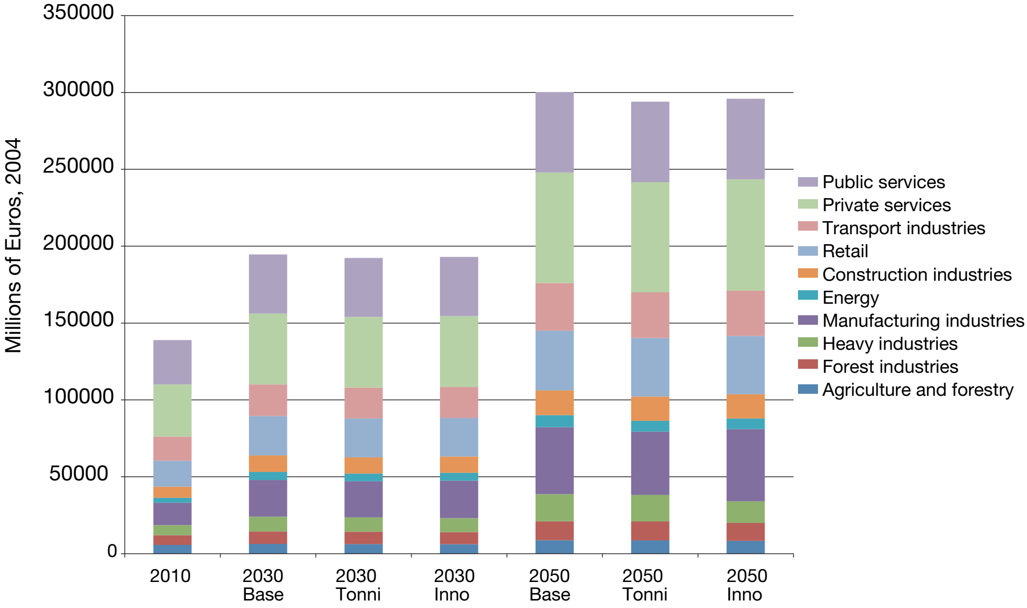


FIGURE 37. Value added of industry and service sectors (in millions of Euros, 2004).

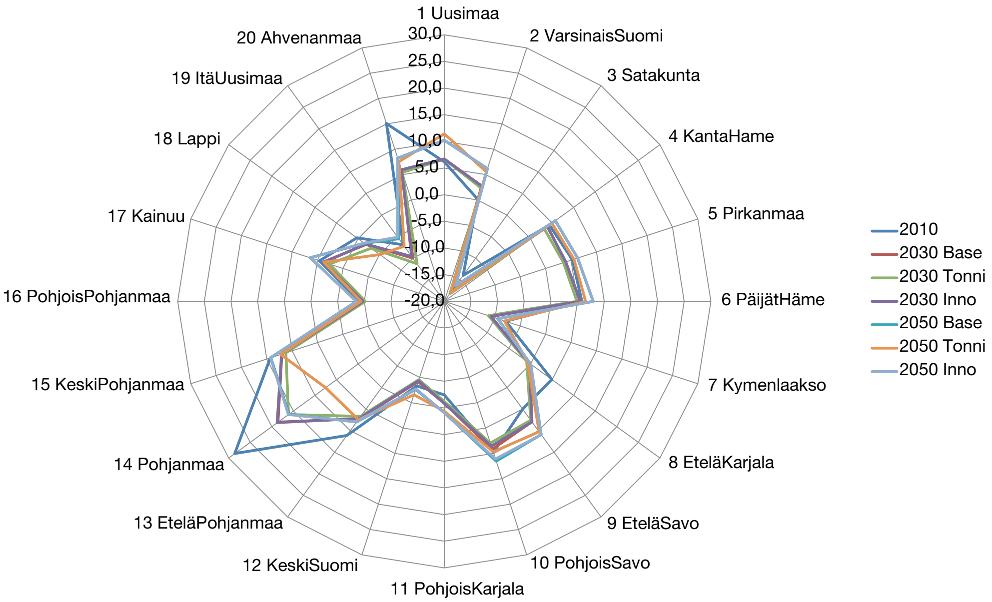


FIGURE 38. Regional employment (percentage change from 2004).

5 Conclusions

5.1 LESSONS FROM THE SCENARIOS

5.1.1 A low carbon society calls for 70–100% greenhouse gas reduction in all the sectors

Achieving a reduction of 80% in greenhouse gas emissions compared to the 1990 level is a great challenge, but possible if all the sectors respond to the mitigation target (Figure 39). With an extensive technology push in clean energy technologies by RD&D, even a 90% GHG reduction might be possible due to Finland's good opportunities in effectively producing and using carbon free energy in all the energy end use sectors.

- **85–100% of domestic electricity production could be carbon-free by 2050.** If we take into account "negative" emissions reached using bio-CCS, 100% could also be reached in the low-nuclear case.
- **In industry, with considerable efficiency improvements and with CCS, about 80% of industrial final energy could be carbon-free.** Efficiency improvements include new high-efficiency processes, and an increased use of recycled materials. In addition, gradual electrification is also contributing to emission reductions in the low-carbon scenarios.
- **In transport, the share of carbon-free energy** in the total final energy **consumption reaches 70–80% by 2050. 25–50% reductions in final energy consumption** are achieved by the steep improvements in energy efficiency produced by major shifts into all-electric cars and advanced hybrid vehicles in heavy transport. The demand for transport biofuels would account for up to 40% of the total final enery in the transport sector.
- **In buildings, from 85% to 95% carbon-free energy** in the total final energy consumption may be reached by 2050. Locally, buildings could even have a surplus of renewable energy production.
- In addition to CO_2 all the other greenhouse gases should also be substantially reduced.

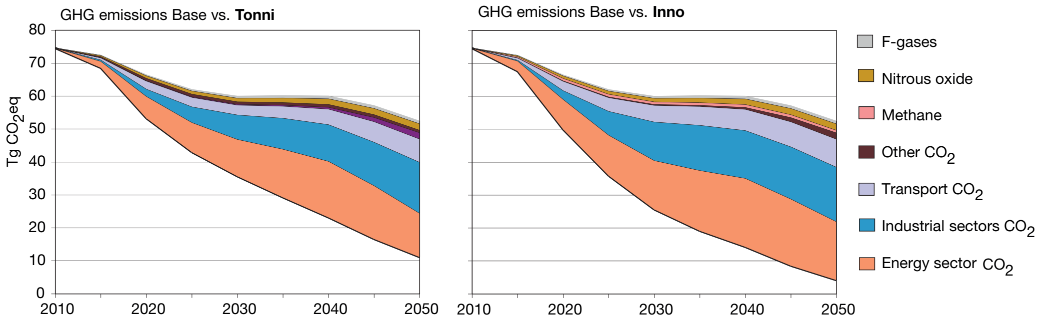


FIGURE 39. Greenhouse gas emissions in the Tonni (left) and Inno (right) scenarios compared to the Baseline. Other includes the residential, commercial and agriculture sectors.

5.1.2 Diversified energy production needed for cost efficient mitigation – with renewables, 50-60% of Finland's energy services could be covered

Characteristically Finland's energy policy has traditionally managed to establish a versatile energy system, based on both large and small scale energy production and diverse energy sources. In the low carbon society, the same characteristic appears be a cost effective solution, even though the share of renewables will be much higher than today: about 50% of primary energy and 50–60% (Figure 40) of final energy could be renewable energy by 2050.

- The **use of biomass for energy increases in power and heat generation and in all end-use sectors**. Most of the additional biofuel supply would still be forest biomass, and this implies that the **biomass supply and logistics chain need to be continuously enhanced.**
- Within the energy supply sector, **completely abandoning the use of fossil fuels would appear to be most difficult in the combined heat and power production of large community energy systems,** because in large-scale demand centres an extensive reliance on biofuels and other renewables would become difficult not only technically but also logistically and economically.

5.1.3 Low-carbon society ensures decoupling of economy and emissions

The Low Carbon Finland 2050 scenarios involve a huge change in technology over the next half-century or so, but the key drivers of economic growth remain essentially familiar. In order to generate growth, the economy has to have access to more factors of production and to better ways of using them. As only modest growth in labour supply was assumed according to the forecast by statistics Finland, the GDP growth needs to stem from technological change. In all of the Low Carbon Finland 2050 scenarios, real GDP grows by a factor of 2.4 compared to 2004, reaching a level of about €540 billion in real terms by 2050. Two thirds of growth stems from technological change, with primary factors – labour and capital – generating most of the rest. In terms of economic welfare, there is thus not much to choose between the scenarios.

In terms of energy economy, two indicators are often used: energy intensity and emission intensity. Both indicators show how energy use or greenhouse gas emissions are dependent on economic growth (Figure 41). Based on statistics, Finland's energy and carbon intensities have been decreasing over the past 20 years, and with current measures both of them will decline up to 2050. In fact, there is not much difference in energy intensities between Baseline and Low Carbon scenarios because much of the energy efficiency investments are already realized in the Baseline. In carbon intensities there is a clear difference, as in low carbon futures Finland's carbon intensity is close to zero.

Currently, Finland pays about €5 billion in energy imports. In the Baseline Finland's energy bill continues growing, but in the low carbon scenarios there are clear savings due to investments in energy saving and renewables. The highest savings are achieved in the Inno scenario, where **the annual savings in fuel costs of imported fuels (both fossil and biofuels) is about €4.6 billion** compared to the Baseline in 2050. In the Tonni and Onni scenarios the savings are about €1.5 billion in 2050 (Figure 42).

It is clear that analysing the costs of reaching low carbon society is extremely challenging. However, all the cost indicators shown in this report show that **investing in RD&D would clearly decrease the costs of mitigation.** All the technological options for reducing greenhouse gas emissions are required to reduce the emissions cost effectively. Finally, human behaviour and choices matter a lot, which we are not able to predict.

5.2 SECTORAL SOLUTIONS

In the following spread, the most significant conclusions and solutions of the project are collected under sectoral topics. The solutions presented are based on both the scenario modelling results and expert views on and working groups.

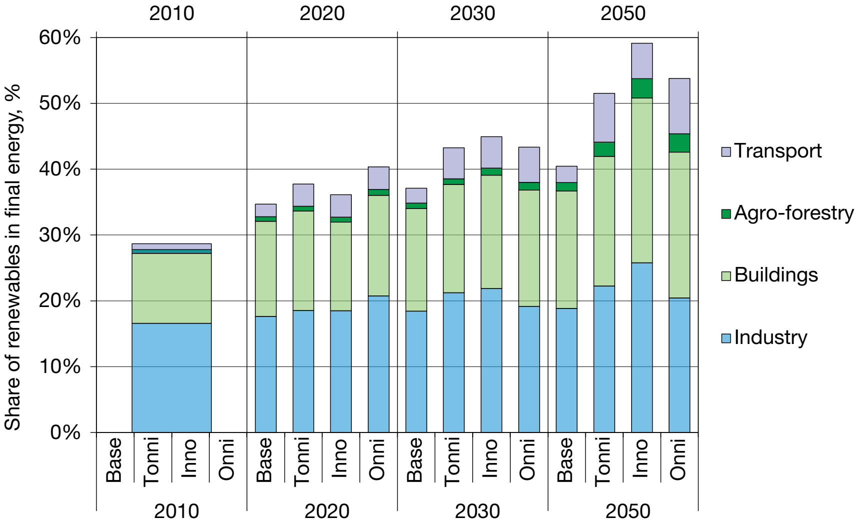


FIGURE 40. Share of renewables in final energy consumption. In the Inno scenario, the final energy consumption is much lower than in the other scenarios, producing the highest share.

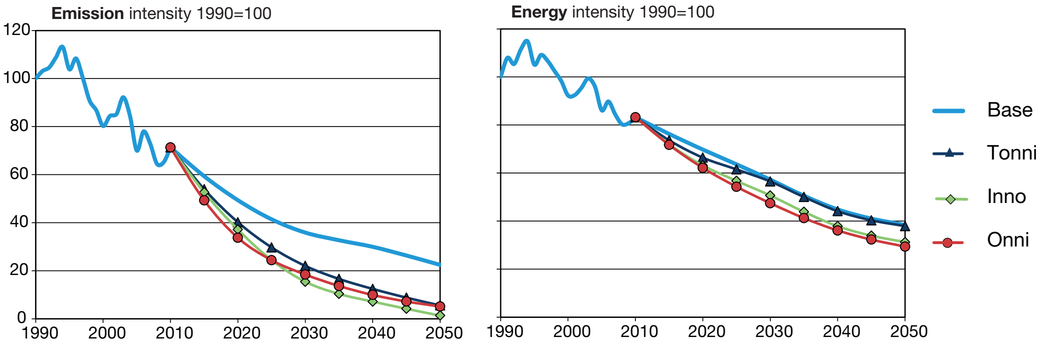
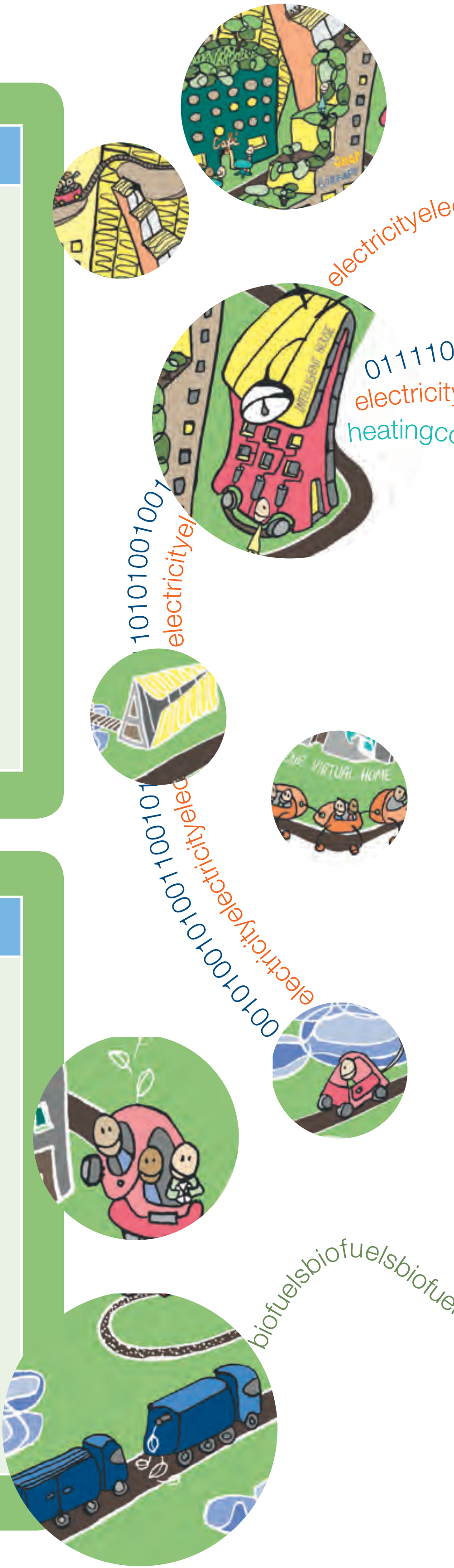


FIGURE 41. Finland's energy intensity (primary energy/GDP) and carbon intensity (GHG emissions/GDP).

FIGURE 42. Annual energy import bill in the scenarios. In the Inno scenario, the bill for energy imports is the lowest in 2050.

Sectoral solutions

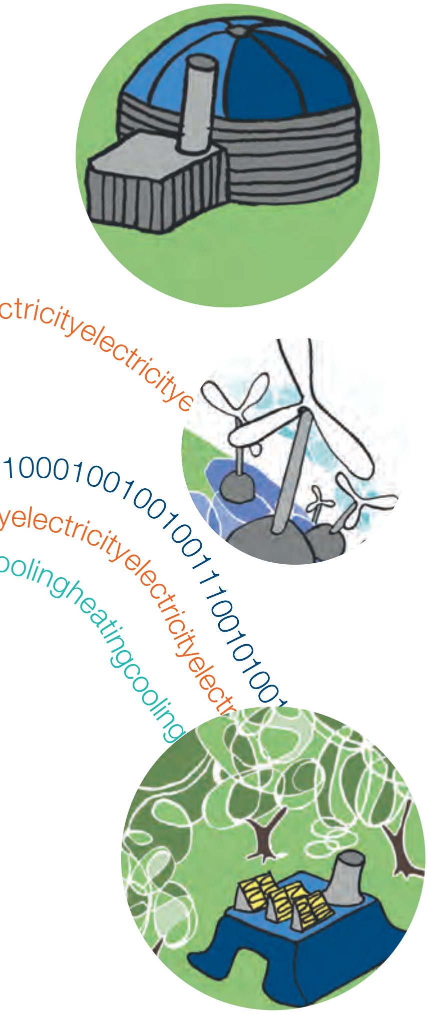


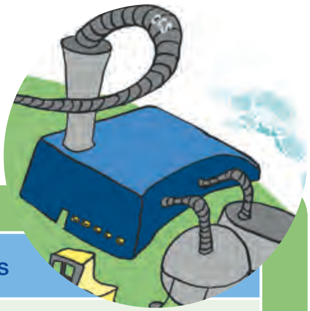
Built environment

- Development of the building stock can in the future take different paths, depending on the choices that society and the economy adopt. Buildings we construct now will be with us for 50–100 years.
- Smart technologies and solutions will make everyday life easier. Automated control enables energy savings also when people are not present.
- Improvements in communication technology will help people avoid unnecessary travel and enable scattered living if needed.
- Two-way networks for electricity and heating will enable local energy production and implementation of plus energy houses.
- The potential for improving the energy efficiency of buildings is large, but its realisation may not be fast enough due to the slow renewal rate of buildings.
- The fastest energy savings can be achieved by using intelligent control strategies and by improving the envelope, ventilation and heating systems and sources.

Transportation

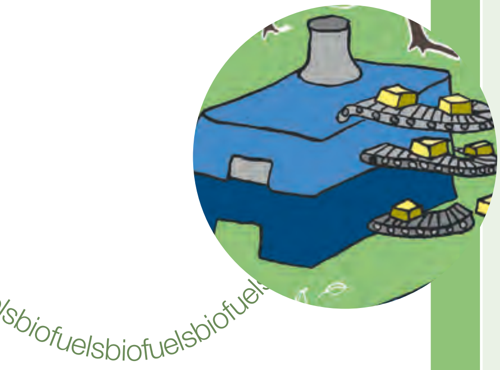
- A dense urban structure enables effective public transport and reduces the number of car journeys.
- Intelligent transport systems (ITS) and use of telecommunication services (ICT) reduces the need for and volume of transport.
- Promoting intermodality and efficiency of transport operations in both passenger and freight transport reduces unnecessary traffic.
- Virtual, contents-based products cut down on volumes of heavy freight transport, but may be largely nullified by daily deliveries and commercial services.
- By 2050, it is possible to reduce the energy demand of transport to less than half of today’s level.
- While passenger cars can run on electricity captured in a battery or released from hydrogen in a fuel cell, only low-carbon or carbon-neutral biofuels can offer sufficient energy density for diesel engines in heavy long-range road haulage.





Energy production and infrastructures

- Multiple solutions with diversified energy production and smart energy systems are needed for cost-efficient low-carbon energy production and transmission.
- Nuclear and renewable energy are the backbone of the electricity production system.
- Renewable energy is utilised widely in all plant sizes: biomass in combined heat and power (CHP) production, onshore and offshore wind energy, and solar in local energy solutions.
- An increased share of electricity from CHP plants with low temperature district heating ensures the competitiveness of CHP in the future.
- Carbon capture and storage (CCS) technologies is a future mitigation option for the use of all fuels, also biomass.
- Variable power generation, especially wind and solar power, will have a central role in Europe. New transmission interconnections are needed to transmit variable generation to load centres. Finland could offer new plant solutions for peak and intermediate loads using biomass based fuels.



Industry

- Industrial development strongly affects Finland's energy balance – future industrial product mix and production volumes of industrial products will drive Finland's energy use.
- Energy efficiency improvements vary by 15 to 25 per cent in various scenarios – new processes can bring major efficiency improvements.
- Decarbonisation of industry to the required level by 2050 also needs carbon capture and storage (CCS).
- Energy-intensive industries and especially the forest industry will have a major impact on energy use and production of biobased combined heat and power (CHP) and biofuels.
- Development of high power-to-heat ratio CHP technologies needed to counterbalance diminishing heat consumption.

5.3 UNCERTAINTIES IN THE SCENARIOS AND CHALLENGES IN IMPLEMENTING LOW CARBON SOLUTIONS

Low Carbon Finland 2050 introduces a wide variety of structural and technological solutions that can be used to improve overall energy efficiency and reduce energy-related emissions. With regard to energy production, numerous advanced solutions based on low-emission technologies are currently being actively developed and implemented. Many of the technologies assessed have either not been commercialised to date, or are still in the initial stages of market entry. Also, the most attractive solutions, not yet assessed, are still to be seen in a low carbon society.

The Tonni, Inno and Onni scenarios represent model-based estimates of cost-efficient technology choices for achieving the at least an 80% GHG emission target in Finland in assumed operational environments. However, the results are dependent on assumptions that contain considerable uncertainties, particularly relating to the national economic structure, the implementation of international climate policies and the introduction of new technologies and services. Considering the scenarios, discernible uncertainties related to technology and its introduction are related to the following factors:

- Energy efficiency improvements are seen in the scenario results in all sectors, but there are barriers to their practical implementation. For example, in the building sector, the relatively slow renewal rate of the building stock, 1–2 % of new buildings and another 1–2% of renovations, means that actions in the building sector have to be swift and decisive so that the effects have time to accumulate.
- The need to cost-efficiently match the supply and demand of electricity creates challenges for the short-term operation of the electricity system and investments in the long term. An increasing share of uncontrollable variable electricity – particularly solar and wind – calls for an increase in the flexibility of energy systems. Therefore, it has been assumed in the scenarios that this development, at least to a large extent, can and will take place when the share of variable generation increases to high levels. The scenarios present options for securing low-cost electricity supply for the Finnish economy and Finnish industry. Overcoming the barriers also requires a versatile electricity supply in the long term.
- CCS technology is under development, and there are still great uncertainties related to implementation of CCS globally due to cost of the technology, sustainability and acceptance of storing CO_2 underground. In the scenarios for Finland, CCS technologies are assumed to be an option for of all fuels, including biomass by new innovative technologies.
- Sustainable use of natural resources in a low carbon society requires intensive multi-disciplinary research and international policies and regulation of the energy economy. IPCC and EU sustainability criteria are being introduced and further developed to steer the way to low carbon 2050 solutions. Nationally, biomass- and bioenergy-related sustainability criteria will be of key interest for balancing the bioeconomy-driven green growth for forest-based industry and bioenergy.
- A technological breakthrough altering the costs of technologies has an effect on the results. This is particularly relevant for technologies in a rapid development phase, such as solar power.

Proper policy instruments are needed for the transition toward a low-carbon society and for the development of technology, including, among others, energy policy, climate policy, development and regional policies, as well as innovation and R&D policy. An active role is needed to be taken by the major stakeholders – government, companies and consumers – to drive the change towards Low Carbon Finland and the technology described.

5.4 VTT'S CONTRIBUTION TO RESPONDING TO THE LOW CARBON CHALLENGE

VTT develops technologies, systems and business models to combine well-being and a low-carbon society for year 2050. Eventually Finland, with the help of VTT, could become a platform to demonstrate these pathways and the technologies involved in the Northern hemisphere.

The contribution of VTT to achieving the Low Carbon Finland 2050 has primarily to do with the inventions and innovations emerging from science and technology. VTT's spearhead programmes, Smart Mobility and Low Carbon Energy, and its innovations programme Safe and Sustainable Nuclear Energy, and innovation programme on Arctic Technology with Wind Energy in Cold Climates as one key element, are the key instruments in its R&D contribution towards a low-carbon society. VTT is also actively participating in international research networks, e.g. in the EU, in the IEA and in the IPCC.

- VTT's key areas in the **energy efficiency of buildings** are arctic zero energy concepts, efficient ventilation, heating and building automation technologies, district-level energy networks and solutions for sustainable communities. VTT's strength is in the knowledge chain from sensor technology to measurement, analysis and control technologies.
- VTT is a prominent actor in research on **energy use in engines and vehicles in real-world situations, and consequent emissions**. As for developing new Intelligent Transport Systems (ITS) and related services, VTT is one of the leading research institutes in Europe, as well as using Information and Communication Technologies (ICT) in transport-related solutions; and it has a significant role in futures research regarding transport in Finland. Finland is a forerunner in the development of biobased transportation fuels from lignocellulosic residues and other non-food raw materials.
- **Fluidised bed technologies and biorefineries.** Finland has been a forerunner in the introduction of new fluidised bed (FB) combustion and gasification technologies, especially for CHP (combined heat and power), since large heat loads exist in cities and process industry, and in the use of biomass as fuel, since biomass has been the most important indigenous fuel resource. The world's leading FB vendors, forest machinery and wood handling companies and their R&D activities are located in Finland, which creates a lucrative operating environment also in the future for the introduction of new technologies connected to new biorefineries producing several biobased products, including biomass-based chemicals and, liquid biofuels and other energy products.
- Technological developments for **nuclear power** in Finland have concentrated on the further development of nuclear safety and spent fuel management and disposal. In the case of third generation nuclear power plants, such as the Olkiluoto 3 reactor unit, even more extensive efforts have been devoted to further increasing the safety of NPPs. Finland has been participating in European fusion research since 1995.
- **Wind energy.** In addition to development and manufacturing of large wind turbines, several different main technologies and components are developed and manufactured in Finland, including gearboxes, generators, power electronics, towers, blade materials and offshore foundations. VTT has internationally recognized RD&D in wind energy in cold climate and wind integration.
- VTT develops techniques for printed thin film technology (R2R) and endeavours to find new material for **solar** cells. VTT is actively developing new emerging technologies utilising **solar energy** – microbial electrosynthesis (MES) and microalgae offering the possibilities of a completely new way of producing fuels and chemicals in future. Solar energy is also an essential component of zero-energy buildings and communities and smart energy grids and is included in VTT's energy system research.
- VTT **develops energy system models and analysis methodologies** as a part of international top-level networks and within the IEA and EU programmes. Nationally, energy system analysis is further developed in multidisciplinary collaboration with Finnish research organisations, universities, companies, and ministries. Sustainability assessments are also a substantial part of VTT's energy system research.

Series title and number
VTT Visions 2

Title	**Low Carbon Finland 2050** **VTT clean energy technology strategies for society**
Author(s)	Tiina Koljonen, Lassi Similä, Kai Sipilä, Satu Helynen, Miimu Airaksinen, Juhani Laurikko, Jussi Manninen, Tuula Mäkinen, Antti Lehtilä, Juha Honkatukia, Pekka Tuominen, Terttu Vainio, Tuuli Järvi, Kari Mäkelä, Seppo Vuori, Juha Kiviluoma, Kari Sipilä, Johanna Kohl, Matti Nieminen
Abstract	The Low Carbon Finland 2050 project by VTT Technical Research Centre of Finland aims to assess the technological opportunities and challenges involved in reducing Finland's greenhouse gas emissions. A target for reduction is set as at least 80% from the 1990 level by 2050 as part of an international effort, which requires strong RD&D in clean energy technologies. Key findings of the project are presented in this publication, which aims to stimulate enlightening and multidisciplinary discussions on low-carbon futures for Finland. The project gathered together VTT's technology experts in clean energy production, smart energy infrastructures, transport, buildings, and industrial systems as well as experts in energy system modelling and foresight. VTT's leading edge "Low Carbon and Smart Energy" enables new solutions with a demonstration that is the first of its kind in Finland, and the introduction of new energy technology onto national and global markets.
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low carbon
finland 2050

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