SITRA STUDIES 140

COST-EFFICIENT EMISSION REDUCTION PATHWAY TO 2030 FOR FINLAND

Opportunities in electrification and beyond

2nd edition
For this second edition a typing error in the model inputs has been corrected. The error lead to a significant overestimation of the emission reduction potential of natural gas as a transport fuel. In this edition, the fuel switches to natural gas in trucks have been removed from the pathway.

Sitra studies 140

Cost-efficient emission reduction pathway to 2030 for Finland
Opportunities in electrification and beyond

Authors:
Anna Granskog, Chiara Gulli, Tapio Melgin, Tomas Naucler, Eveline Speelman, Laura Toivola, Daan Walter (McKinsey & Company)

Sitra project team:
Outi Haanperä, Tuuli Hietaniemi, Mariko Landström, Janne Peljo, Saara Tamminen

ISBN 978-952-347-082-8 (paperback)
ISBN 978-952-347-083-5 (PDF) www.sitra.fi

ISSN 1796-7104 (paperback)
ISSN 1796-7112 (PDF) www.sitra.fi

Erweko, Helsinki, Finland 2018

SITRA STUDIES is a series of publications reporting the results of Sitra's future-oriented work and trials.

The accessibility of the publication has been improved in the summer of 2020.

Sitra studies 140
Cost-efficient emission reduction pathway to 2030 for Finland
Opportunities in electrification and beyond
November 2018

Contents

Foreword

In the Paris Agreement the world's nations committed to keeping the global temperature rise well below 2 degrees Celsius above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius. Many European countries have since updated or are in the process of updating their long- and medium-term climate targets. In Finland, the current government has stated a vision for Finland to become carbon neutral by 2045, but the accompanying domestic emission reduction targets are yet to be discussed. To be in line with the Paris commitments, based on separate assessments by the Finnish Climate Change Panel and Climate Analytics, Sitra recommends Finland set a medium-term target of at least 60 per cent reduction in emissions by 2030 compared to 1990.

To date, Finland has succeeded in reducing emissions by 21 per cent since 1990 to roughly 56 million tonnes of carbon dioxide equivalents ($MtCO_2e$) per year, driven mainly by increased biomass use in power and heat production, decreased use of oil in heating and decreased landfill disposal of waste. At the same time, the carbon sink of Finnish land and forests has nearly doubled in size since 1990 as the result of increasing forest biomass. Despite these achievements, the current trajectory leaves Finland roughly 18 $MtCO_2e$ above the 60 per cent emissions reduction ambition, which highlights the need for Finland to clearly alter its course.

Even with a strong shared understanding of the imperative to reduce greenhouse gas emissions, there is uncertainty about the most impactful measures. To support Finland's decarbonisation journey and the charting of our national emission abatement path, we want to provide an objective fact base of the most economical abatement technologies and fuels. To that end, together with McKinsey & Company, we reviewed carbon dioxide abatement technologies, their abatement potential and associated costs, and prioritised them into a minimum-cost pathway for decarbonisation. A key result of our study is this pathway, a consistent collection of measures, that would lead to the 60 per cent emission reduction target by 2030 in a cost-efficient way. We believe that the pathway advances the discussion on what the decarbonisation measures and costs could look like for Finland.

Although subject to some uncertainty, our analysis suggests that implementation of the 60 per cent abatement target is not only technically feasible but also economically viable, even considering the restrictions put on the abatement measures in this report. Following our analysis, Finland can achieve approximately 50 per cent abatement by leveraging technology switches with negative or neutral abatement costs, most notably in the electrification of transport and wind power generation. The remaining 10 percentage points to reach the 60 per cent abatement target are more challenging, yet feasible, and may involve further industrial decarbonisation or a combination of other measures. The keys to achieving the goal include setting and following a national decarbonisation plan, transforming the power system to support emission-free electricity and setting carefully formulated policies and incentives consistent with the decarbonisation plan.

The report intentionally avoids directly assessing policies, political implementation programmes and other governmental interventions. Instead, it is intended to serve as a fact base for policymakers, academics and corporate leaders when setting concrete targets and discussing how best to achieve the required emissions reductions.

The analytical base of the report is built on existing literature and a number of global and local databases. We thank all the parties who contributed to this work; compiling this report would not have been possible without the valuable knowledge and insights from private sector experts, industry associations, research institutes and government entities.

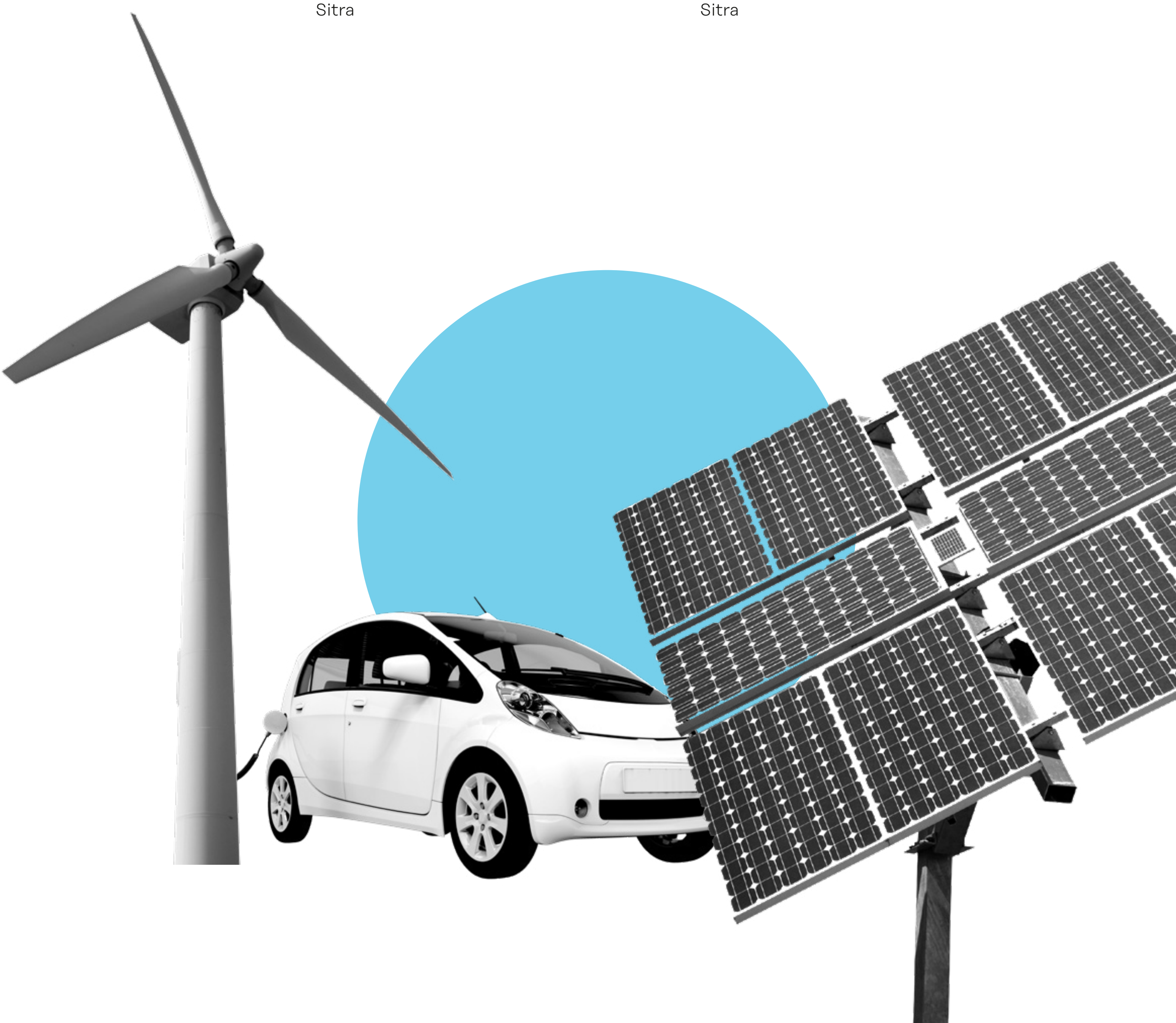
The Intergovernmental Panel on Climate Change (IPCC), the United Nations expert body for assessing the science related to climate change, recently warned that limiting global warming to 1.5°C would require “rapid and far-reaching” transitions in all sectors to avoid the most devastating impacts of climate change.

The time to act is now, and this report charts a pathway for Finland to cut emissions in a cost-efficient way.

Helsinki, 19 November 2018

MARI PANTSAR
Director
Carbon-neutral Circular Economy
Sitra

JANNE PELJO
Project Director
Climate Solutions
Sitra



Glossary

A/C	Small cars segment
BAU	Business-as-usual scenario
BEV	Battery electric vehicle
C/D	Mid-sized cars segment
CH_4	Methane
CHP plant	Combined heat and power plant, i.e. cogeneration plant
CNG	Compressed natural gas
CO_2	Carbon dioxide
CO_2e	CO_2 equivalent
DRI-EAF	Direct reduced iron - electric arc furnace (a steel industry solution combining hydrogen and electrification technology)
E85	Fuel containing 85 per cent ethanol fuel and 15 per cent gasoline or similar fuel
E/F	Large cars segment
EU ETS	European Union Emissions Trading System (refers to price of European emission allowances)
EV	Electric vehicle
GHG	Greenhouse gas
GW	Gigawatt, 1,000 MW
GWh	Gigawatt hour, 1,000 MWh
HDT	Heavy-duty truck: >16 tonnes
HEV	Hybrid electric vehicle
HFO	Heavy fuel oil
HVO	Hydrotreated vegetable oil, a renewable diesel fuel
ICE vehicle	Internal combustion engine vehicle
IPCC	Intergovernmental Panel on Climate Change
J	Sport utility cars segment
LCOE	Levelised cost of electricity
LDT	Light-duty truck: <7 tonnes
LULUCF	Land Use, Land Use Change and Forestry
Luke	Luonnonvarakeskus, Natural Resources Institute Finland
LVM	Liikenne- ja viestintäministeriö (Ministry of Transport and Communications of Finland)
MDT	Medium-duty truck: >7, <16 tonnes
Mt	Megatonne (1,000,000 tonnes)
MW	Megawatt
MWh	Megawatt hour
N_2O	Nitrous oxide
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule, 0.278 TWh
PPA auction	Power purchase agreement auction or renewable energy auction

System level System level indicates what the savings or costs for a certain technology or fuel switch are from the perspective of Finland as a whole, i.e. from the combined perspective of all the Finnish residents, companies and governmental bodies. The owner of the solution would typically incur the saving or the costs (e.g. in electric vehicles, the owner of the vehicle typically collects the savings from using electricity instead of gasoline or diesel). However, these savings and costs can be redistributed by policies such as taxation or subsidies.

TCO Total cost of ownership

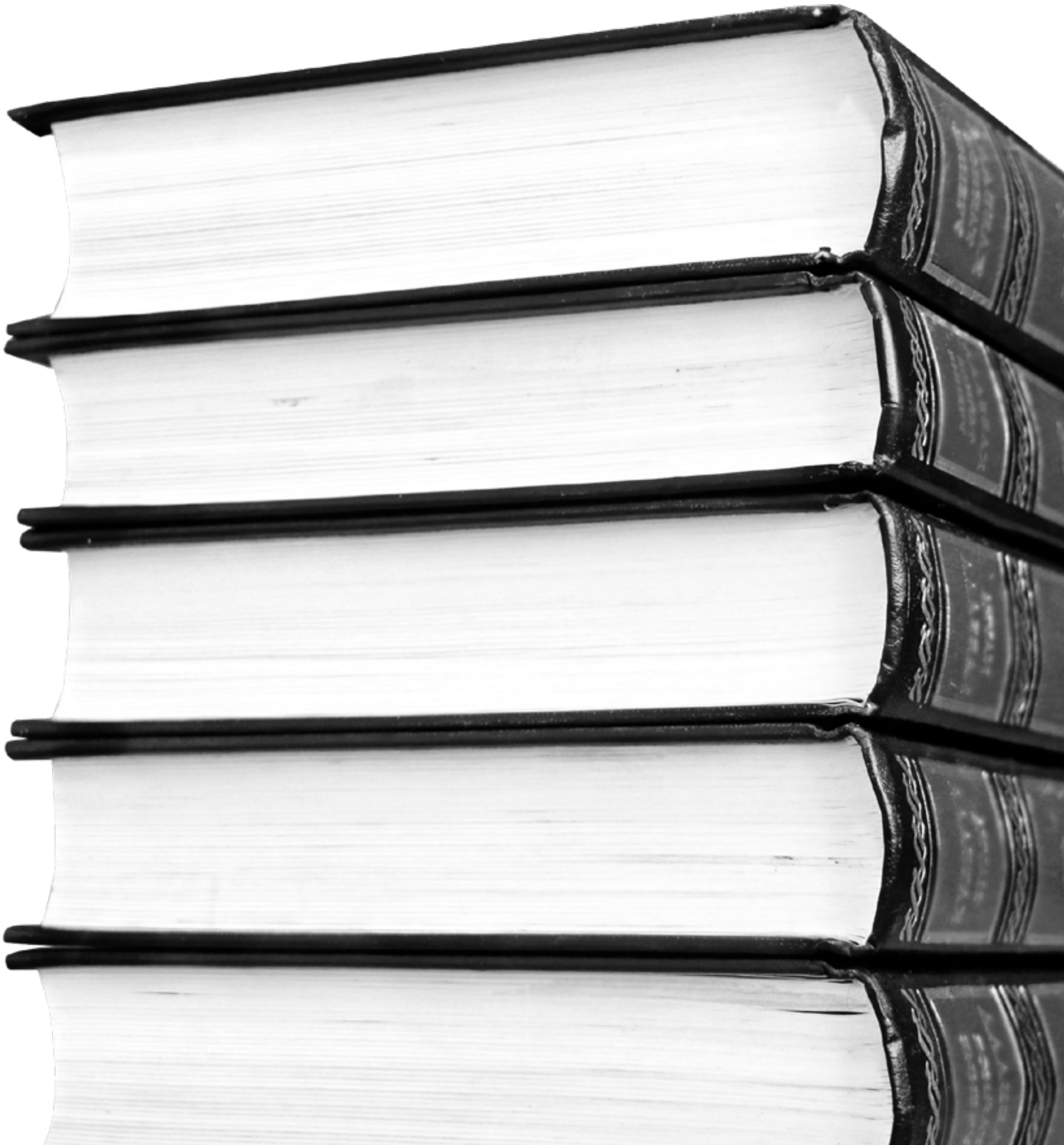
tCO_2 Tonne of CO_2

TEM Työ- ja elinkeinoministeriö (Ministry for Economic Affairs and Employment of Finland)

TWh Terawatt hour, 1,000 GWh

WAM With Additional Measures scenario (from Finnish national climate reports)

WEM With Existing Measures scenario (from Finnish national climate reports)



1. Executive summary

In the Paris Agreement the world's nations committed to keeping the global temperature rise well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius. The need to strengthen the global response to the climate crisis is further emphasised in the 2018 IPCC special report "Global warming of 1.5°C", underlining the need for "rapid and far-reaching" transitions in all sectors.

Since Paris, many European countries have updated or are in the process of updating their long- and medium-term climate targets. In Finland, the current government has stated a vision for Finland to become carbon neutral by 2045, but the accompanying domestic emission reduction targets are yet to be discussed. To be in line with the Paris commitments, based on separate assessments by the Finnish Climate Change Panel and Climate Analytics, Sitra recommends Finland set a medium-term (2030) target of at least 60 per cent reduction in emissions compared to 1990.

Sitra recommends Finland set a medium-term target of at least 60% reduction in emissions by 2030.

This report aims to present an objective and fact-based description of a pathway that would bring us to a 60 per cent reduction in emissions by 2030 in a cost optimal way, as well as the sequence of decisions that needs to be initiated as of now to secure the desired outcome. The analysis suggests that the pursuit of the 60 per cent abatement goal, or roughly 27 $MtCO_2e$ abatement between 2015 and 2030, is not only technically feasible but also economically viable, and that approximately 50 per cent abatement compared to 1990 levels could be achieved by deploying measures that are either cost neutral or result in net savings at the system level. However, to get onto this abatement path, critical policy decisions will have to be made during the 2019–2023 government term.

The presented pathway contains a coherent set of carbon dioxide emission abatement measures across the four sectors that emit the most: industry, power and heat, transport and buildings. It has been built by assessing over 300 business cases for technology and fuel switches and selecting the sequence of switches that provides the most economical way to reach 60 per cent emissions reduction. It is important to highlight that the described pathway is made up of a consistent set of actions. Leaving one major lever out may make another more costly to execute.

Substantial reductions in emissions through electric vehicles and wind power

Cost-neutral or cost-negative emission reduction levers, i.e. measures that result in net lifetime cost savings at the system level, have an abatement potential of up to roughly 50 per cent of 1990 emissions. Road transport electrification will become the single most economical abatement lever as a result of the rapidly decreasing cost of battery packs. Wind power will be the most economical option for electricity production, including new capacity needed to meet the increased power demand from transport electrification. The measures for the remaining 10 percentage points of abatement, however, tend to be more costly and more uncertain. For these emissions, the pathway presents further industrial decarbonisation as the most cost-efficient measure, but cost-efficient solutions may also be found in other sectors such as agriculture or in demand-side measures such as behavioural changes or increased materials recycling, which are not covered by this analysis.

The pursuit of the 60% abatement goal is not only technically feasible but also economically viable.

The main abatement levers to reach the 60 per cent or 27 $MtCO_2e$ reduction in emissions in a cost-efficient way (in order of pathway abatement potential) are:

- Wind power generation to replace fossil fuel-based generation, and substitution of fossil fuels with biomass in cogeneration plants [8.7 $MtCO_2$]
- Steel plant conversion to carbon-neutral production with hydrogen and electrification technology (DRI-EAF) [4.3 $MtCO_2$]
- Industrial plant conversions to electrify heat production or biogas replacing other fuels, most notably in pulp and paper, refining, cement and ethylene [3.4 $MtCO_2$]
- Switch from gasoline and diesel vans, trucks and buses to electric vehicles; 180,000 electric and 20,000 plug-in hybrid vans and trucks and almost 8,000 electric buses [2.6 $MtCO_2$]
- Continued shift away from oil heating in residential, commercial and public buildings to heat pumps and electricity [2.1 $MtCO_2$]
- Switch from gasoline and diesel passenger cars to electric vehicles with roughly 700,000 battery electric vehicles and 100,000 plug-in hybrids between 2022–2030 [2 $MtCO_2$]
- Transport biofuel blending rate increase to 30 per cent by 2030 and internal combustion engine car efficiency improvements [1.6 $MtCO_2$]
- Expected business-as-usual development for non-covered emissions such as F-gases and development in line with national With Existing Measures (WEM/TEM) scenario for non-covered sectors such as waste [1.9 $MtCO_2e$]

Investments in infrastructure and changes in power market mechanisms needed

The proposed measures will shift final power and fuel consumption patterns in Finland. Final energy demand will decrease by almost 10 per cent by 2030 in transport, industry and buildings driven by increased energy efficiency and technology switches. At the same time, the energy mix will shift from fossil fuels to electricity and renewable fuels. Electricity demand will increase by almost 30 per cent to 102 TWh.

There are several important prerequisites that need to be in place to enable the electrification-related abatement:

- Securing land and building permits needed for new wind power plants along a timeline that matches the demand build-up. Roughly 24 TWh or 6.3 GW of new wind power needs to be online by 2030. Out of this, roughly 15 TWh or 4 GW should be offshore wind, coming online between 2024 and 2030, while the current offshore project pipeline, also including idea-phase projects, is only 2.5 GW. This requires permitting capacity and a fast ramp-up of the construction supply chain. Since 2015, 1.1 GW of onshore wind has already come online, and the strong pipeline should be able to fulfil the 1.2 GW additional capacity requirement defined in the pathway.
- Developing the national transmission grid to match the increasing volumes of wind power (onshore and offshore). Moderate grid investments to build up to five new 400 kV lines at roughly 100 million euros each (in addition to currently planned capital investments) will be needed, driven by significant growth in electricity supply and demand. Increased maintenance and capital costs may require up to a 10 per cent increase in transmission fees. Also, the storage capacity, the demand-side measures and the interconnection capacity to balance peak load have to offer up to 5–6 GW of flexibility to deal with the intermittent nature of wind power production.

- Reviewing the current price-setting mechanisms in the power markets to ensure financing of power investments when wind power with near-zero marginal costs starts pushing down hourly day-ahead prices. So far, many countries have resolved this challenge through power purchase agreement (PPA) auctions specifically targeted at renewable capacity.
- Ensuring that the regulation of electricity distribution grids enables distribution companies to develop and use their networks appropriately. The local distribution grids need to be able to accommodate large volumes of electric vehicles (EVs), including the ability to both charge and discharge EV batteries to balance overall load. The EV charging infrastructure needs to expand within the next five years, requiring the upgrade of the power grid and installing over a hundred thousand public charging stations (in addition to home chargers) with a 1.5 billion euro investment.

In addition to increased electricity demand, alternative fuel demand will grow at the expense of fossil fuels.

As indicated above, the pathway suggests that in addition to increased electricity demand, alternative fuel demand will grow at the expense of fossil fuels. Biogas use will roughly quadruple from today to 4.5 TWh, replacing other fuels in industrial use. It will require cost-efficient production from, for instance, manure or waste sludges, and efficient use of the current distribution network. Hydrogen use will still remain limited to several industrial applications until 2030, but with rapid breakthroughs in production costs or fuel cell vehicles, it could have a larger role to play in the energy system as early as the next decade.

Replacing fossil fuels with biomass in cogeneration plant electricity and heat generation will result in 17 TWh of additional electricity and heat generated from biomass. Combined with the planned industrial biomass use, the additional biomass extraction from forests will become a challenge for the forest carbon sink, unless the biomass imports also increase significantly. One opportunity to limit biomass use could be to reduce its demand in power and heat generation by improving energy efficiency in buildings, increasing waste heat capture and heat pumps, reducing heat peak demand through smart grids and leveraging solar collectors and seasonal heat storages. Furthermore, the demand for biomass could be reduced if alternative cost-efficient technologies become available. Technical developments could make new technologies such as deep geothermal heat competitive even before 2030. However, fast technological advancement is highly uncertain.

New financing solutions and a redistribution of costs and savings required

Implementation of the abatement pathway will require changes in the public finances. While assessing these impacts was not included in the scope of this effort, some of the implications can be outlined.

- Many of the measures, such as electric vehicles, power generation and grid investments or industrial site refurbishments, will require more capital and new financing solutions. Upfront capital needs are significant even though the lifetime costs of most measures are lower than those of the current technologies and fuels.
- There will be significant room for the government to use levers such as taxation, investment incentives and other policies to redistribute the costs and savings to make the short-term switches happen and to balance the government budget in the long term.
- Clarity of the policy measures and regulatory framework needs to be created quickly. Economic actors need a

predictable environment and transparency on the future to be able to plan their decarbonisation investments early enough to meet the 2030 timeline.

National decarbonisation plan, regulation and support measures to drive the change

National decarbonisation plan

A national plan laying out the path to decarbonisation in every sector is important for creating clarity around climate targets and providing longer-term predictability beyond electoral terms. It should create a broad commitment to the 60 per cent reduction target by 2030 as a milestone towards decarbonisation and build a shared understanding of the necessary abatement actions and their timings. As for the land use, land use change and forestry (LULUCF) sector and sustainable biomass use, clear targets should be in place alongside a joint fact base, acknowledging both the sustainability concerns related to the use and availability of biomass and the importance of carbon sinks in the pursuit of carbon neutrality over time. Furthermore, a national plan should define some key guiding principles for pursuing the needed reductions in emissions, such as how the costs and benefits of decarbonisation actions should be distributed between all relevant sectors and stakeholders.

A national decarbonisation plan is crucial for providing predictability beyond electoral terms.

The plan should also identify priority areas for technology development and cross-sector and cross-stakeholder collaboration, and identify possible opportunities to redirect public research and development funding.

Policy incentives to drive decarbonisation

The main task for the government is to ensure that the necessary infrastructure for decarbonisation is in place and that companies and individuals alike have the correct incentives to choose low-emission alternatives. Similarly, the government should ensure that policies and regulation do not present barriers that hinder or discourage investments in low-emission alternatives. On the pathway, government guidance in the form of policies will be critical in directing the investments of both individuals and companies to low-emission alternatives.

More broadly, economic instruments to guide and support individuals and companies to adopt low-emission alternatives should be deployed to speed up the transition to a low-carbon pathway. However, the policies need to be carefully designed since measures such as heavier taxation of emissions or setting emission caps could unequally affect certain companies or groups of individuals. Through setting ambitious long-term climate targets, removing regulatory and infrastructural bottlenecks and ensuring economic conditions and incentives that promote the transition to low-emission technologies, the government can provide long-term visibility for individuals and companies and ensure that the transition takes place in an orderly and economical manner.

Decisions that Finland now needs to take to further reduce its greenhouse gas emissions are truly course-altering. The chosen path must be cost-efficient and comprise a consistent set of actions. The time to make these decisions is now. Many of the measures require lengthy periods of preparation, co-ordination and implementation, and the medium-term milestone of 2030 is approaching fast. Taking these decisions is critical to move Finland in the direction of the trajectory mandated in the Paris Agreement. The sooner the shift is initiated, the less dramatic and costly it will be.

Tiivistelmä

Pariisin ilmastosopimuksessa maailman maat sitoutuivat rajaamaan maapallon keskilämpötilan nousun selvästi alle kahden asteen verrattuna esiteolliseen aikaan, pyrkimyksenä rajata nousu 1,5 asteeseen. Vuonna 2018 julkaistu hallitustenvälisen ilmastonmuutospaneelin IPCC:n 1,5 asteen erikoisraportti painottaa entisestään, miten tärkeää on lisätä maailmanlaajuisia toimia ilmastokriisin hillitsemiseksi. Raportti alleviivaa tarvetta ”nopeisiin ja kauaskantoisiin” muutoksiin kaikilla sektoreilla.

Pariisin sopimuksen jälkeen monet Euroopan maat ovat päivittäneet tai päivittämässä keskipitkän ja pitkän aikavälin ilmastotavoitteitaan. Suomi on ilmoittanut pyrkivänsä hiilineutraaliksi vuoteen 2045 mennessä, mutta varsinaisesta päästövähennystavoitteesta ei kuitenkaan ole käyty keskustelua. Sitran mukaan Suomen tulisi vähentää päästöjään vähintään 60 prosenttia vuoden 1990 tasosta vuoteen 2030 mennessä. Sekä Suomen Ilmastopaneelin että Climate Analytics -tutkimuslaitoksen mukaan tämä olisi linjassa Pariisin ilmastosopimuksen tavoitteiden kanssa.

Tämän selvityksen tavoitteena on esittää puolueeton ja faktapohjainen kuvaus polusta, jolla Suomi voi kustannustehokkaasti vähentää päästöjä 60 prosentilla vuoteen 2030 mennessä. Lisäksi selvitys esittelee sarjan toimia, joita polun toteuttaminen edellyttää. Analyysi osoittaa, että 60 prosentin tavoite eli noin 27 miljoonan hiilidioksidiekvivalenttitonnin päästövähennys vuosien 2015 ja 2030 välillä on sekä teknisesti että taloudellisesti toteutettavissa. Tälle polulle pääseminen kuitenkin vaatii, että keskeisiä poliittisia päätöksiä tehdään jo hallituskaudella 2019–2023.

Esitettävä päästövähennyspolku on kokoelma päästövähennystoimia neljällä eniten päästöjä tuottavalla sektorilla: teollisuus, sähkö ja lämpö, liikenne sekä rakennukset. Polku on rakennettu arvioimalla yli 300 mahdollisuutta teknologia- ja polttoainevaihdoksiin sekä valitsemalla sarja vaihdoksia, joka johtaa mahdollisimman kustannustehokkaasti 60 prosentin päästövähennykseen. On tärkeää huomata, että polku koostuu eri toimien yhdistelmästä. Jos yhden toimen jättää pois, voi toisen hinta nousta.

Huomattavia päästövähennyksiä sähköautoilla ja tuulivoimalla

Noin 50 prosentin päästövähennyksiin verrattuna vuoden 1990 tasoon on mahdollista päästä keinoilla, jotka ovat elinkaaritarkastelussa kustannusneutraaleja tai -negatiivisia verrattuna nykyvaihtoehdolla jatkamiseen. Tieliikenteen sähköistämisestä tulee nopeasti halpenevien akustojen myötä kaikkein kustannustehokkain yksittäinen päästövähennyskeino. Tuulivoima tulee puolestaan olemaan kustannustehokkain tapa tuottaa sähköä, myös liikenteen sähköistämisen vaatiman kapasiteetin kasvun osalta.

Keinot, joilla katetaan viimeinen 10 prosenttiyksikköä päästövähennyksistä, ovat sen sijaan kalliimpia ja epävarmempia. Selvityksessä käytetyn mallin mukaan kustannustehokkain ratkaisu on entistä vähähiilisempi teollisuus, mutta kustannustehokkaita keinoja voi löytyä myös tässä selvityksessä käsiteltyjen toimien ulkopuolelta: muilta sektoreilta, kuten maataloudesta, sekä kysyntäpuolelta, kuten käyttäytymisen muutoksista, tai kiertotaloudesta ja materiaalikiertojen tehostamisesta.

Merkittävimmät päästövähennyskeinot, joilla voidaan kustannustehokkaasti saavuttaa 60 prosentin eli 27 $MtCO_2e$ päästövähennys, ovat:

- Fossiilisiin polttoaineisiin perustuvan sähköntuotannon korvaaminen tuulivoimalla sekä fossiilisten polttoaineiden

korvaaminen biomassalla sähkön ja lämmön yhteistuotannossa [8,7 $MtCO_2$].
- Teräksen tuotannon muuntaminen hiilettömäksi sähköistämällä masuunit valokaariuuniksi ja korvaamalla koksi vedyllä [4,3 $MtCO_2$].
- Teollisuudessa lämmöntuotannon sähköistäminen tai fossiilisten polttoaineiden korvaaminen biomassalla tai biokaasulla, erityisesti metsäteollisuudessa, öljynjalostuksessa sekä sementin ja etyleenin tuotannossa [3,4 $MtCO_2$].
- Bensiini- ja dieselkäyttöisten pakettiautojen, rekkojen ja bussien sähköistäminen; 180 000 sähkö- ja 20 000 ladattavaa hybridipakettiautoa ja -rekkaa sekä lähes 8 000 sähköbussia 2030 mennessä [2,6 $MtCO_2$].
- Öljylämmityksen vaihtaminen lämpöpumppuihin ja sähkölämmitykseen asuinrakennuksissa sekä kaupallisissa ja julkisissa kiinteistöissä [2,1 $MtCO_2$].
- Siirtymä bensiini- ja dieselkäyttöisistä henkilöautoista sähköautoihin: 700 000 sähköautoa ja 100 000 ladattavaa hybridiautoa 2030 mennessä [2,0 $MtCO_2$].
- Liikenteen biopolttoaineiden sekoitevelvoitteen nostaminen 30 prosenttiin vuoteen 2030 mennessä ja polttomoottoriautojen energiatehokkuuden parantaminen [1,6 $MtCO_2$].
- Business as usual -ennusteen tai kansallisen perusskenaarion (WEM) mukainen kehitys selvityksen ulkopuolelle rajattujen päästöjen ja sektorien osalta [1,9 $MtCO_2e$].

Investointeja infrastruktuuriin ja muutoksia sähkömarkkinoiden toimintaan

Esitetyt toimenpiteet muuttavat sähkön ja polttoaineiden loppukulutusta Suomessa. Energian loppukäyttö vähenee vuoteen 2030 mennessä lähes 10 prosenttia liikenteessä, rakennuksissa ja teollisuudessa teknologiavaihdosten sekä energiatehokkuuden parantumisen johdosta. Samaan aikaan energian loppukäytössä siirrytään fossiilisista polttoaineista sähkön ja uusiutuvien polttoaineiden käyttöön. Sähkön kysyntä kasvaa lähes 30 prosenttia 102 terawattituntiin. Kuvattu sähköistyminen voidaan saavuttaa, mikäli seuraavat edellytykset toteutuvat:

- Tuulivoimalle on kaavoitettava riittävästi maa-alueita ja myönnettävä rakennuslupia aikataululla, joka mahdollistaa riittävän kapasiteetin rakentamisen. Verkkoon tulee saada vuoteen 2030 mennessä noin 24 terawattitunnin tai 6,3 gigawatin verran lisää tuulivoimaa. Tästä mallin mukaisesti merituulivoimaa on noin 15 terawattituntia tai neljä gigawattia. Tällä hetkellä merituulivoimaa on suunnitteilla ainoastaan 2,5 gigawatin verran, ja tavoitteen saavuttaminen vaatii riittävää kapasiteettia sekä lupaprosesseihin että rakentamisen tuotantoketjuun. Vuoden 2015 jälkeen maalla sijaitsevaa tuulivoimaa on tullut verkkoon jo 1,1 gigawattia lisää, ja suunnitteilla olevat projektit toteuttanevat päästövähennyspolun vaatiman 1,2 gigawatin lisäyksen.
- Kansallista sähkönsiirtoverkkoa tulee kehittää niin, että se pystyy vastaamaan maa- ja merituulivoiman kasvuun. Sähkön tuotanto ja kulutus tulevat kasvamaan huomattavasti, minkä vuoksi sähköverkon osalta tulee investoida nykysuunnitelmien lisäksi noin viiteen uuteen 400 kilovoltin siirtolinjaan, joiden yksikköhinta on noin 100 miljoonaa euroa. Nousevat huolto-, ylläpito-, ja pääomakustannukset voivat vaatia jopa 10 prosentin korotuksen sähkönsiirtomaksuihin.
  Tuulivoimatuotannon suuren vaihtelun vuoksi järjestelmään tarvitaan lisäksi 5-6 gigawattia joustokapasiteettia, kuten varastointikapasiteettia, kysyntäjoustoa ja sähkönsiirtoyhteyksiä naapurimaihin.
- Sähkömarkkinoiden nykyinen hinnoittelumalli tulee arvioida uudelleen, jotta tuotantoinvestoinnit taataan myös silloin, kun tuulivoiman matala marginaalituotantokustannus alkaa

painaa alas sähkön hintaa vuorokausimarkkinoilla. Monet muut maat ovat vastanneet haasteeseen sähkön pitkäaikaisten ostosopimusten huutokaupoilla, jotka on kohdistettu erityisesti uusiutuvaan sähköntuotantoon.
- On varmistettava, että jakeluverkon sääntely mahdollistaa tarkoituksenmukaisen verkkojen kehityksen ja käytön. Paikallisten jakeluverkkojen on voitava palvella suuria määriä sähköautoja. Lisäksi on mahdollistettava sähköautojen akkujen hyödyntäminen sähköverkon kuormituksen tasaamisessa. Sähköautojen latausinfrastruktuuria tulee laajentaa seuraavien viiden vuoden aikana: yksityisten latauspisteiden lisäksi on asennettava yli 100 000 uutta julkista latauspistettä. Vaaditun investoinnin arvo on karkeasti arvioiden 1,5 miljardia euroa.

Sähkön kokonaiskysynnän kasvun lisäksi vaihtoehtoisten polttoaineiden kysyntä kasvaa fossiilisten polttoaineiden kustannuksella. Biokaasun käytön arvioidaan nelinkertaistuvan nykytasolta 4,5 terawattituntiin ja korvaavan muita teollisuuden käyttämiä polttoaineita. Toteutuakseen tämä vaatii biokaasun tuottamista kustannustehokkaasti esimerkiksi lannasta ja jätelietteistä sekä nykyisen jakeluverkoston tehokasta käyttöä. Vetyä käytetään vuoteen 2030 saakka vain muutamissa teollisissa sovelluksissa, ellei tuotantokustannuksissa tai polttokennoautojen kehityksessä tehdä nopeita läpimurtoja. Tällöin vedyllä voi olla energiajärjestelmässä suurempi rooli jo tulevalla vuosikymmenellä.

Fossiilisten polttoaineiden korvaaminen biomassalla sähkön ja lämmön yhteistuotantolaitoksissa nostaa biomassalla tuotetun sähkön määrää noin kuusi terawattituntia. Yhdessä teollisuuden suunnitteleman biomassan käytön lisäyksen kanssa kasvu muodostuu metsän hiilinielun kannalta ongelmalliseksi, ellei biomassan tuontia lisätä merkittävästi. Biomassan käyttöä sähkön ja lämmön tuotannossa on kuitenkin mahdollista pienentää vähentämällä sähkön ja lämmön yhteistuotannon kysyntää. Tämä edellyttäisi esimerkiksi rakennusten energiatehokkuuden tehostettua parantamista, hukkalämpöjen laajaa hyödyntämistä, lämpöpumppujen käytön lisäämistä, lämmön huippukulutuksen pienentämistä älyverkkojen avulla sekä aurinkokeräimien ja lämmön kausivarastoinnin lisäämistä. Lisäksi biomassan kysyntää lämmöntuotannossa voidaan vähentää, jos tarjolle tulee vaihtoehtoisia, kustannustehokkaita lämmöntuotantoteknologioita. Nopean kehityksen myötä uusista teknologioista, kuten syvästä geotermisestä lämmöstä, voi tulla kilpailukykyisiä jo vuoteen 2030 mennessä. Nopea tekninen kehitys on kuitenkin erittäin epävarmaa.

Tarvitaan uudenlaisia rahoitusratkaisuja sekä säästöjen ja kustannusten uudelleenjakoa

Päästövähennyspolun toimeenpano aiheuttaa muutostarpeita valtion budjettiin. Vaikka näiden vaikutusten tarkastelu on rajattu selvityksen ulkopuolelle, on mahdollista hahmotella muutamia seurauksia:
- Monet toimet, kuten sähköautot, investoinnit sähköntuotantoon ja sähköverkkoon sekä teollisuuslaitosten korjausinvestoinnit vaativat pääomaa ja uusia rahoitusratkaisuja. Alkuinvestointien tarve nousee suureksi, vaikka valtaosalla keinoista elinkaarikustannukset jäävät nykyisiä teknologioita alhaisemmiksi.
- Hallituksella on mahdollisuus käyttää lukuisia ohjauskeinoja, kuten verotusta, investointitukia ja muita keinoja jakaakseen kustannukset ja säästöt siten, että lyhyellä aikavälillä tarvittavat muutokset saadaan toteutumaan ja toisaalta valtion budjetti pysyy pitkällä aikavälillä tasapainossa.
- Keskeisistä politiikkatoimista ja sääntelystä on sovittava pikaisesti.

Ennustettava ja läpinäkyvä toimintaympäristö on tärkeää taloudellisille toimijoille, jotta investoinnit vähähiilisiin teknologioihin voidaan suunnitella riittävän ajoissa tarvittavien päästövähennysten toteuttamiseksi.

Suomi tarvitsee kansallisen hiilineutraaliussuunnitelman ja murrosta tukevan sääntelyn

Kansallinen hiilineutraaliussuunnitelma

Kansallinen suunnitelma, joka hahmottelee kaikille sektoreille polun kohti hiilineutraaliutta, on tärkeä ilmastotavoitteiden selkiyttämiseksi ja yli vaalikausien ulottuvan ennustettavuuden luomiseksi. Suunnitelman tulisi sitouttaa Suomi vähintään 60 prosentin päästövähennystavoitteeseen vuoteen 2030 mennessä matkalla hiilineutraaliuteen. Sen tulisi myös lisätä jaettua ymmärrystä tarvittavista päästövähennystoimista ja niiden ajoituksesta. Maankäyttösektorille (LULUCF) ja biomassan käytölle tulisi asettaa selkeät tavoitteet sekä muodostaa yhteinen tietopohja, joka huomioi biomassan saatavuuden, kestävän käytön rajat ja hiilinielujen tärkeyden hiilineutraaliuden tavoittelussa. Lisäksi tulisi määritellä vaadittujen päästövähennysten tavoittelua ohjaavat keskeiset periaatteet, kuten miten toimenpiteiden kustannukset ja hyödyt jaetaan keskeisten sektoreiden ja toimijoiden kesken.

Suunnitelman tulisi myös tunnistaa tärkeimmät alueet teknologiselle kehitykselle sekä sektoreiden ja toimijoiden väliselle yhteistyölle. Lisäksi tulisi pohtia mahdollisuuksia kohdentaa voimakkaammin julkista tutkimus- ja kehitysrahoitusta näille alueille.

Päästövähennyksiä tukevat politiikkatoimet

Hallituksen keskeisin tehtävä on varmistaa, että päästövähennysten edellyttämä infrastruktuuri on paikallaan ja että yrityksillä ja yksilöillä on kannusteet valita vähäpäästöisiä ratkaisuja. Vastaavasti tulisi varmistaa, että olemassa oleva sääntely ja kannusteet eivät estä tai vaikeuta investointeja vähäpäästöisiin ratkaisuihin. Päästövähennyspolun kannalta on kriittistä, että hallitus ohjaa toimillaan sekä yksityisen sektorin että yksilöiden investointeja vähäpäästöisiin ratkaisuihin.

Yleisesti ottaen taloudellisia ohjauskeinoja tulee käyttää vauhdittamaan siirtymää vähähiiliseen talouteen. Ohjauskeinot on kuitenkin suunniteltava huolellisesti, sillä päästöverojen noston kaltaiset toimet voivat vaikuttaa epätasaisesti eri yrityksiin tai ihmisryhmiin.

Hallituksen tulee tarjota yksityiselle sektorille ja yksilöille pitkän aikavälin uskottava näkymä siirtymään kohti vähäpäästöisempää taloutta ja näin tukea sitä, että murros tapahtuu sujuvasti ja taloudellisesti kestävällä tavalla. Tämän näkymän luomista tukevat kunnianhimoisten pitkän aikavälin ilmastotavoitteiden asettaminen, sääntelyn ja infrastruktuurin pullonkaulojen korjaaminen sekä vähäpäästöisiä teknologioita edistävien taloudellisten olosuhteiden ja kannusteiden tarjoaminen.

Suomen on tehtävä suuria päätöksiä päästöjen vähentämiseksi nykysuunnitelmia enemmän ja nopeammin. Valitun päästövähennyspolun tulee olla kustannustehokas ja koostua laajasta kokoelmasta erilaisia, mutta toisiaan tukevia toimia. Nyt on päätösten aika. Monien toimien osalta valmistelu, koordinointi ja toimeenpano vievät paljon aikaa, ja keskipitkän aikavälin tavoitevuosi 2030 lähestyy nopeasti. Ripeä päätösten teko on kriittistä, jotta voimme ohjata Suomen Pariisin ilmastosopimuksen mukaiselle polulle. Mitä nopeammin toimimme, sitä kustannustehokkaampi ja tasaisempi muutos tulee olemaan.

2. Greenhouse gas emissions in Finland today and the challenge ahead

The strong global will to avoid the most disastrous consequences of climate change was reinforced in the 2015 Paris Agreement when 195 countries entered into a legally binding global climate deal, agreeing to keep the global temperature rise well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius. The current pledge of the EU is to reduce its greenhouse gas (GHG) emissions by a minimum of 40 per cent by 2030, and by 80–95 per cent by 2050 compared to 1990 emission levels. Finland, along with a group of other member states, has called for an increase in ambition, as the current emission reduction targets are not in line with the new commitments. By 2020, the European Union needs to deliver a long-term greenhouse gas reduction strategy in accordance with the Paris Agreement.

Finland has committed to the current EU emission reduction objective of at least an 80 per cent reduction in GHG emissions by 2050 in the national Climate Change Act (609/2015). The climate policy is operationalised through the Energy and Climate Strategy and the Medium-term Climate Change Plan of each government, and the Long-term Climate Change Policy Plan, which is to be presented at least every decade and is now due during the next government term.

For 2030, the EU commission has set a target for Finland to reduce GHG emissions in the effort sharing sector by 39% compared to 2005. In addition, the government has set multiple other climate-related targets, most notably a 50% reduction in transport emissions compared to 2005.

Since the formulation of the Paris Agreement, many European countries have updated or are in the process of updating their long- and medium-term climate targets. In Finland, the current government has stated a vision for Finland to become carbon neutral by 2045, but the accompanying domestic emission reduction targets are yet to be discussed. According to the Finnish Climate Change Panel, Finland needs to reduce emissions by 85–100 per cent by 2050 compared to 1990 in order to meet the Paris targets. By 2030, emissions need to be reduced by 44–66 per cent.[1] Based on this and an assessment by Climate Analytics[2], Sitra recommends Finland set a medium-term target for 2030 of a 60 per cent reduction in emissions compared to 1990. The 60 per cent emission reduction ambition implies an abatement need of 26.9 $MtCO_2e$ between 2015 and 2030, while a 40 per cent target level in line with the current EU target would entail abating 12.7 $MtCO_2e$ by 2030.

In the period from 1990 to 2015, Finnish GHG emissions were reduced by 22 per cent

---

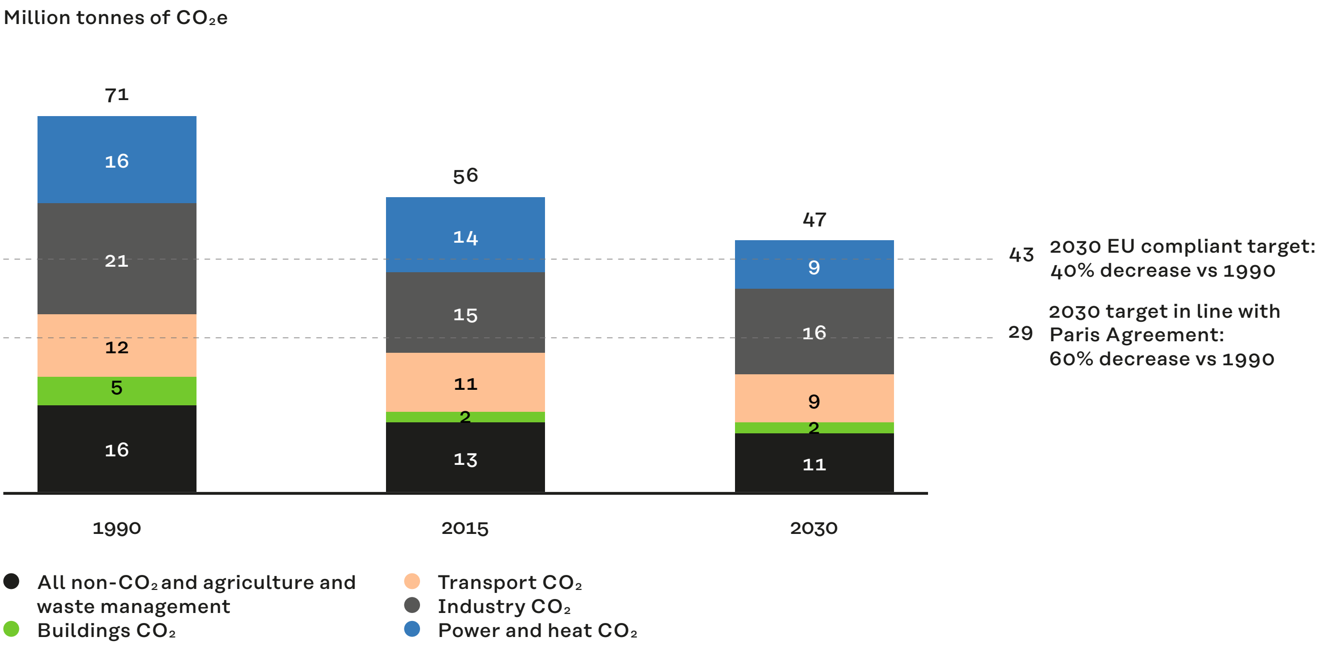
1 The Finnish Climate Change Panel: Ilmastopaneelin näkemykset pitkän aikavälin päästövähennystavoitteen asettamisessa huomioon otettavista seikoista (2018). The Panel has since updated its calculations and tightened the recommendations based on the new carbon budget presented by IPCC (2018), but the updated estimates were not available for this study.

2 Climate Analytics and Sitra: What does the Paris climate agreement mean for Finland and the European Union? (2016).

to 55.6 $MtCO_2e$[3] (Figure 1). Preliminary data from Statistics Finland shows that emissions increased to 58.8 $MtCO_2e$ in 2016 and dropped again to 56.1 $MtCO_2e$ in 2017.[4] The emissions peaked in 2003 at 85.5 $MtCO_2e$, after which they have annually declined by roughly 3.5 per cent or 2.5 $MtCO_2e$ on average. Between 1990 and 2015, the split between CO_2 and non-CO_2 of national emissions in CO_2 equivalents has stayed relatively constant with roughly 80 per cent CO_2 and 20 per cent non-CO_2 emissions.[5] Looking at CO_2 emissions, all sectors are below their 1990 emission levels. The largest decline since 1990 has taken place in the industrial sector, where emissions have been reduced by almost 6 $MtCO_2$, or nearly a third, due to energy efficiency improvements, lower production volumes, particularly in the forest industry, technical abatement measures implemented to reduce N_2O emissions in nitric acid production and the use of black liquor as a fuel in the forest industry. Significant reductions have also been achieved in emissions from buildings with a 3.2 $MtCO_2$ or 60 per cent decline driven by switching oil heating to district heating or heat pumps. Today, the CO_2 emissions from the three largest sectors account for nearly three quarters of Finnish GHG emissions; industry CO_2 emissions cover 27 per cent, power and heat 26 per cent and transport 20 per cent of national GHG emissions in CO_2 equivalent.

Additionally, the carbon sink of the Finnish land use, land use change and forestry

Figure 1: Greenhouse gas emissions in Finland historically and in 2030 business-as-usual scenario, and their relation to 40% and 60% emission reduction targets
Please note that the numbers may not add up due to rounding.



[3] United Nations Climate Change National Inventory Report 2017.
[4] This report will treat 2015 emissions figures as the emissions baseline, as these are the most recent and comprehensive figures reported in the National Inventory Report submitted by Finland to the EU in 2017.
[5] Statistics Finland.

(LULUCF) sector has nearly doubled in size to 27.1 $MtCO_2e$ from 1990 as a result of sustainable forestry practices and changes in climate conditions impacting the annual growth. However, until 2020 LULUCF will be excluded from abatement goals under the EU's international reporting of GHG inventories.

If Finland continues without employing further abatement measures (the "business-as-usual" or "BAU" scenario), [6] it would come close to the 2030 EU emission reduction commitment of 40 per cent with a 4 $MtCO_2e$ gap. However, there would be a sizeable 18 $MtCO_2$ emissions gap to reach the 60 per cent abatement in 2030. This highlights the need for a significant change in the course of action.

With this in mind, this report focuses on exploring abatement measures needed to reach a more ambitious 60 per cent abatement target compared to 1990 levels.

[6] Assuming current trends continue at the same pace as historically and currently enacted policies to realise the anticipated impacts (such as an increase in the biofuels blending rate of transport fuels of up to 20 per cent by 2030), in line with projections from sources such as International Energy Agency and Statistics Finland, and conservative adoption of new technologies, Finnish GHG emissions would reduce by roughly 16 per cent to 46.8 $MtCO_2e$ in 2030. Further details in the Appendix.

3. The pathway for Finland to a 60 per cent reduction in emissions

To support the discussion on the best measures to reduce emissions and assess the feasibility of emission targets, this chapter describes what measures could bring the needed 60 per cent emissions reduction in line with the Paris Agreement targets by 2030. The outlined pathway forms a coherent set of plausible technology and fuel switches that would achieve the emissions reduction in a cost-efficient way. Exploiting the technology and market trends which are driving down costs, the report finds that a majority of the measures would come at a negative cost and result in net savings at the system level.

As with any analysis, the outcomes depend on the underlying assumptions and thus are subject to some uncertainty. To ensure like-for-like comparability, the analysis assumes the same cost of capital for low-carbon and the business-as-usual technology investments when calculating the total cost of ownership (TCO). TCO includes costs associated with the initial investment and the costs of operation for the full lifetime of the measure.

Methodology

The report focuses on abatements in transport, buildings, industry, and power and heat that cover about 80 per cent of total emissions in Finland. Within these sectors, technology-specific abatement levers have not been applied for: i) domestic aviation, marine and rail transport; ii) heat-only plants[7] and iii) other industries excluding steel, refining, cement, ethylene, and pulp and paper.[8] Therefore, in total, the technology-specific analysis covers 65 per cent of Finnish GHG emissions. For these, the actual technology mixes per sector (e.g. the share of residential heat provided by district heating, oil boilers, heat pumps, etc.) are modelled on a year-by-year basis up to 2030, using full-system optimisation based on over 300 business cases of deployable technologies and fuels. The analysis considers abatement opportunities in technology and fuel switches only and does not include potential abatement from behavioural changes.

The selected abatement technologies and fuels are visualised on an abatement cost curve; a graph where each column represents one specific technology or fuel switch that reduces emissions. The curve gives a view of how much abatement can be realised at what cost. The width of each column represents the realised reduction of annual CO_2 emissions associated with the measure by 2030 when compared to 2015, and the height of each column the average cost of abating one tonne of CO_2. The columns are organised from the most economical to the most expensive measure, expressed in EUR/tCO_2 abatement.

The pathway considers the TCO, which includes the costs of the initial investment and the costs of operation for the full lifetime of the measure. The cost of abatement on the cost curve is the difference in the TCOs between the low-emission technology or fuel and the existing technology or fuel that is

---

7 Both district heating and industrial steam production. However, even though heat-only plants are in general excluded from the analysis, some industry business cases include electrification of heat production.

8 Primarily: agriculture and forestry fuel combustion for machinery etc.; the food and tobacco industry; other material and mineral production (outside chemicals, cement, iron and steel).

replaced. The difference in the TCOs can be both positive (i.e. the measure leads to more costs over its lifetime) or negative (i.e. the measure saves money over its lifetime compared to what it replaces). The TCOs are considered from a system perspective, i.e. what the costs or savings are from the perspective of Finland as a whole, and do not include taxation on consumers or companies in order to have objective, quantitative comparisons of different abatement options. Therefore, the presented costs or savings differ from those that consumers and companies would incur in practice. Finally, the cost curve should not be considered as a stand-alone representation of the pathway as it does not include all the enablers needed to implement the measures. More details about the methodology can be found in the Appendix.

Opportunities in cost-efficient emissions reduction

Given our assumptions and scoping, to reduce emissions by 25 $MtCO_2$[9] between 2015 and 2030 needs contributions across all sectors (Figure 2). The analysis suggests that abatement of up to approximately 17 $MtCO_2$ or to some 50 per cent compared to the 1990 level could be achieved with cost-negative or cost-neutral levers.[10] The remaining 10 percentage points of abatement appear more costly.[11]

The cost-negative abatement opportunities lie mainly in transport, power and heat, and buildings. Particularly attractive opportunities can be found within the electrification of passenger vehicles and trucks and with wind power, where major global trends in technological development and decreasing costs are projected to enable cost-negative abatement. The average cost per tonne of CO_2 compared to the conventional technologies for these measures would be approximately –100 euros, which signifies cost savings from a system point of view.

However, given our assumptions and scoping, a 60 per cent reduction in emissions is not possible unless industry as the sector with largest current emissions can make further substantial contributions and cover most or all of the remaining 10 percentage points or 7.7 $MtCO_2$ abatement. These include electrification, biomass and biogas use and hydrogen technology.

In summary, the key measures by sector for the 60 per cent pathway are as follows.

- **Power and heat** *8.7 $MtCO_2$ abatement, 35% share of total targeted emissions reduction*: Most CHP generation shifts from fossil fuels to biomass abating 5.1 Mt, and onshore and offshore wind power generation increases to 26.5 TWh, partly replacing coal- and gas-based production and partly covering the increased electricity demand from electrification. In total, wind power production increases elevenfold from today to cater for over a third of Finland's electricity needs.
- **Industry** *7.7 $MtCO_2$ abatement, 31% share of total targeted emissions reduction*: 3.4 $MtCO_2$ abatement is achieved through decarbonising heat production with electrification, energy efficiency improvements and replacing fossil fuels with biomass and biogas in pulp and paper, refining, cement and ethylene production, with costs ranging

---

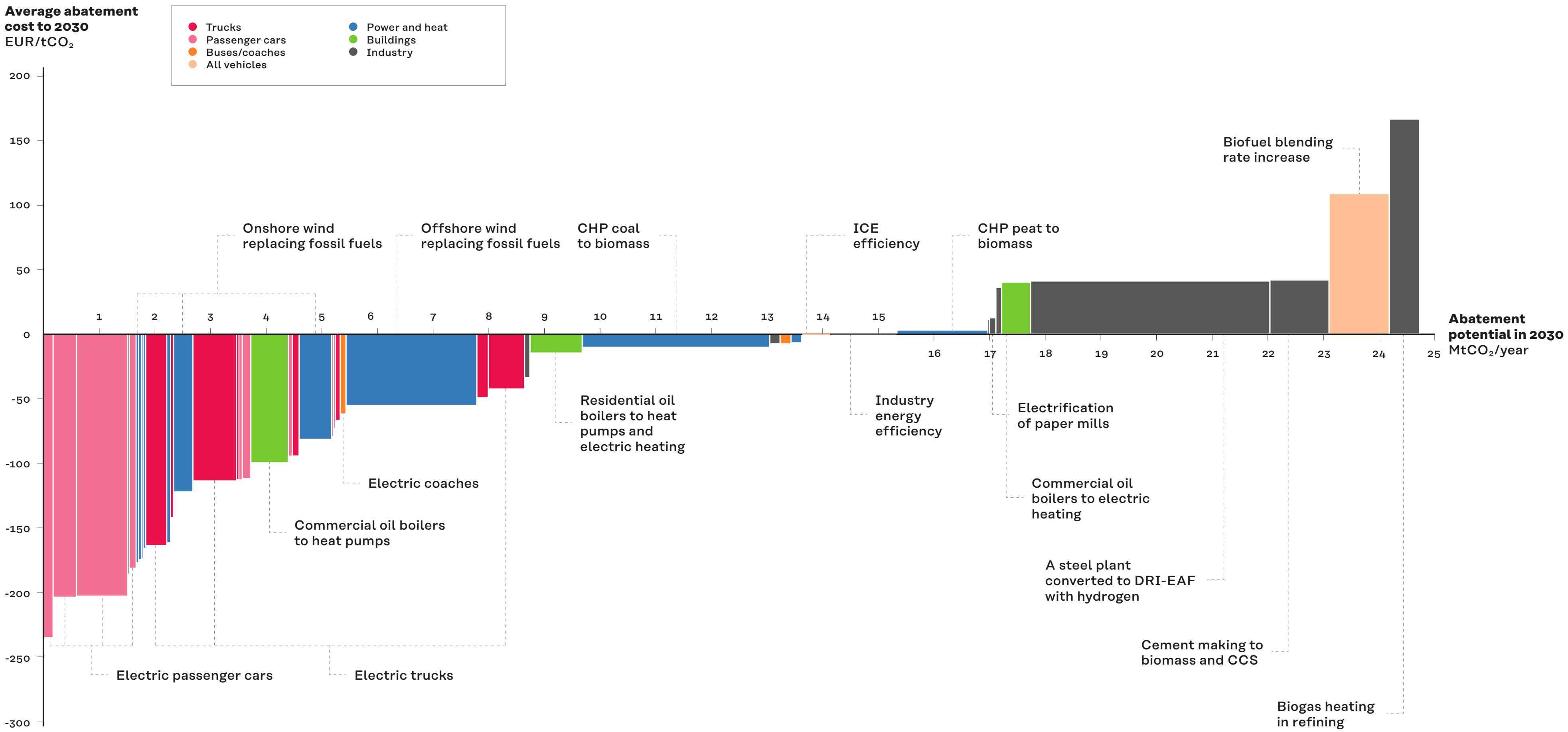
9 In the sectors modelled in detail, the total abatement needed is ~27 $MtCO_2e$, with the remaining ~2 $MtCO_2e$ abatement gap covered by non-covered emissions such as F-gases and non-covered sectors such as waste management. See Appendix for further details.

10 For industry and power and heat, the costs shown in the graph are on top of the ETS price (assumed to increase from ~8 EUR/tCO_2 in 2015 to 31 EUR/tCO_2 in 2030). Therefore, measures with costs similar to ETS price are close to the zero-cost line. See Appendix for further details.

11 Within the considered emission reduction opportunities in this report. Beyond the considered emissions, sectors and measures, there may be more cost-effective measures available.

Figure 2: Pathway to 60% abatement

The horizontal axis shows the abatement potential of the technology switches and the vertical axis displays the average abatement cost as EUR/tCO_2 for each switch. The CO_2 price of the EU ETS is included in the cost of measures for industry and power and heat. The measures have been ordered according to their cost. Transport and power and heat yield large cost-negative abatement, while industry measures have higher costs.



from −185 to 170 EUR/tCO_2.[12] Additionally, the pathway suggests converting the last remaining plant with steel blast furnaces to electric arc furnaces using hydrogen technology (DRI-EAF[13]) (4.3 $MtCO_2$). However, the likelihood of this lever being implemented by 2030 is relatively low; the blast furnaces will not reach the end of their life cycle until later and the needed hydrogen supply is unlikely to be available at required cost and volume by 2030. If the steel plant is unable to convert, the remaining emissions gap needs to be covered by a wide set of measures from other industries and other sectors. The alternative abatement packages are explored in more detail later in this report (see the section Deepdive: Alternatives to large-scale industry abatement).

- **Transport** *6.2 $MtCO_2$ abatement, 25% share of total targeted emissions reduction:* Diesel and gasoline vehicles are rapidly and extensively replaced by battery electric vehicles and plug-in hybrids both in consumer and commercial use, reaching 800,000 electric passenger cars, 200,000 trucks and almost 8,000 buses on Finnish roads by 2030. Electric trucks, buses and passenger cars could realise an abatement of about 4.6 $MtCO_2$ by 2030, while increasing the biofuel blending rate to 30 per cent[14] and internal combustion engine (ICE) efficiency improvements could realise another 1.6 $MtCO_2$.
- **Buildings** *2.1 $MtCO_2$ abatement, 9% share of total targeted emissions reduction:* Oil boilers switch to heat pumps and electric heating in residential, commercial and public buildings, essentially abandoning oil boilers in Finland by 2030.

The pathway is consistent with the current target set by the EU commission for Finland to reduce emissions in the effort sharing sector[15] by 39 per cent compared to 2005 emission levels. On the pathway, emissions reductions within the transport and buildings sectors only will reduce effort sharing sector emissions by roughly 41 per cent compared to 2005.[16] In transport, the pathway will reduce emissions by 63 per cent by 2030 compared to 2005, achieving the government target of 50 per cent reduction.[17]

Key enablers for the pathway include the following.

- A charging infrastructure for EVs
- The reinforcement and expansion of the electricity grid to enable electrification and onshore and offshore wind power connections
- Securing electricity price-setting mechanisms that support investments in wind power
- Widespread adoption of energy-efficient appliances (energy label class A) in residential and commercial buildings to reduce electricity need and thus support decarbonisation.

In order to achieve the targeted 60 per cent abatement by 2030, decisions to drive power

---

12 Calculated with the 4 per cent social discount rate.
13 Direct Reduced Iron – Electric Arc Furnace.
14 Costs for increasing biofuel blending rates have not been assessed in detail. The report acknowledges that multiple differing views on the topic exist due to uncertainties concerning the future prices of fossil and different biofuels and specific blends used to cover the requirement. Sipilä et al. (2018) discuss these topics in more detail.
15 Non-ETS sectors, i.e. ground transportation, agriculture, waste and buildings.
16 Based on European Union Transaction Log (for ETS emissions) and United Nations Climate Change National Inventory Report 2017 (for total emissions); the percentage calculated assuming that all effort sharing sector emissions outside transport and buildings remain at the 2015 level.
17 Based on United Nations Climate Change National Inventory Report 2017.

grid extension permits and plans and to assess feasible industry abatement measures would first need to be taken before 2020 (see Getting on with the pathway: decisions needed before 2020).

The pathway to 60 per cent confirms that substantial reductions could be achieved within the emissions considered in this report. However, the modelled emissions cover some 65 per cent of total Finnish GHG emissions, and additional or alternative abatement opportunities may be found in the non-modelled parts of the focus sectors such as heat-only plants, in non-modelled gases such as nitrous oxide or F-gases and in non-modelled sectors such as agriculture and waste management.

Transport: strong shift to electric

The transport sector accounts for 20 per cent of total emissions in Finland with just over 11 $MtCO_2$ in 2015. These emissions primarily originate from road transportation, which accounts for roughly 90 per cent of transport emissions. The other 10 per cent of transport emissions come from domestic aviation, marine and rail, which are not modelled at technology level. Within road transportation, the main emitters are passenger vehicles (58 per cent) and vans and trucks (37 per cent). Other vehicles such as buses and motorbikes account for only 5 per cent of emissions. Currently almost the entire Finnish car fleet consists of internal combustion engine (ICE) vehicles running on diesel or gasoline. There is an increasing biofuel blending requirement, and 12 per cent of the transport fuel energy content was biofuel in 2015. Going forward, the biofuel blending requirement rises to 13.5 per cent of fuel energy content by 2020 (20 per cent including double counting of advanced fuels) and to 30 per cent by 2030 (excluding double counting). Furthermore, energy efficiency improvements in ICE vehicles are projected to have a significant impact on the sector's emissions, as the energy use per kilometre is expected to fall by some 2 per cent per annum.

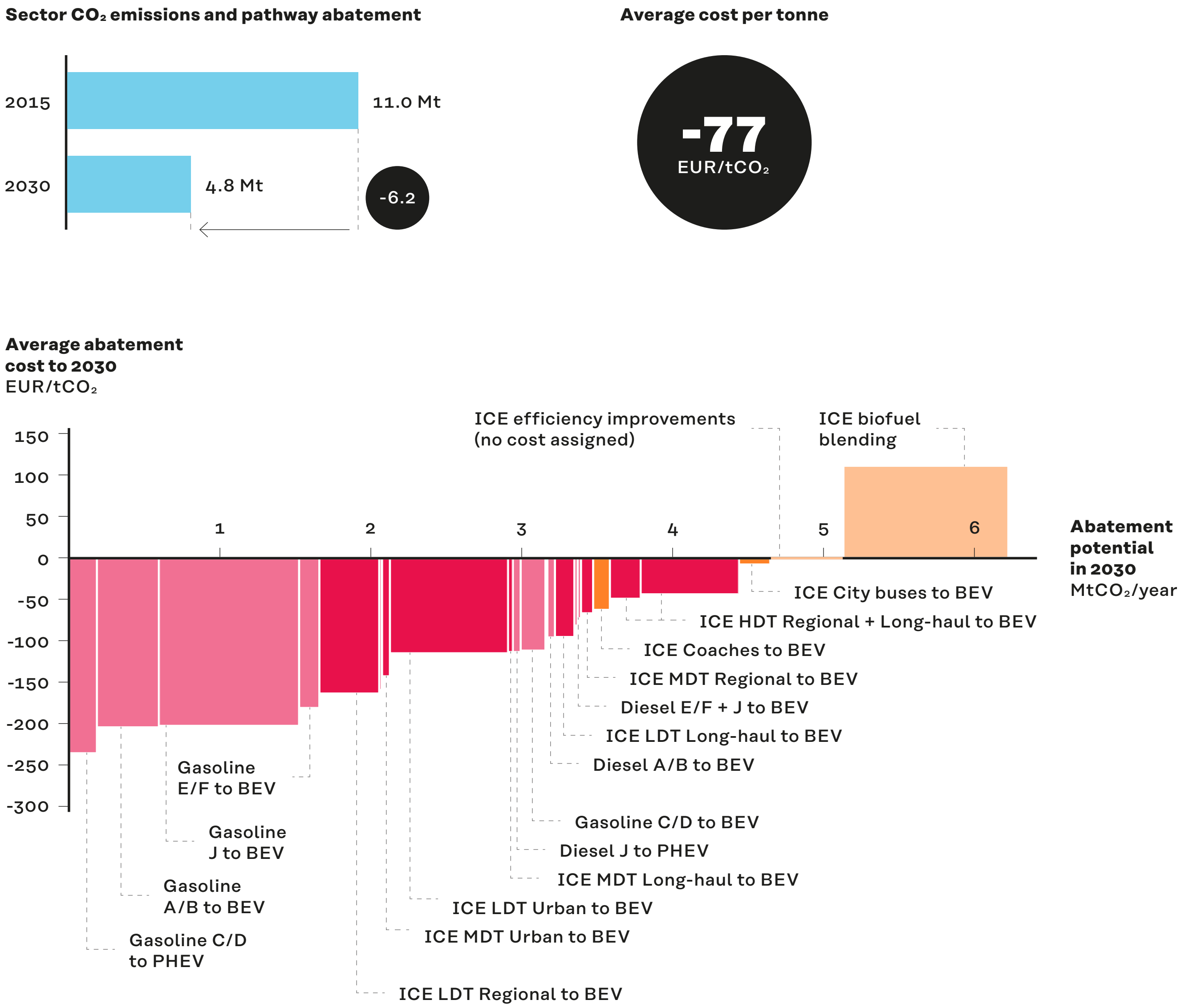
In the 60 per cent pathway, transportation contributes 6.2 $MtCO_2$ of abatement between 2015 and 2030, which accounts for roughly 57 per cent of the sector's emissions. This abatement consists of 4.6 $MtCO_2$ from adoption of electric vehicles (EV), 1.1 $MtCO_2$ from an increase in the biofuel blending rate and 0.5 $MtCO_2$ through ICE efficiency improvements.[18] The EV contribution is split into 2 $MtCO_2$ from passenger cars, 2.3 $MtCO_2$ from trucks and 0.3 $MtCO_2$ from buses.

Even though the emissions reduction in the transport sector is substantial, it can be reached at a net saving from a system point of view; the average cost for the measures is approximately -77 EUR/tCO_2 abated. The lower operating costs could also directly benefit consumers. The initial capital investments are, however, relatively high, given that the measures increase the costs of stable renewal of the Finnish car fleet.[19] The 60 per cent pathway requires an additional 12–15 billion euros, or roughly a 30 per cent increase, of upfront investments between

[18] Taking into account the rapid adoption of EVs on the pathway. The efficiency improvements only apply to new ICE vehicles entering the market and plug-in hybrid electric vehicles (PHEVs); the wide-scale adoption of battery electric vehicles (BEVs) on the pathway reduces the potential from ICE energy efficiency improvements since BEVs would be purchased in place of new ICE vehicles. The number of passenger cars is projected to remain almost constant at 2.7 million.

[19] With the new car registration rate being roughly the average for the past decade according to Trafi data on 120,000 cars.

Figure 3: Cost-curve sector summary for transport
Please note that the numbers may not add up due to rounding.



- Trucks
- Passenger cars
- Buses/coaches
- All vehicles

A/B	small cars segment	MDT	medium-duty truck, >7t, <16t
C/D	mid-sized cars segment	HDT	heavy-duty truck, >16t
E/F	large cars segment	BEV	battery electric vehicle
J	sport utility cars segment	ICE	internal combustion engine
LDT	light-duty truck, <7t	PHEV	plug-in hybrid electric vehicle

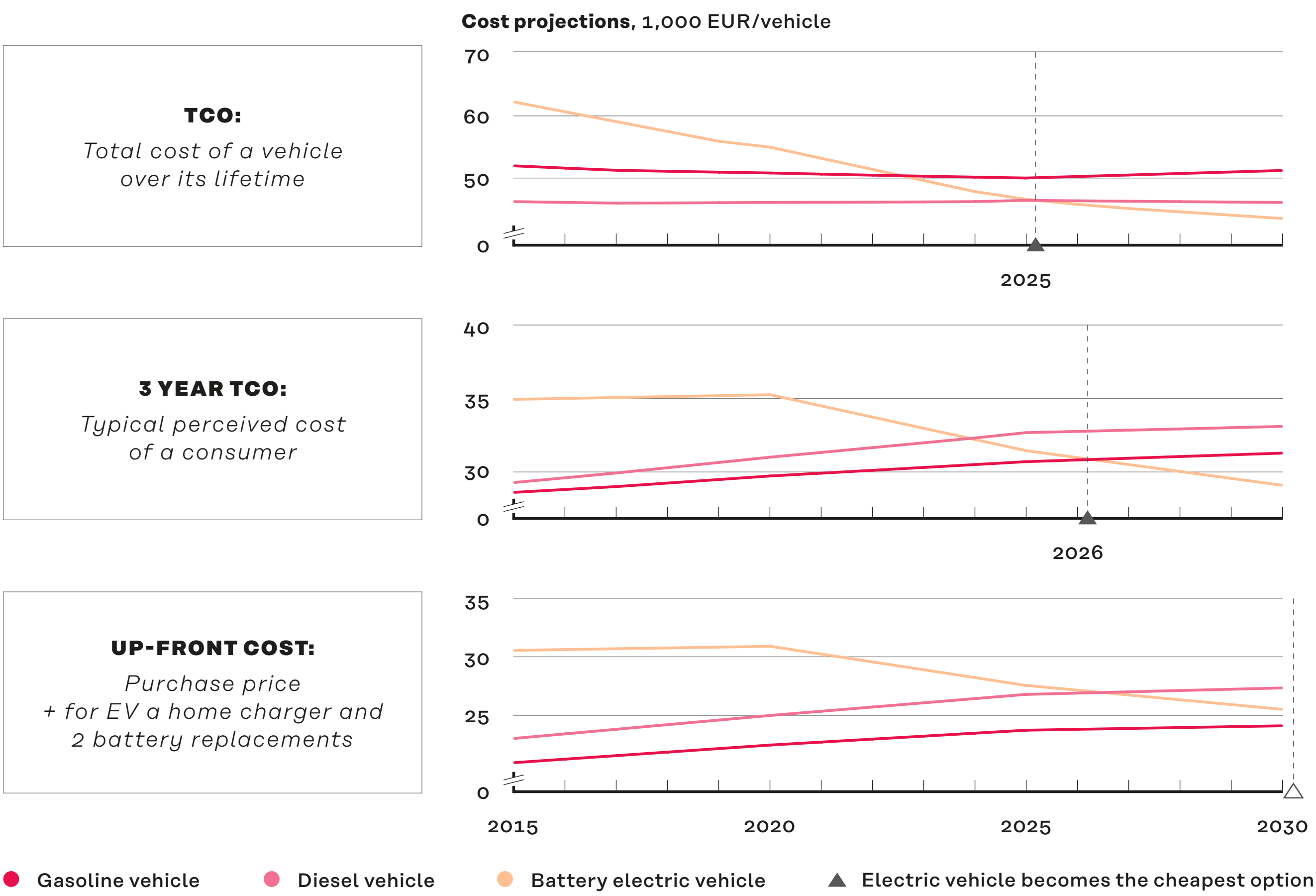
2021 and 2030 compared to buying similar ICE vehicles.

The abatement pathway outlines the following measures.

- **Large-scale adoption of electric vehicles**
  4.6 $MtCO_2$ abatement by 2030, approximate cost: –90 EUR/tCO_2:
  The sizeable abatement potential from transport electrification combined with rapidly falling battery technology costs[20] make accelerating EV adoption a very attractive opportunity, which many countries such as Norway, Sweden and China are already pursuing.

  While Finland today has only roughly 11,000 passenger EVs on the road, the 60 per cent pathway reaches 0.8 million by 2030 (including both battery electric vehicles (BEVs) and

Figure 4: Example of passenger vehicle cost outlooks for mid-size cars (C/D segment)
Total cost of ownership for battery electric vehicles calculated here with current 2018 electricity prices.



[20] Further details in the Appendix.

plug-in hybrids (PHEVs). This corresponds to about 30 per cent of the Finnish passenger car fleet and approximately half of the retiring cars between 2019 and 2030.[21] The uptake of EVs will start accelerating in the year when cost parity[22] with ICEs is achieved, with large-scale adoption starting between 2021 and 2026 depending on car class, starting with small vehicles in 2021.

For trucks and vans, roughly half of the vehicles in the fleet will switch to EVs by 2030 (180,000 BEVs and 20,000 PHEVs), starting with vans and light and medium-duty trucks in urban and regional use in 2022, with regional heavy goods vehicles and long-haul trucks following from 2025 once TCO parity is reached.

A majority of the fleet – almost 8,000 – of around 13,000 buses will shift to BEVs, starting from 2019, driven by similar economics as trucks.

Policies and support schemes are pivotal to realising the most value from EVs because the upfront costs for EVs are projected to remain higher than for ICEs until 2030 and because consumers and leasing companies tend to consider shorter cost outlooks than the full lifetime TCO[23] (Figure 4 illustrates how the parity points would change if instead of a full lifetime TCO only a three-year TCO was considered). In the future an increasing share of new cars could be lease cars if Finland follows the Nordic example, which would enable setting policy requirements for the leased cars (further discussed in Chapter 5, under Rapid adoption of electric vehicles.[24] Trucks and buses will be used for professional transport, and their cost outlook can be assumed to range from several years to a full lifetime TCO.

- **Improved ICE efficiency and a biofuel blending rate increase to 30 per cent**
  1.6 $MtCO_2$ abatement by 2030, cost on average 110 EUR/tCO_2 for the 30 per cent blending requirement[25]: Efficiency improvements in ICE technology are projected to reduce emissions by some 0.5 $MtCO_2$ by 2030, as the energy use per kilometre is projected to decrease by roughly 2 per cent per annum. The efficiency improvements affect both ICE vehicles and PHEVs. The abatement potential of efficiency improvements will be limited by the significant uptake of BEVs on the pathway, which reduces the number of new, more efficient ICE vehicles in the Finnish car fleet. There is no cost allocated to the efficiency improvements.

---

21 In the analysis, the following restrictions were applied: a maximum of 85 per cent of new cars could be BEVs, while the remaining 15 per cent of new cars would have to include an internal combustion engine (either ICE vehicle or PHEV). The limitation is set to take into account the traffic in areas which might have limited access to electricity. In practice after the cost parity between ICE vehicles and PHEVs is reached, the 15 per cent would consist of PHEVs. Conversion of old passenger ICE cars to biogas or flexi-fuel motors is not included as a business case. These changes could provide additional emission reductions to the transport sector.

22 The cost parity does not include Finnish car taxes but only manufacturing-related taxes and manufacturing margin. If Finnish car taxes were included (assuming current taxation), the cost parity would be reached roughly a year earlier.

23 For instance, while full lifetime cost parity for mid-range vehicles will be reached in 2025, a typical consumer can be expected to be sensitive to upfront investment costs although the price difference between ICE and BEV is a few thousand euros. A typical leasing company can be assumed to have three-year depreciation schedule, reaching C/D class TCO parity in 2026. With more aggressive battery cost development, these parity points may be reached earlier.

24 According to Trafi, in 2016 only 16 per cent of passenger cars were newly registered as lease cars, while in Sweden and Denmark the share of lease cars was over 40 per cent.

25 Costs for increasing biofuel blending rates have not been assessed in detail. The estimate reflects the future price estimates of Sipilä et al (2018); which analyses the topic in more detail.

The blending rate requirement for biofuel is expected to increase to 30 per cent by 2030 as outlined in national policy. The higher biofuel content reduces emissions in remaining ICE vehicles by some 1.1 $MtCO_2$, or about 10 per cent of transport emissions compared to 2015. The abatement cost from biofuels has not been assessed in detail in this work. Based on the future price estimates of fossil diesel and HVO,[26] the abatement cost of the 30 per cent blending requirement would be on average 110 EUR/tCO_2. However, because of the high uncertainty surrounding the future prices of HVO and fossil diesel, the abatement cost can vary significantly.

By using EV, ICE efficiency and biofuel measures in transport, the emissions will reduce by a total of 6.2 $MtCO_2$. The utilisation of biogas in both trucks and passenger cars provides additional emissions reduction potential, but it has not been analysed in this report due to lack of global data. Also, demand-side measures not considered on the pathway could considerably support abatement by decreasing demand for vehicles or reducing the kilometres travelled by cars. These demand-side behavioural measures could for instance include increased walking, cycling or the use of public transportation, or a shift towards Mobility-as-a-Service (MaaS).

Any 2030 abatement target should be viewed as a milestone on the way to becoming carbon neutral by 2045 at the latest. Given that the typical lifetime of a passenger car in Finland is currently 20 years, carbon neutrality will require one of the following: from 2025 onwards new car sales will have to be exclusively CO_2 neutral; biofuel blending rates will have to gradually reach 100 per cent by 2045; or before 2045 all ICE cars purchased post-2025 will have to be scrapped before the end of their lives to be replaced with CO_2 neutral cars.

All the transport measures on the pathway focus on road transport, as it is by far the largest source of emissions in domestic transport. However, abatement measures should eventually extend to the remaining transport (air, water, rail) despite their emissions being only roughly 10 per cent of transport emissions.

There are three key enablers needed to be put in place in order to capture the transport abatement opportunity, covered in more detail in Chapter 4.

- First, the infrastructure for EV charging needs to be put in place, as sufficient public charging networks are a prerequisite for many consumers and businesses looking to purchase these vehicles. For EVs, public charging stations integrated into the parking infrastructure need to complement the home charging and high-speed charging along the main highways.[27] Due to the long lead times associated with such national-level infrastructure building efforts, this is a

---

[26] Sipilä et al. (2018; see above) project the price of fossil diesel to be on average around 700 EUR/t in 2030 (based on an IEA long-term raw oil price estimate), but with a potential variation from 470 to 920 EUR/t. They estimate the average price of HVO to be around 1,066 EUR/t in 2030, but with potential variation from 770 to 1,370 EUR/t. Assuming the combustion of HVO to be emission-free, the cost of the 30 per cent biofuels blending requirement as an abatement measure varies between –40 EUR/tCO_2 and 270 EUR/tCO_2 with an average of 110 EUR/tCO_2. These calculations take into account the fact that the high number of EVs and increased ICE efficiency will significantly reduce the need for liquid fuels in Finland. Therefore, the potential biofuel need is only likely to be around 22 PJ in 2030. It is assumed that this need will be wholly met by HVO, based on the current capacity information provided by Sipilä et al. (2018).

[27] LVM: Alternative fuels infrastructure – a proposal for a national framework until 2020/2030 (2015) estimates that in 2030 25,000 recharging points accessible to the public should be provided for a minimum of 250,000 electric vehicles, according to the AFI directive that estimates one publicly available charging point per 10 EVs. Accordingly, the 800,000 passenger vehicles would require some 80,000 public charging points.

particularly time-sensitive item requiring decisions within the next few years.

- Second, in addition to the infrastructure, an increased supply of power is needed as large-scale EV adoption requires additional electricity. Uptake of electric vehicles will increase electricity demand by roughly 7 TWh by 2030.
- Third, careful policies and support schemes are needed to drive consumer and business-driven adoption of electric vehicles, especially to overcome the challenge of electric vehicle upfront investment. Given that over 20 per cent of Finnish passenger vehicles are owned by companies,[28] private initiatives could also considerably support EV uptake. Companies could also be incentivised to favour EVs in their car policies.

Buildings: phasing out oil boilers

Buildings account for approximately 2.2 $MtCO_2$ or 4 per cent of Finnish emissions. Within the buildings sector, heating is one of the main sources of energy consumption and CO_2 emissions due to the cold climate and consequent large heating need. By 2030, energy demand for space and water heating in buildings is projected to increase by 7 per cent from 2015 levels. The increase will be driven by population growth and increasing average floor space per person, while energy efficiencies from insulation and energy management improvements will slow down the growth. District heating is currently the most widely used form of heating, accounting for almost half of all heating, and it is projected to remain the dominant source of heating in both residential and non-residential buildings in 2030.

In this sector, the largest potential for cost-effective emissions abatement is in replacing oil boilers with low-emission alternatives such heat pumps and electric heating. In the 60 per cent pathway, oil heating systems will be almost fully phased out by 2030, and consequently only 0.1 $MtCO_2$ of emissions will remain within the buildings sector, as electric and district heating are accounted for in the power and heat sector.

The abatement pathway outlines the following measures.

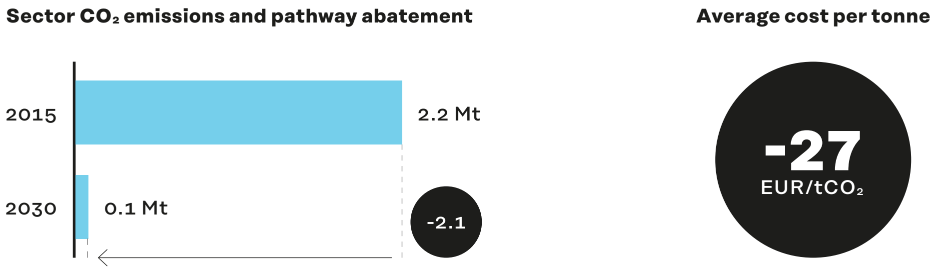
- **Oil boiler phase-out in commercial and public buildings** *1.2 $MtCO_2$ abatement by 2030, cost from –100 to 40 EUR/tCO_2:* Oil boilers in commercial and public buildings switch to low-emission solutions, with ground-to-water heat pumps as the prevalent solution. The ground-to-water heat pumps account for 0.7 $MtCO_2$ abatement with an average cost of –100 EUR/tCO_2. The replacements will take place in the early 2020s as the annual average cost of the technology is projected to already be some 30-40 per cent below the cost of commercial oil boilers by then.

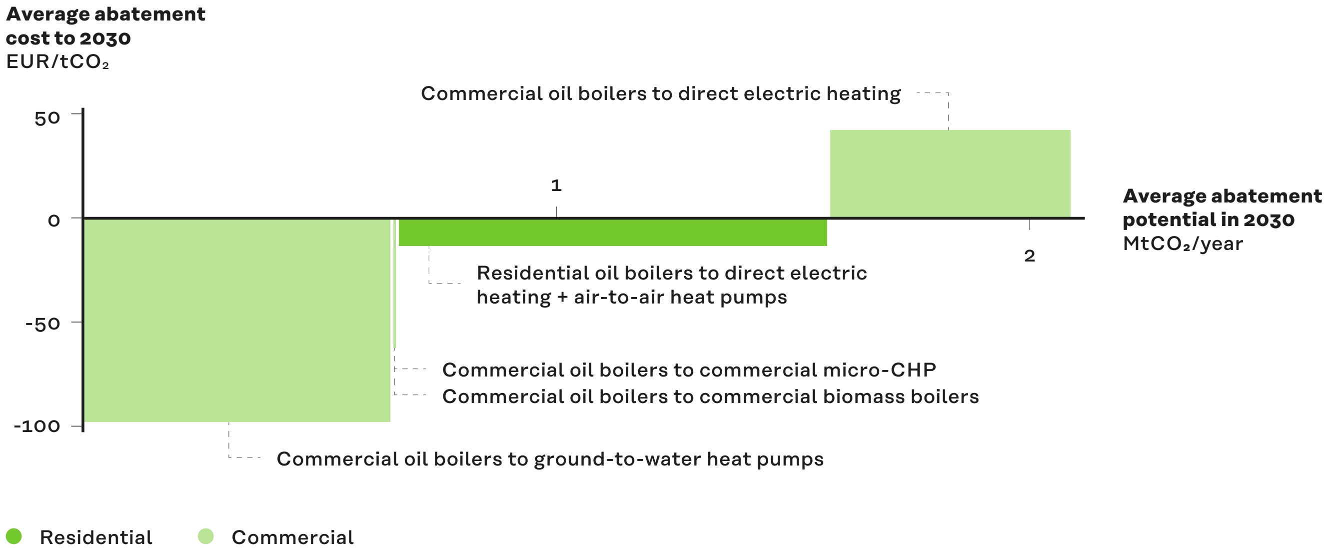
  For those buildings where ground-to-water heat pumps might not be a suitable solution, biomass boilers and direct electric heating would be the most cost-efficient low-emission alternative.[29] The operating costs for these technologies are higher than for ground-to-water heat pumps, with abatement costs per tonne roughly at –60 euros for biomass boilers and 40 euros for direct electric heating. These replacements will take place in the late 2020s.
- **Oil boiler phase-out in residential buildings** *0.9 $MtCO_2$ abatement by 2030, cost –15 EUR/tCO_2:* In residential buildings, oil boilers will be replaced with

---

28 Trafi Vehicle fleet July 2018.
29 Ground-to-water heat pumps require the presence of ground water or other ground-to-water systems nearby and become more expensive if bedrock is deep in the ground. To reflect this, in the analysis the annual increase in commercial ground-to-water heat pump use has been limited to a maximum of 10 per cent.

Figure 5: Cost-curve sector summary for buildings
Please note that the numbers may not add up due to rounding.





a hybrid solution of air source heat pumps and direct electric heating as the most cost-efficient measures of the available options. This abates approximately 0.9 $MtCO_2$ with a negative cost of –15 EUR/tCO_2, and the lever will become cost effective in the early 2020s. Already now, a stand-alone air-to-air heat pump can provide households with up to 200-250 euros a year savings compared to an oil boiler (accounting for both investment and operating costs). This reduces the average cost per kWh of heat supplied by 8 per cent.[30]

It is likely that supporting policies will be needed to reach the full abatement potential in the buildings sector: the oil boiler replacement rate will need to be accelerated above the current average lifetime replacement rate of 18 to 20 years. There may also be consumer-driven market inertia, some owners of oil boilers potentially choosing not to switch the heating technology despite the availability of other more economical long-term options.[31]

Beyond 2030, additional efforts should be directed towards replacing gas boilers in residential and non-residential installations, which will, after the pathway measures,

[30] Lämmitystapojen vertailulaskuri: ~13.6 cEUR/kWh against 15c EUR/kWh.
[31] A lack of information or ability to finance investment has been identified as one of the key barriers to adoption by Sahari A.: Essays on Households' Technology Choices and Long-Term Energy Use (2017).

DEEPDIVE

Circular economy measures focused on the better use and reuse of products and materials complement the supply-side measures on the pathway

The discussion around emission abatement typically revolves around the supply-side measures, i.e. how industrial production, transport and energy production can be conducted with lower emissions. From another perspective, reductions in emissions can be achieved by circulating materials and using them more efficiently. In their 2018 report, Material Economics, together with Sitra and other collaborators, estimated that in the ambitious scenario seizing these demand-side opportunities could abate up to 300 million tonnes or over 50 per cent of heavy industry CO_2 emissions per year by 2050 in the EU. The report suggests that most of the measures are also economically attractive: material reuse decreases demand for new materials, which drives down carbon-emitting production volumes in materials – therefore reducing the need for costly materials while reducing emissions.

Circular economy measures centre around demand-side measures: recycling, material input reduction or increasing asset and material use though new business models. The minimum-cost pathway approach described in this report focuses on supply-side measures and does not consider opportunities in material recycling or reuse. In practice, the demand-side levers complement the supply-side abatement measures and should be leveraged in tandem with the decarbonisation efforts.

Most potential measures from the report for Finland include concrete recycling, material efficiency measures in construction, such as mandated design for element reusability, and increasing the circularity of plastics. As an example, cement production is highly localised and provides opportunities within Finnish borders through either reusing structural elements or recovering unused cement from concrete – though the latter requires commercialisation of these recycling technologies. The design of buildings for future reuse and recycling will be the key lever to unlocking the broader potential of material recycling in construction. However, the largest opportunities can most likely be found in the circularity of plastics in the petroleum value chain, where using waste plastics either in fuel or plastics generation has significant decarbonisation and material reduction potential.

Upon progressing on the decarbonisation path, new circularity opportunities (and challenges) could emerge. For instance, increased electric vehicle demand will create a need to recycle a significant amount of batteries, which is both a challenge but also a potential new business opportunity.

All in all, implementation of demand-side levers is essential for reaching the Paris Agreement targets and, combined with supply-side measures, can enable a faster and possibly more cost-effective abatement of emissions.

account for the majority of remaining CO_2 emissions in buildings despite representing less than 1 per cent of total heating installations in Finland.

In addition, the adoption of energy-efficient appliances and lighting will drive down electricity consumption as an enabler but not as a direct abatement measure on the pathway.[32] It is assumed that improvements in building insulation and energy management will continue like in the business-as-usual scenario, somewhat slowing down the growth of heating demand.

Industry: technology changes beyond energy efficiency efforts

The industry sector accounts for 27 per cent of Finnish GHG emissions, which makes it the largest source of emissions. The emissions, including both process and fuel combustion emissions, are expected to stay relatively steady, driven by fairly stable production volumes and modest efficiency improvements of 1.2 $MtCO_2$ by 2030. These improvements are included in the BAU scenario as well as in the 60 per cent pathway. Beyond them, additional energy efficiency-driven reductions in emissions of some 1-1.5 $MtCO_2$ could be achieved if either the ETS price significantly increases or the industrial companies prolong their typical payback time for energy efficiency improvements from two to 10 years. Due to the high degree of uncertainty involved, these additional energy efficiency improvements are not included in the pathway. Moreover, high investments in energy efficiency could eventually become partly sunk cost if the addressed sites later undergo major refurbishments, switching production or heating technology altogether.

On the pathway, abatement efforts in industry account for a major part, 7.7 $MtCO_2$ or some 30 per cent of the abatement needed. The majority of the measures entail electrifying heat production or switching to bio-based fuels and feedstocks. The single largest abatement opportunity would be in converting the last remaining blast furnace steel plant to hydrogen-based, direct reduced iron electric arc furnaces, but the timeline for this could be challenging and other measures should be considered. Most of the industry abatement measures on the pathway require significant one-off investments in major technical alterations of a specific industrial site, which makes them more expensive with an average cost of 40 euros[33] per tonne of CO_2 abated. The most expensive measures can go up to 170 EUR/tCO_2. However, all industry solutions are site-specific, and feasibility, costs and approach to realising the proposed abatement can vary significantly (estimates in the report are based on European averages). Additionally, the abatement costs in this analysis use a cost of capital rate that is clearly lower than the rate industrial companies apply for their investment decisions.[34]

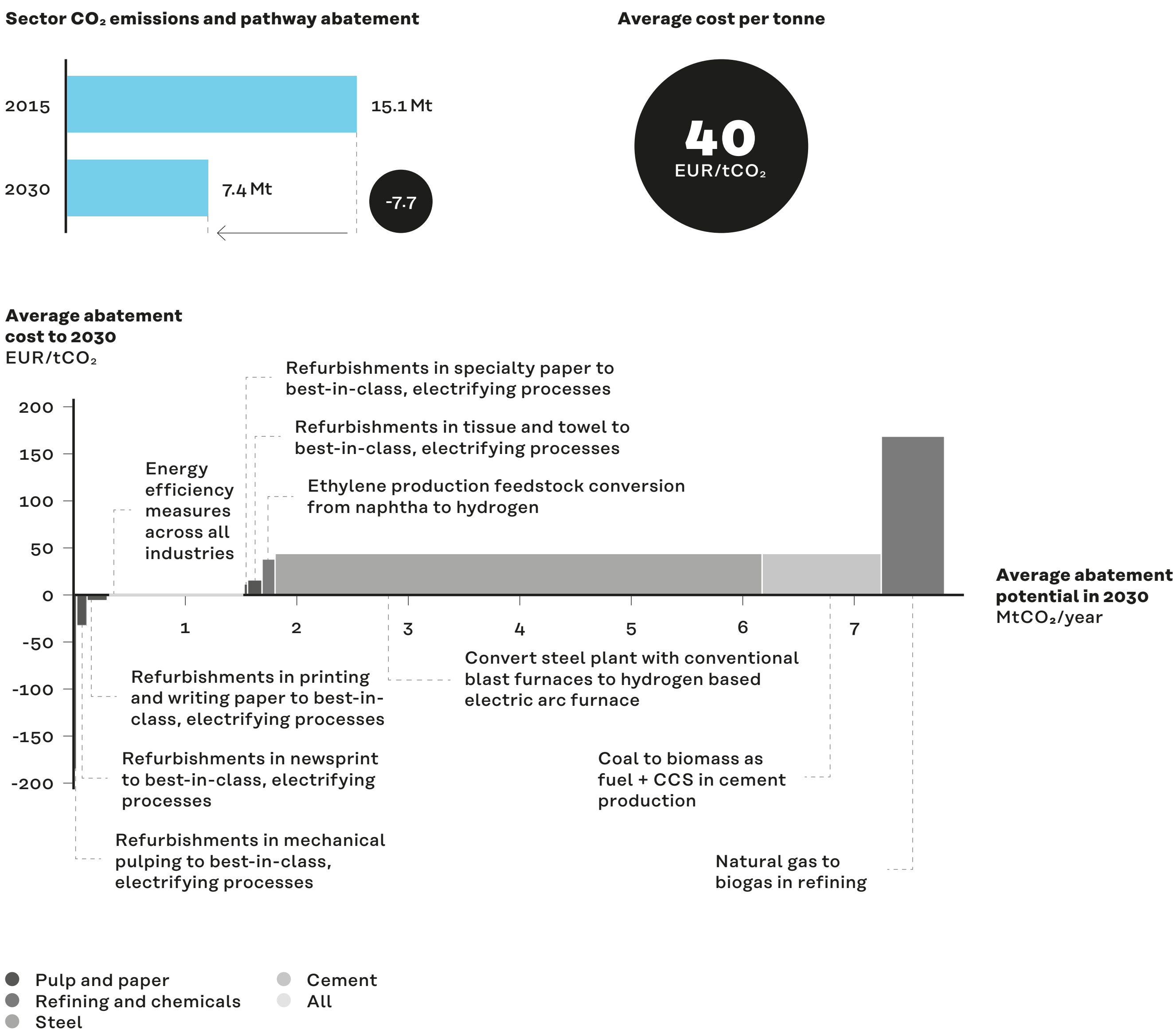
The abatement pathway outlines the following measures (the costs are on top of an assumed ETS price of 8-31 EUR/tCO_2).[35]

- **Steel plant conversion to electric arc furnaces and hydrogen technology**
  4.3 $MtCO_2$ abatement by 2030, cost 40–45 EUR/tCO_2 [36]*:* The 60 per cent pathway suggests that applying the hydrogen and electrification technology DRI-EAF (direct reduced iron – electric arc furnace) at a large steel plant is the

---

[32] Energy-efficient appliances reduce the need for electricity, reducing the need to generate electricity in the power and heat sector.
[33] On top of the ETS price – see Appendix for further details.
[34] Weighted Average Cost of Capital used by industrial companies is typically in range of 8-10 per cent, while this report applies the 4 per cent social discount rate.
[35] ETS price of ~8 EUR/tCO_2 in 2015 and 31 EUR/tCO_2 in 2030 – see Appendix for further details.
[36] Technology still in development, and consequently relatively high level of uncertainty associated with the cost level.

Figure 6: Cost-curve sector summary for industry
The CO_2 price of the EU ETS is included in the costs. Please note that the numbers may not add up due to rounding.



most efficient measure for further abatement, but in practice the likelihood of this lever being implemented by 2030 is quite low. The furnaces of the last remaining blast furnace plant will not reach the end of their life cycle until later and the required hydrogen supply is unlikely to become available at the required cost by 2030. If so, this leaves carbon capture and storage (CCS) as the only feasible interim solution. Yet CCS also becomes economically unfeasible if the ultimate hydrogen conversion is expected to occur around 2040, leaving too short a payback period for the CCS installation. If the steel plant cannot be converted, the remaining emissions gap needs to be covered by a wide set of measures from other industries and other sectors. The alternative abatement packages are explored further later in this report (see Deepdive: Alternatives to large-scale industry abatement).

- **Decarbonisation of other industrial sectors: cement, refining and ethylene** *1.7 $MtCO_2$ abatement by 2030, costs from 40 to 170 EUR/tCO_2*: Several other industrial sites in the cement and petrochemicals value chains could make step changes in decarbonisation with retrofits or by replacing fossil fuels with bio-based alternatives. In cement, biomass as fuel instead of coal and carbon capture and storage (CCS) in the calcination process reduces emissions on the pathway at 43 EUR/tCO_2, but other options such as electrification could also be considered. Refining can replace part of the natural gas used in heating with biogas, which is at the more expensive end of measures with costs of up to 170 EUR/tCO_2. In ethylene production, hydrogen-based technology can be used to replace naphtha as fuel at 37 EUR/tCO_2.

- **Energy efficiency improvements** *1.2 MtCO_2 abatement by 2030, cost 0 EUR/tCO_2 (cost similar to ETS price):* Driving energy efficiency improvements across sectors will abate an additional 1.2 MtCO_2. These improvements could for instance include opportunities in the use of pumps, optimising hot gas furnaces in steel and steam balance calibration in pulp and paper. The cost of these measures is estimated to be close to the projected ETS price.
- **Electrification of pulp and paper plant heat production to replace use of fossil fuels** *0.4 MtCO_2 abatement by 2030, costs from –185 to 15 EUR/tCO_2:* CO_2 abatement in heat production can be achieved at relatively low costs with electrification in pulp and paper plants. Pulp and paper is an industry well positioned to electrify some of its processes, such as heating or drying, because of the relatively low temperatures required. Moreover, solutions are more scalable because of the high number of plants, resulting in a learning curve for technology adoption through scale. Hence, pulp and paper measures tend to be more economical. Electrification of mechanical pulping, newspaper and printing and writing paper are expected to bring savings, while the electrification of tissue, towel and speciality paper come with small costs.

DEEPDIVE

Alternatives to large-scale industry abatement

The last 6 $MtCO_2$ of industry abatement is significantly more expensive than the other measures in the 60 per cent abatement pathway. Additionally, as discussed earlier, there is a significant timing risk with regard to the single largest lever (blast furnace conversion). Thus, we have identified three combinations of alternative measures that could be deployed to reach 60 per cent abatement if the blast furnace conversion timing risk is realised (Figure 7).

1. Higher contribution from the power and heat sector and the transport sector together with additional industry energy efficiency efforts

The first alternative portfolio of levers could consist of a further industry energy efficiency push together with actions in the other modelled sectors of transport, buildings and power and heat. The extension of energy efficiency measures in industry could reach up to 1–1.5 $MtCO_2$ of additional efforts (on top of the 1.2 $MtCO_2$ on the pathway), but this would require longer (10-year, for example) payback times or a significantly higher ETS cost. The remaining 4.5–5 $MtCO_2$ should come from the other sectors.

First, faster scrapping of ICE passenger vehicles could be a cost-efficient alternative, although challenging to implement with theoretically large but in practice <1 $MtCO_2$ potential. Second, reaching higher blending rates also becomes easier even with a limited supply as the total fleet of ICE cars would reduce along with the electrification of transport. This lever has potential for over 1 $MtCO_2$ abatement if biodiesel blending were increased towards 100 per cent, also making EVs more attractive at the same time if the additional cost of biofuel is passed onto the consumer.[37] Third, heat-only generation plant conversions to biomass or replacement with emerging technologies such as deep geothermal heat could bridge the gap (2–3 $MtCO_2$) to the 60 per cent target by 2030. Replacement of the remaining coal in power generation in the 60 per cent pathway with renewable alternatives could abate 0.3 $MtCO_2$.

2. Abatement from non-covered emissions

Non-covered sectors have been assumed to only provide a modest reduction of 2 $MtCO_2$ out of a base of 13 $MtCO_2$ in 2015. Some additional opportunities, also mentioned in the WAM[38] scenario, could include, for example, measures in waste management, the reduction of F-gases, expanding the biofuel blending requirement to other uses such as working machinery or aviation, the replacement of fossil fuels in heat-only plants or further efforts in agriculture. However, the costs of these measures could be high.

3. Wide range of options

Probably the most feasible approach to replacing some of the industry efforts – if needed – would be to find abatement options from a wide spectrum of measures in different sectors. This could consist of: energy efficiency efforts in industry, faster EV roll-out, increased biofuel blending rates, solar collectors and waste heat capture, behavioural changes in

[37] The exact quantity of biofuels needed and their global supply should be checked before increasing the biofuel blending mandate. With current regulations the supply of raw material for liquid biofuels could be limited if many countries increase their demand for them.

[38] “With Additional Measures” scenario from TEM Government report on the National Energy and Climate Strategy for 2030 (2017).

Figure 7: Three alternative examples to abate the last 6 $MtCO_2$ of industry emissions in the 60% pathway

transport, demand-driven reduction in agriculture emissions through lower meat consumption, improved waste management, a coal ban, a potential peat ban or omitting fossil fuels in heat-only plants. This approach would differ from the first combination of alternative measures by relying on multiple smaller-scale measures in all sectors.

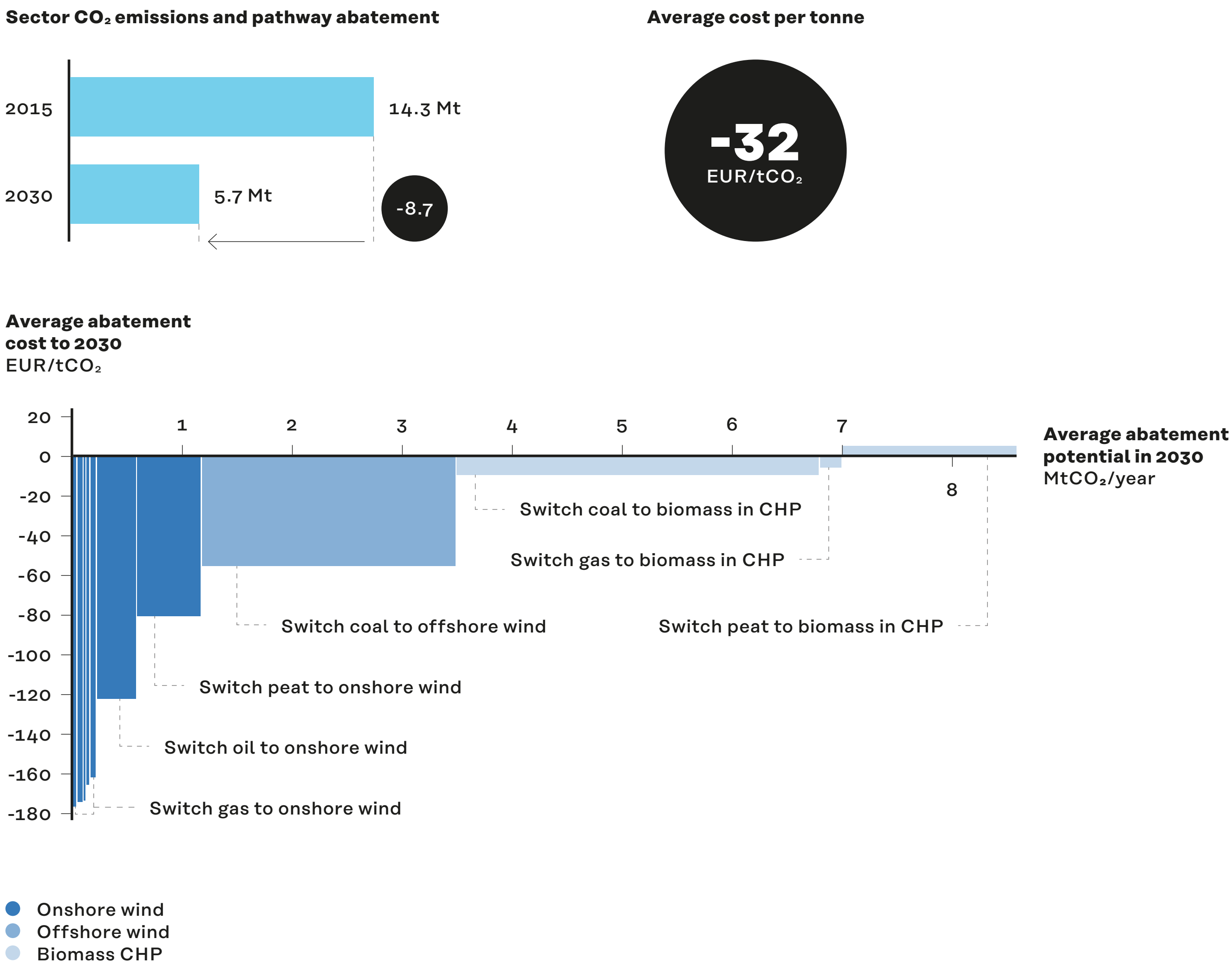
Although work remains to establish a more ambitious national plan on decarbonisation across all sectors and emission types, there seems to be potential to reach and possibly bypass 60 per cent, even if some industry efforts would need to be pushed beyond 2030. While these options exist, industry should consider when and how larger technology switches should be done. Industry should eventually be decarbonised to achieve a zero-emission society.

Power and heat: wind adoption at scale, biomass in cogeneration plants

The power and heat sector in Finland includes plants that only produce electricity, heat-only generation plants and cogeneration plants (combined heat and power or CHPs). CHPs produce both electricity and heat for industry processes[39] or district heating purposes, ensuring high fuel efficiency. This report focuses on electricity generation plants and CHPs. However, as discussed in Deepdive: Alternatives to large-scale industry abatement, biomass conversions and other measures in heat-only generation plants could also be leveraged for emissions abatement.

Since 1990, the emissions from electricity production and CHP plants have decreased

Figure 8: Cost-curve sector summary for power and heat
The CO_2 price of the EU ETS is included in the costs. Please note that the numbers may not add up due to rounding.



[39] Industry CHPs are included in the power and heat sector section of this report. In Finland, industry CHP allocation varies at the plant level on an annual basis to categories 1.A.1a or 1.A.2x in the United Nations Climate Change National Inventory Report, depending on whether the plant is owned by a manufacturing or energy company.

about 15 per cent[40] due to the growing share of bioenergy in the system and recent support-driven uptake of other renewable energy sources.

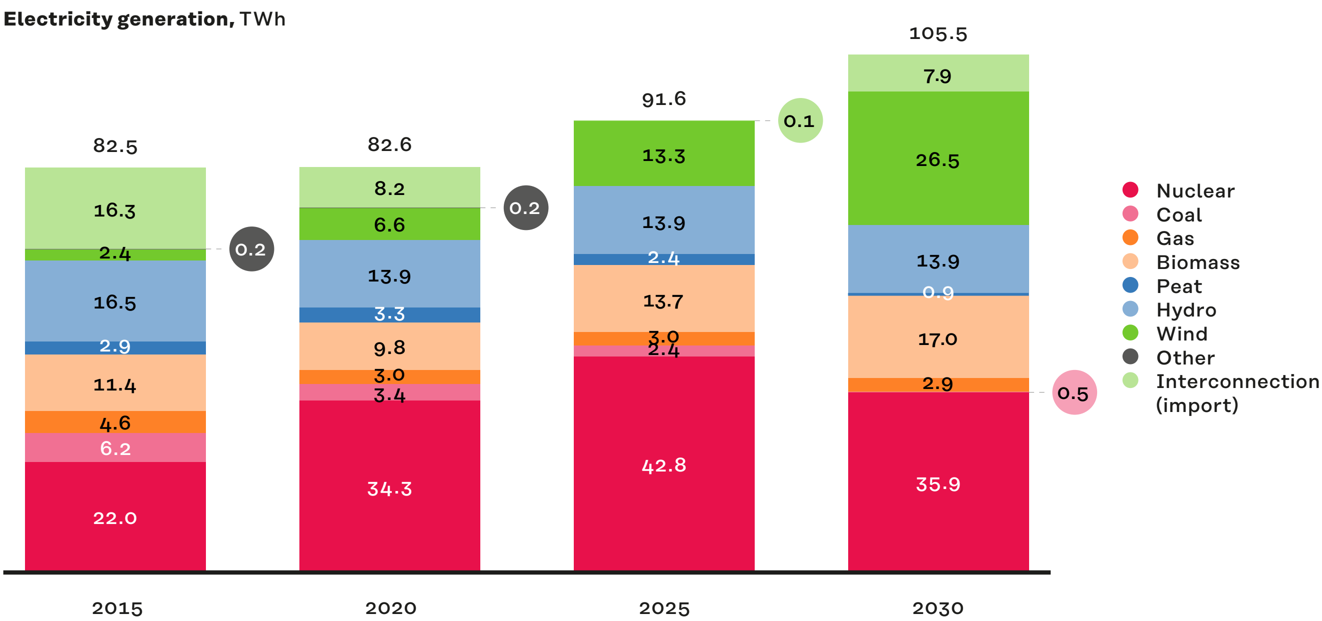
On the 60 per cent emissions reduction pathway, decarbonisation of other sectors is projected to increase electricity demand by 28 per cent by 2030 from 2015 levels. To meet this growing power demand without jeopardising emissions reductions in the power sector, onshore and offshore wind and bioenergy need to be leveraged. These fossil-to-renewable power generation switches are shown on the pathway, but it is important to recognise that power sector measures are more complex than, for example, individual plant conversions.

Power sector changes affect the integrated energy system, additional intermittent wind power creating a need for storage and/or other types of flexibility. Costs beyond the single asset replacement are incurred at the system level.

New wind power will also be needed more than is shown on the 60 per cent pathway: wind will replace fossil fuel electricity generation, but there is also new capacity coming online to generate the electricity needed to cover the increased power demand from space heating, transport and industry electrification.[41]

Wind appears as the most cost-efficient of renewable power options, driving its adoption as an abatement measure.[42]

Figure 9: net generation grows 28% driven by demand increase
Please note that the numbers may not add up due to rounding.



[40] United Nations Climate Change National Inventory Report category 1.A.1a: Public electricity and heat production.
[41] Therefore, exactly how much offshore and onshore wind would be split on the curve is a rather technical question, depending on which generation units are matched to fossil fuel generation units. Here most abatement is allocated to offshore wind which comes online at the same time when fossil-burning units go offline, replacing coal, whereas onshore would replace more expensive oil earlier in the pathway. Total abatement allocated between the two wind types is 3.5 $MtCO_2$.
[42] Cost-efficiency has been determined by system-level modelling. The model simulates the hourly load and the hourly supply and picks the new capacity according to a cost minimisation of the total system. This resulted in choosing wind and complementing battery storage as capacity additions.

Onshore wind costs have been falling rapidly in the last 5–10 years, driven by a decline in commodity prices – for example, the halving of steel prices between 2010 and 2016 – increasing supply chain competition and economies of scale. The cost reductions are expected to continue in the future due to blade design improvements and further increases in turbine size. Because of this, the levelised cost of electricity (LCOE) produced with onshore wind is expected to reach 25-27 EUR/MWh by 2030.[43] In comparison, Fennovoima reported a cost of electricity to its shareholders of about 50 EUR/MWh for production from the Hanhikivi 1 nuclear plant once it is online in 2024–2025[44], while Fortum estimates roughly 60 EUR/MWh for future nuclear investments.[45]

The sizeable increase in offshore wind will be enabled by expected rapid improvements in the economics of the technology in the coming years, driven by similar technical developments as onshore wind, i.e. improvements in blade design and manufacturing and increases in turbine size. Moreover, standardisation is increasing and economies of scale are driving down construction costs. When put together, all of the technical and design developments are projected to bring offshore wind LCOE as low as 30–35 EUR/MWh by 2030. The analysis shows that even if support mechanisms, such as the feed-in tariff that is in place until 2023, were excluded, offshore wind would be the preferred solution post-2025 because of the high performance of this technology and its great potential in Finland.

The increase in wind power capacity and its implications will be discussed in depth in Chapter 4.

The abatement pathway for power and heat includes the following measures (the costs are on top of an assumed ETS price of 8–31 EUR/tCO_2).[46]

- **CHP switch from coal and peat to biomass** *5.2 MtCO_2 abatement by 2030, costs from –10 to 5 EUR/tCO_2:* The pathway suggests that all the CHP power plants using coal as their main fuel and the peat-based plants that are older than 30 years[47] will switch to biomass by 2030 to achieve an emissions reduction of roughly 5.2 MtCO_2 in cogeneration. This will result in approximately 6 TWh of additional power generated from biomass by 2030. The cost of replacing coal is estimated at –10 EUR/tCO_2, while the switch from peat cogeneration to biomass is estimated to cost 5 EUR/tCO_2, given the relatively lower current fuel price compared to the assumed wood fuel price.

  Cogeneration is expected to remain a fundamental part of the Finnish energy system. Cost-competitiveness of cogeneration CHPs in low electricity price scenarios could be questioned, but this report assumes CHPs will continue to produce electricity in the system, reflecting also the impact estimate from Pöyry[48] on coal phase-out findings.

  Emerging low-emission alternatives such as small modular nuclear reactors and deep geothermal energy have not been included in this analysis because of

---

43 Calculated with social weighted average costs of capital of 4 per cent.
44 World Nuclear Association.
45 Fortum investor presentation September 2018.
46 ETS price of ~8 EUR/tCO_2 in 2015 and 31 EUR/tCO_2 in 2030 – see Appendix for further details.
47 Assumption made for modelling purposes. In practice, most peat-based plants can seamlessly switch to biomass, but this may increase plant operational cost because of higher fuel costs, lower efficiency and increased maintenance work. Older plants are expected to have a more positive business case for conversion.
48 Pöyry Management Consulting: EU:n 2030 ilmasto- ja energiapolitiikan linjausten toteutusvaihtoehdot ja Suomen omien energia- ja ilmastotavoitteiden toteutuminen (2016) suggests that heat-only plants are not cost competitive against CHPs, for example, unless a scenario of both low power demand growth and low electricity prices are applied. As this analysis focuses on most economic options, heat-only plants would not be picked up as technology replacements in modelling.

their relatively early stage of development. Possible alternatives to the heavy use of biomass in energy production are discussed in more detail in Chapter 4.

Levelised cost of electricity (LCOE) of onshore wind is expected to reach 25-27 EUR/MWh, offshore wind 30-35 EUR/MWh by 2030.

- **Shift from fossil fuels-based electricity generation to offshore wind power**
  2.4 $MtCO_2$ abatement by 2030, cost –55 EUR/tCO_2: On the pathway, deployment of offshore wind will abate some 2.4 $MtCO_2$ by replacing coal-based electricity generation. The share of electricity from offshore wind will increase to 19 per cent of the Finnish power generation mix by 2030, since in addition to the direct abatement, it also supplies a large part of the additional power demand. In total, approximately 4 GW of new offshore wind capacity will be needed. Currently, 2–2.5 GW of offshore capacity are in different stages of the land permit and environmental assessment process.[49] If realised, these projects could provide about half of the additional offshore capacity needed in the pathway.
  The remaining capacity needs to come from new projects. Finland holds the largest technical potential for offshore wind in the Baltic Sea region, with up to 16–17 GW of "golden zones", excluding protected areas.[50] Key advantages of the Finnish coastal region are the relatively shallow waters and high wind speeds. Moreover, offshore wind provides certain advantages compared to the on-land technology, as offshore wind speeds tend to be faster and steadier and hence provide a more reliable source of a larger energy amount generated per unit of capacity.
  The replacements result in cost savings at the system level with negative abatement cost of roughly −55 EUR/tCO_2.
- **Shift from fossil fuels-based electricity generation to onshore wind power**
  1.1 $MtCO_2$ abatement by 2030, costs from −175 to −80 EUR/tCO_2: The abatement potential of onshore wind in the pathway is roughly 1.1 $MtCO_2$. This translates into a need to build some 1.2 GW[51] of additional onshore wind capacity between 2018 and 2030. The current onshore wind pipeline consists of about 11 GW of projects at different stages of the land permit process,[52] which can be expected to be realised to cover the additional needs.
  The replacements result in cost savings at the system level with negative abatement costs ranging from −175 to −80 EUR/tCO_2 depending on the technology replaced.

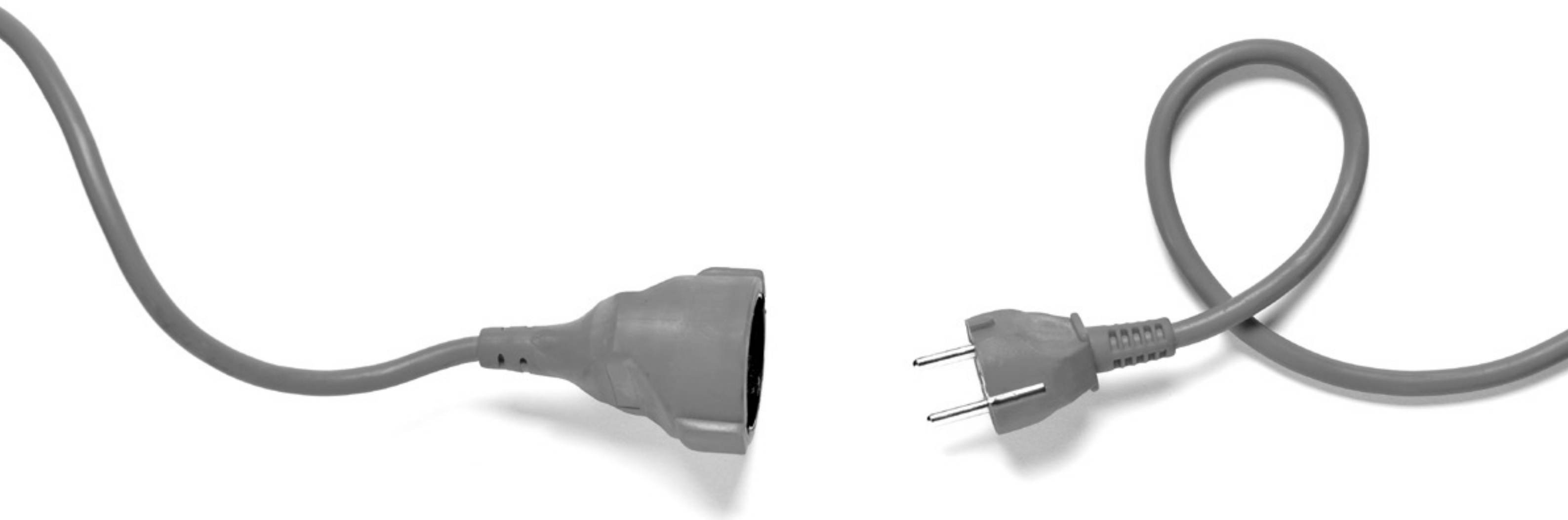
In the pathway, some additional implications for the energy system should be expected. Assuming no increase in the level of annual net imports compared to the BAU scenario, up to 5 GW of flexibility[53] would be needed to provide adequate load-shifting and

49 Suomen Tuulivoimayhdistys ry: Wind power in Finland.
50 Baltic Sea Region Energy Co-operation (BASREC).
51 Capacity factors expected to increase from ~28% in 2016 to ~36% in 2030.
52 Suomen Tuulivoimayhdistys ry: Wind power in Finland.
53 Modelled as storage capacity, but it could also include other types of flexibility, such as demand-side measures or interconnections.

flexibility in demand. The most cost-effective way to achieve this could be to install large-scale batteries, as battery technology costs are projected to decline rapidly. Such a solution would result in approximately 3 billion euros of additional investments in storage capacity between 2020 and 2030, but in practice at least half of this could be covered by interconnections and demand measures, discussed further in Chapter 4.

Furthermore, new grid investments will need to occur at a sufficiently fast pace to allow for fast renewable penetration without compromising the reliability of the power system, and to ensure the expansion of the network to the areas where demand will grow. The outstanding challenges and their policy implications are discussed in Chapter 4.

New grid investments will need to occur at a sufficiently fast pace to allow for fast renewable penetration without compromising the reliability of the power system.



DEEPDIVE

Pathway to a 40 per cent reduction in emissions

The analysis also outlined a pathway for reaching the current EU emission reduction commitment of at least 40 per cent abatement by 2030 compared to the 1990 level. The target requires abating at least 11 $MtCO_2$[54] from 2015. Finland is very well positioned to close this emissions gap and, compared to the 60 per cent abatement pathway, could mainly focus on using the electric vehicle levers and wind power, with a limited need to deploy more expensive measures in the industry sector (Figure 10). By using only cost-negative or cost-neutral measures, Finland would be able to exceed the 40 per cent abatement target and reduce emissions by some 13.5 $MtCO_2$. This would translate to an approximate 43 per cent abatement compared to 1990 levels. The measures on this pathway are all included in the 60 per cent pathway, but the 40 per cent pathway excludes almost all industry measures, the biofuel blending rate increase and the more expensive CHP switches from peat to biomass.[55]

The cost-negative and cost-neutral abatement measures by sector would include the following.

- **Power and heat** *6.9 $MtCO_2$ abatement, 51% share of cost-negative or cost-neutral emissions reduction:* CHP generation would shift from coal to biomass according to the most feasible schedule delineated by the Ministry of Economic Affairs and Employment's impact report for the coal ban by 2029.[56] This would drive an abatement of 3 Mt, and lead to additional power generation from biomass of about 3 TWh. An additional 3.9 $MtCO_2$ would be abated by scaling up wind power. To meet the additional demand for electricity resulting from electrification measures in other sectors, wind power production would further increase to cover 22 TWh or 21% of Finnish electricity generation by 2030.
- **Transport** *4.8 $MtCO_2$ abatement, 36% share of cost-negative or cost-neutral emissions reduction:* diesel and gasoline passenger vehicles would be rapidly and extensively replaced by battery electric vehicles and plug-in hybrids both for consumer and commercial use. Some 800,000 electric passenger cars, 200,000 trucks and 8,000 buses on Finnish roads by 2030 could realise an abatement of about 4.3 $MtCO_2$ by 2030, and ICE efficiency improvements would realise another 0.5 $MtCO_2$.
- **Buildings** *1.6 $MtCO_2$ abatement, 12% share of cost-negative or cost-neutral emissions reduction:* a continued shift from oil boilers to heat pumps and electric heating in residential and commercial buildings would see a continuation of the historical replacement rate, reducing oil boiler prevalence from approximately 10% of building heat supply in 2015 to <2% in 2030.
- **Industry** *0.1 $MtCO_2$ abatement, 1% share of cost-negative or cost-neutral emissions reduction:* heat production would be decarbonised by either electrification or replacing fossil fuels with biogas in pulp and paper plants.

---

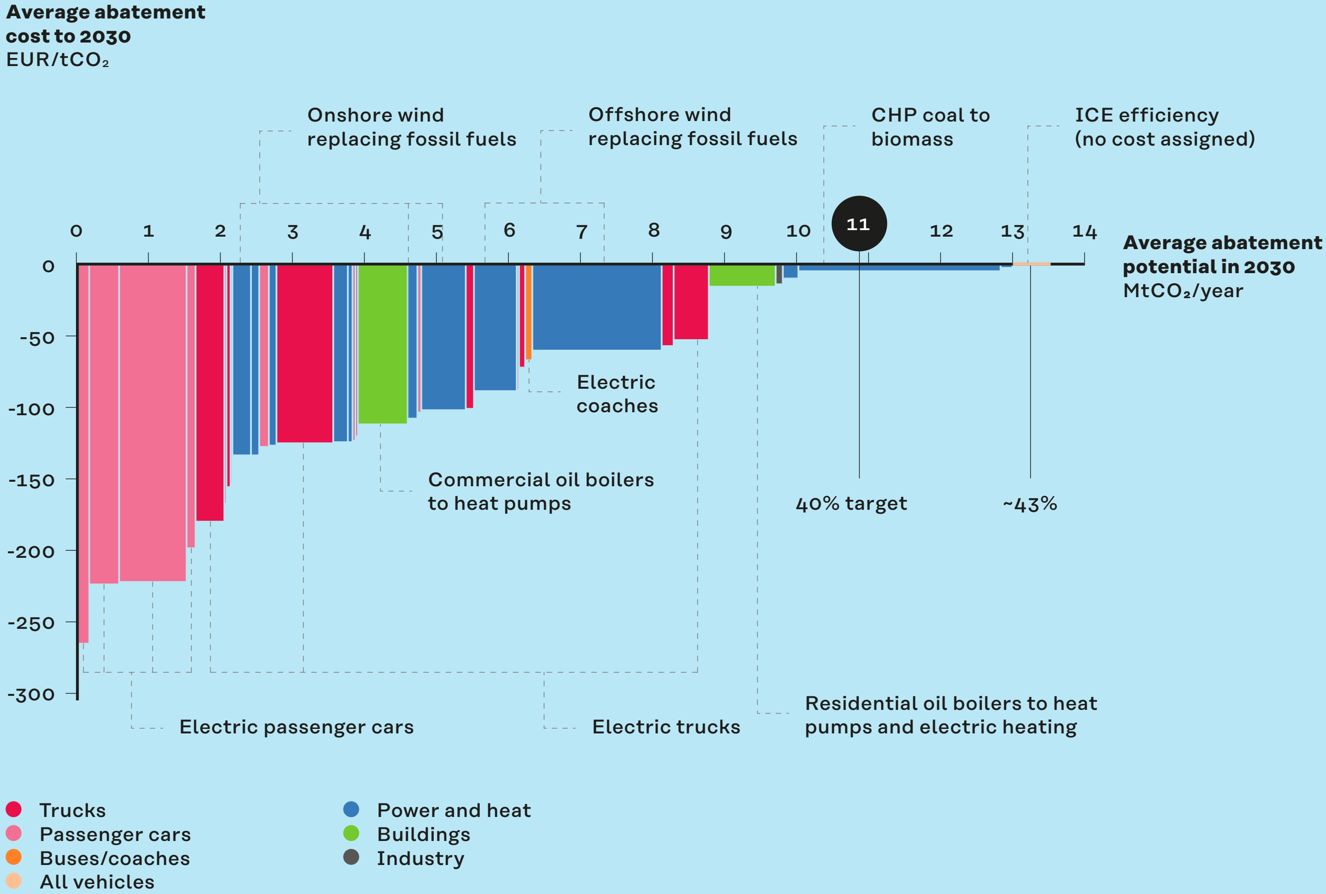
[54] In the sectors modelled in detail: total abatement needed ~13 $MtCO_2e$ with the ~2 $MtCO_2e$ gap covered by non-covered emissions such as F-gases and non-covered sectors such as waste management.

[55] The main differences between the two pathways are the industry measures and the different degree of decarbonisation in CHPs, with many small differences in the degree to which certain levers are pulled. Looking at the pathway cost curves, in the 40 per cent pathway the cost-neutral or cost-negative measures reach ~14.5 $MtCO_2$, while in the 60 per cent pathway similar measures add up to ~16.5 $MtCO_2$. This is primarily due to excluding industry-efficiency measures that could be reached with costs similar to the ETS price (showing around zero on the chart).

[56] TEM: Kivihiilen käytön kieltämisen vaikutusten arviointi (2018).

Figure 10: Pathway to a 40% reduction in emissions

EVs, wind power and oil boiler phase-out drive abatement to approximately 43% at negative or neutral cost. The CO_2 price of the EU ETS is included in the cost of measures for industry and power and heat.



It is important to note that even though there might be net savings by pursuing this pathway, this does not imply that the shown measures will happen by themselves. A series of enabling polices will need to be in place to realise the indicated abatement and cost saving potential.

The key enablers for the pathway include:

- a charging infrastructure for EVs;
- reinforcement and expansion of the electricity grid to enable electrification in transport and buildings and to enable onshore and offshore wind power connections
- adjustment of electricity price-setting mechanisms to support investments in wind power[57]
- widespread adoption of energy-efficient APPLIANCES (energy label class A) in residential and commercial buildings to reduce the electricity need and thus support decarbonisation.

[57] Although more moderate than in the 60 per cent pathway.

Figure 11: Finnish emissions in 2030 in different pathways
Please note that the numbers may not add up due to rounding.

Sector	2015 Emissions, $MtCO_2e$	2030 Current policies – BAU, $MtCO_2e$	2030 40% pathway, $MtCO_2e$	2030 60% pathway, $MtCO_2e$
Industry CO_2	15	16	15	7
Power and heat CO_2	14	9	7	6
Transport CO_2	11	9	6	5
Buildings CO_2	2	2	1	0.1
Other: agriculture, waste management, non-CO_2	13	11	11	11
Total:	**56**	**47**	**40**	**29**

● Modelled on technology level and as BAU
● Projected according to WEM

End point of the pathway: the Finnish greenhouse gas emissions landscape in 2030

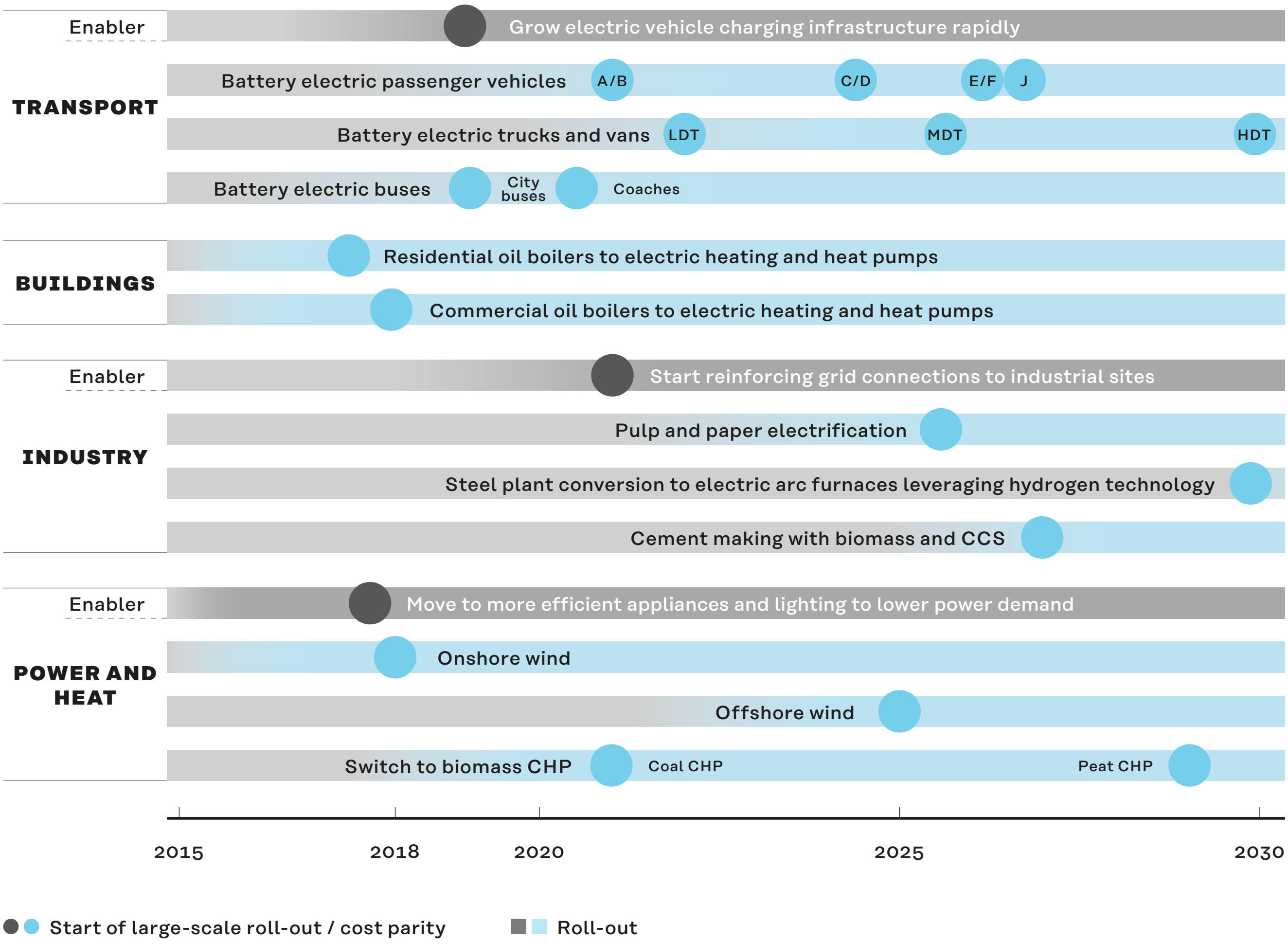
As a result of the 60 per cent pathway, the emissions landscape in 2030 will look remarkably different from today (Figure 11). In total, GHG emissions will be approximately half of today's emissions, down to 28 $MtCO_2e$. The transport, industry, and power and heat sectors' emissions will be roughly halved, while the buildings sector and the non-modelled sectors represent an exception; for buildings, emissions will be approaching zero, with only some gas boilers remaining with less favourable economics of replacement. In power and heat, the remaining emissions originate from gas and remaining peat use in CHPs (roughly 60 per cent of emissions) and heat-only plants (roughly 40 per cent of emissions).

In contrast, the emissions from the non-modelled sectors and gases will decline very moderately in line with WEM and BAU respectively, resulting in only an approximate 15 per cent abatement. As the report has not considered any additional measures for these emissions, the remaining emissions highlight the potential for additional abatement opportunities.

Getting on with the pathway: decisions needed before 2020

Getting to the 60 per cent pathway from current business-as-usual development requires multiple critical decisions to be taken. These decisions are characterised by the type and the timing. Figure 12 depicts when the technologies must be rolled out and when the building of their enablers should start.

Figure 12: Technology adoption over time on the 60% pathway



On the BAU pathway and the 60 per cent pathway, one key similarity is the continued abatement through efficiency improvements across sectors. Energy efficiency will be a smaller lever for the 60 per cent pathway because of more industry technology switches, converting more sites and leaving less for efficiency-related abatement.[58] Otherwise the paths start to diverge as of now.

Electrification creates many needs for early actions. The 60 per cent pathway splits off from the BAU pathway immediately, as early as 2018–2019, as a result of doing the following.

1. Investing heavily in more energy-efficient household appliances and residential and commercial lighting, leading to as much as a 3–4 TWh reduction in power demand from residential and commercial sectors by 2022. This reduction in power use can to some extent compensate for the surge in power demand from the

[58] For example, after switching from natural gas to biogas heating, energy efficiency improvement will no longer lead to a reduction in emissions.

electrification of transport, industry and space heating that will roll out after 2020.

2. Starting large-scale permit processes and preparations for power grid extensions: grid extensions are needed to enable onshore wind, offshore wind, large industrial site electrification projects and EV adoption.
3. Building an understanding of whether the largest and site-specific industrial measures could be realised, and executing those, or identifying the alternative packages of measures to reach the 60 per cent target by 2030.

In addition, between 2020 and 2025, the 60 per cent pathway includes a rapid roll-out of electric vehicles, representing >80 per cent of sales by 2025. To account for the upsurge in electricity demand, a large roll-out of wind power will be needed – with a total generation of 13 TWh a year by 2025 (instead of the more moderate 8 TWh in the BAU).

By 2025, supporting mechanisms and decisions should be in place to enable the roll-out of electrification measures in industry. Most industry measures will be taken in the period 2025–2030: industry electrification, the use of biomass for cement production, biogas mixing in refining and, by 2030, the use of hydrogen for steel making. An estimated 10 billion euros of additional capital needs to be spent in the 60 per cent pathway between 2025 and 2030 compared to the 40 per cent pathway, primarily on industry refurbishments.

4. Impacts on the energy system and the economy

As discussed earlier, the 60 per cent decarbonisation pathway builds on drastically reducing the role of fossil fuels in the Finnish energy system and on introducing intermittent wind power production at scale. The implications of this shift, including the prerequisites for the needed supply and infrastructure investments and the challenges related to growing biomass use are reviewed in more detail in this chapter. Finally, the possible implications of the 60 per cent abatement pathway on the Finnish economy more broadly are discussed briefly.

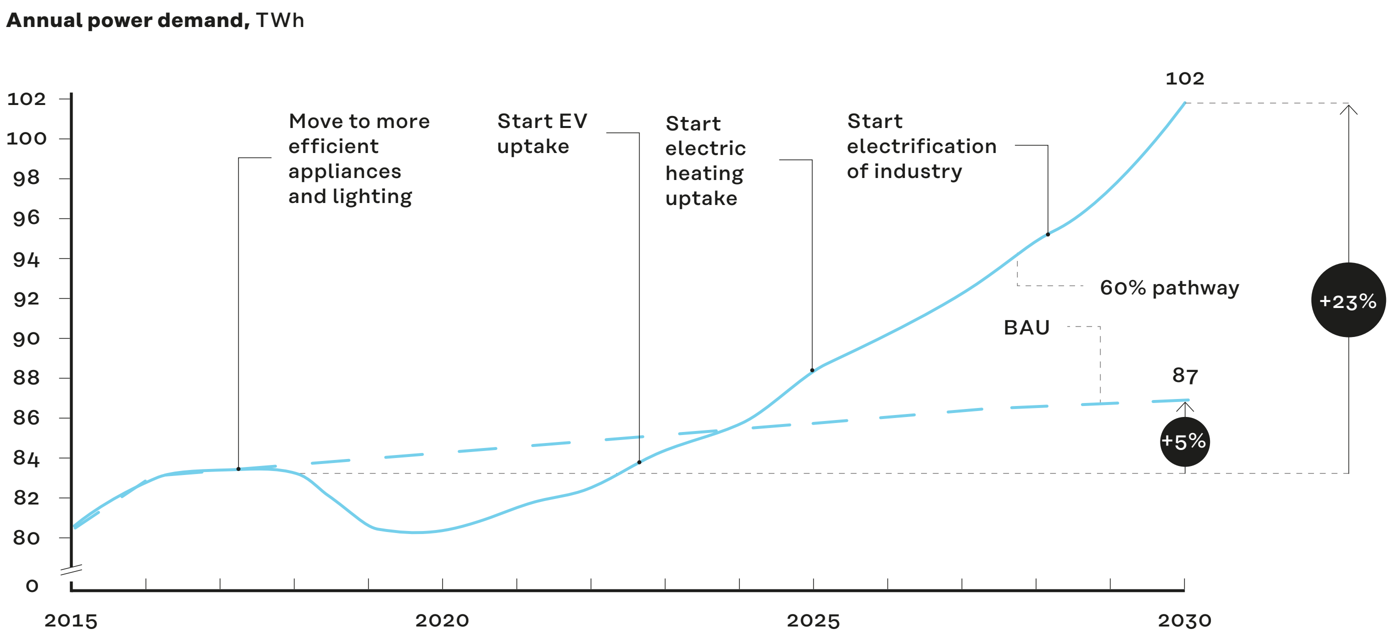
Implications for the energy system

Final energy demand in sectors modelled at technology level will decrease by 8 per cent in the 60 per cent pathway despite growth in electricity demand. This is driven by several changes. The electrification of transport, industrial processes and space heating will reduce the need for fossil fuels in transport, industry and buildings. At the same time, use of bio-based fuels and hydrogen will replace fossil fuel alternatives. Increasing energy efficiency in buildings, transport and industry will reduce the overall need for electricity, fuels and feedstocks.

Electrification will increase electricity demand by nearly 30 per cent

The 60 per cent pathway with electrification as the main decarbonisation lever will lead to significant power demand growth.

Figure 13: Annual power demand and main demand growth drivers
In the 60% pathway, power demand increases by 23% compared to today, 18 percentage points more than in BAU.



Annual power demand will grow from 80 TWh in 2015 to 102 TWh in 2030, primarily driven by EV uptake (+7 TWh), industry electrification (+8 TWh) and electricity used for heating in buildings (+7 TWh) (Figure 13). While electricity demand will grow also in other applications, energy efficiency improvements in, for instance, household appliances will counterbalance (-3 TWh) the additional demand.

As shown in Figure 13, electricity demand will grow gradually over the period until 2030. It will start with the increase in EV adoption in large cities, while industry electrification will accelerate electricity demand growth closer to 2030. The largest step increase (+5 TWh) will occur in 2029 with the possible steel plant conversion to hydrogen technology combined with electric arc furnaces. There will also be other smaller plant electrification measures with under 1 TWh of new demand each, which accumulate to drive a significant increase in electricity demand.

In electricity supply, wind wins as the most competitive clean energy source

To meet the growing electricity demand, new generation capacity will be required. Of the considered emission-free alternatives (nuclear, hydro, solar, wind), wind has the most favourable economics and the technical potential to be scaled up. In the 60 per cent pathway, wind power production will increase from 2 TWh in 2015 to up to 26.5 TWh by 2030. Biomass use in CHPs to replace fossil fuels will contribute another 5.6 TWh (Figure 9). Nevertheless, some practical constraints apply to the implementation of the technologies.[59]

The levelised cost of electricity (LCOE) for onshore and offshore wind is expected to decrease with technology improvements, the scaling up of technology and high capacity factors. LCOE for onshore wind is projected to fall to 25–27 EUR/MWh and offshore wind to 30–35 EUR/MWh by 2030. Both figures are significantly lower than the projected LCOE for nuclear, which both Fortum and Fennovoima estimate at 50–60 EUR/MWh in 2030.[60] Therefore, the share of onshore and offshore wind will grow on the pathway.[61]

Until 2030, there are some uncertainties affecting electricity supply. For instance, a new nuclear plant in Hanhikivi is scheduled to come online in 2024 but might be delayed until 2028–2029. Finland is also likely to ban coal in energy production in 2029, provided that the proposed government legislation is passed. While the effects of these topics have been widely discussed in Finland, the conducted analysis shows that their effect on the abatement pathway would be temporary and would not affect the power generation mix in the target year 2030 to a significant extent. However, if the lifetimes of the Loviisa 1 and 2 nuclear plants were extended by a decade, it could replace some of the wind capacity on the pathway. The impact would persist until 2040.

---

59 While the theoretical potential for onshore wind power in Finland might be high, zoning and permit provision, for instance, could pose challenges. In the analysis, 13 GW has been assumed as the maximum onshore capacity by 2030 (Valtakunnallinen yhteenveto maakuntien liittojen tuulivoimaselvityksistä 2011) while annual growth has been capped at 1 GW per annum. That is twice as much as the 0.5 GW of realised wind projects in 2017 (Suomen tuulivoimayhdistys ry), which might have implications for the supply chain (in terms of installation or maintenance) and the availability of capital. Offshore wind capacity constraints would also be more related to practical technical feasibility than theoretical wind power production capacity, which has been estimated to be ~70 GW (BASREC 2012). For CHP biomass use, sustainable biomass availability could be a challenge, discussed further later in this chapter.

60 Fortum investor presentation September 2018.

61 According to full-system cost optimisation, wind and battery storage are the cheapest alternatives for fulfilling the power demand.

Increased use of intermittent supply requires more sophisticated load balancing

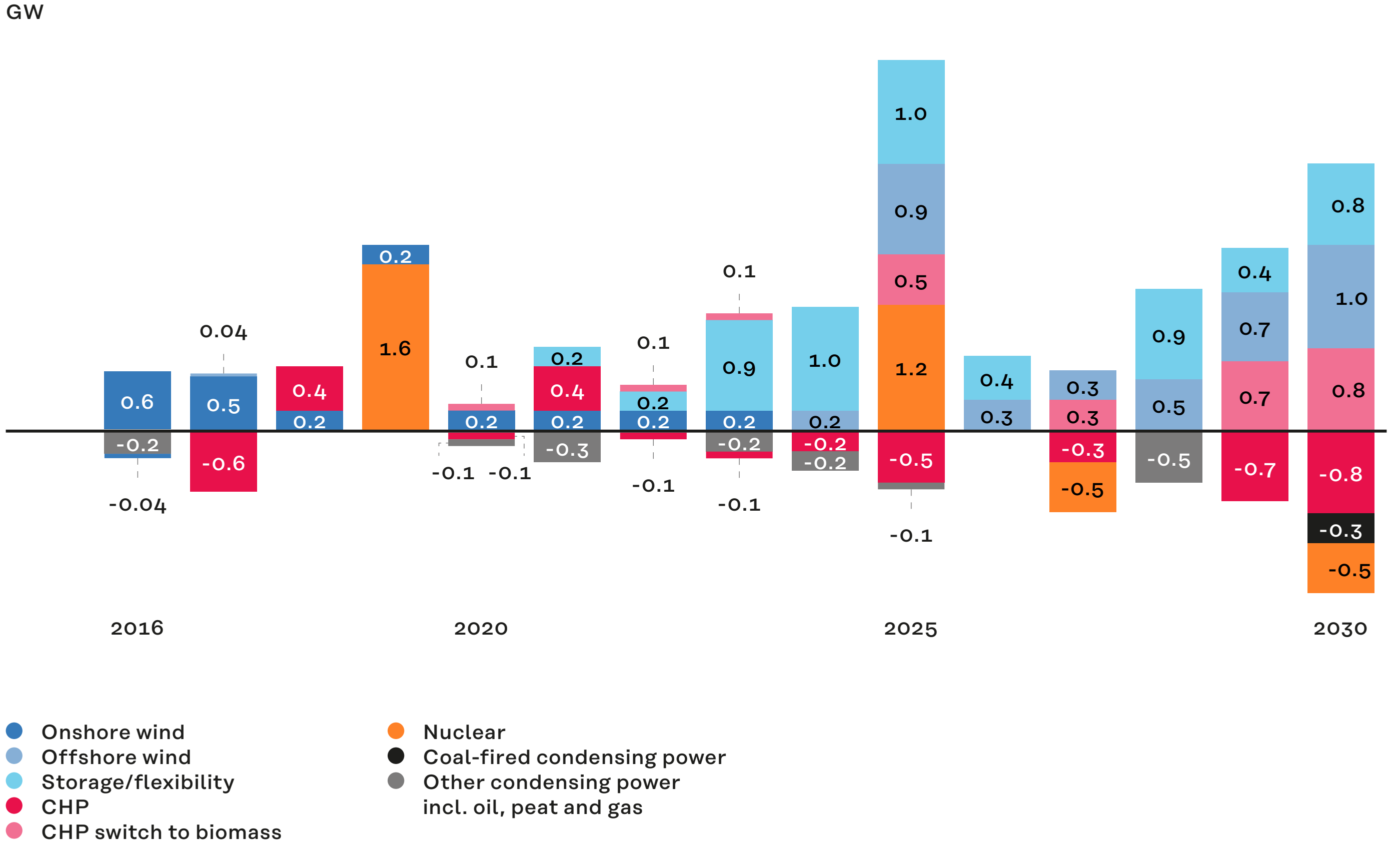
On the pathway, storage capacity, demand-side measures and the interconnection capacity to balance peak usage will be needed to enable the large share of intermittent sources in the electricity supply.

Significant storage capacity and the ability to optimise the grid and implement load-shifting are prerequisites for balancing the increasingly volatile supply. In the theoretical modelling of the pathway, up to 5-6 GW of flexible capacity[62] might be required to provide reliable supply of peak loads if interconnections and demand-side measures are not considered (Figure 14). This would require 3–4 billion euros of additional investments in storage.

However, in practice the issue is likely to be tackled differently, and interconnections and demand-side measures will be leveraged to reduce the need for storage. Further interconnector capacity could replace a significant share of the load-shifting needs, halving the required storage capacity to 2–2.5 GW while also allowing for additional exports to fully exploit the potential of all the intermittent capacity. The role of interconnectors should be further assessed in light of the capacity investment plans of Sweden and Norway in

Figure 14: Annual generation gross additions and retirement in the 60% pathway

2016 and 2017 are realised capacity changes. Wind and storage are crucial players in power decarbonisation.



[62] There are multiple technology alternatives for providing the necessary load-shifting and meeting the peak capacity requirements, such as gas turbines, fuel cells, pumped hydro and batteries.

particular. On the demand side, for instance, dynamic pricing could be used to balance the demand.[63]

Although significant storage capacity investments would be required even after these considerations, battery storage capacity in the generation system could provide other benefits: frequency regulation, voltage control and congestion relief, thus leading to other economic savings for the system operator. Also, the electrified transport system has significant potential to act as a balancing mechanism together with industry efforts. The potential of this or other demand-side balancing mechanisms has not been taken into account in the analysis beyond EV charging load profile balancing.[64] In practice the required total balancing on the supply side would be lower than in the presented power scenario.

Moderate grid investments needed in addition to current sustaining capital investments

Significant growth in electricity supply and demand will have implications for transmission and distribution grid investments and operations.

The wind buildout will increase the need for transmission line investments. From a grid point of view, wind power additions in the proximity of current North-South transmission lines are likely to be the most cost-efficient alternative. The 5.2 GW of wind capacity is estimated to require roughly five 400 kV lines at an approximate investment cost of 100 million euros each. The estimate is that an approximately 2 per cent increase in transmission fees is needed to cover the increased maintenance costs and capital investment per line. Naturally, the costs could be higher if new wind capacity is built further away from the current grid.

On the local distribution level, the EV charging infrastructure needed to enable the rapid shift to electric vehicles within the next five years will have additional requirements. Power grid and charging stations will need to deliver the electricity to homes, workplaces and service hubs. The network will also need to be managed smartly, balancing the demand load at peak hours and leveraging electric vehicles to balance intermittent power supply. Building the public charging infrastructure could require an investment of 1–1.5 billion euros, based on an assumption that there would be one public charging station per 10 vehicles (with the opportunity to charge multiple vehicles from the same station, including workplace charging) at an approximate cost of 10,000 euros and one fast charger per hundred vehicles at 40,000 euros each.[65] Home chargers have been included in car costs. With gasoline and diesel demand falling towards 2030, the current fuel station network might at the same time shrink, unless charging stations create enough demand to provide sufficient customer traffic to keep the stations in operation.

Conditions for carbon-free generation capacity investments must be ensured

To reach the wind power production increases, almost 1.2 GW worth of large-scale onshore wind projects need to be realised between 2018 and 2023. Between

---

[63] Examples of demand-side measures could include: electric vehicle charging management with automated tools and dynamic price signals; smart grids, dynamic price or hourly contracted electricity prices for households and small businesses; automation of flexibility provision to large industrial consumers. g the necessary load-shifting and meeting the peaking capacity requirements, such as gas turbines, fuel cells, pumped hydro and batteries.

[64] Managing electricity consumption from EV charging so that the largest charging peaks could be avoided and the electricity demand would be distributed more evenly over time.

[65] LVM "Alternative fuels infrastructure – a proposal for a national framework until 2020/2030" (2015); VTT research report "How to Reach 40% Reduction in Carbon Dioxide Emissions from Road Transport by 2030: Propulsion Options and their Impacts on the Economy" (2015).

2024 and 2030, about 4 GW or 15 TWh of new offshore wind capacity (or more onshore) should come online at an accelerated pace. The current pipeline of onshore wind projects could reach the onshore target,[66] but the offshore wind target requires in total 4 GW of highly cost-efficient projects, while the current pipeline of projects stands at 2.5 GW. Currently the timeline for a large wind project in Finland is from three to six years, of which the actual construction takes roughly two years. International benchmarks show that project permit-issuing phases can take up to seven years. If the average permit-issuing phase in Finland develops in this direction, the new offshore wind projects would have to be started as early as 2020. The rapid increase in the use of wind power will also place significant pressure on the land permit processes, the construction supply chain and the financing of the investments.

Our analysis shows that by 2030 average captured power prices for offshore and onshore wind will still be higher than the LCOE of these technologies, with power price ranging between 37 and 45 EUR/MWh. However, it is possible that price erosion will be more rapid post-2030 and that the uncertainty of recovering the investments across their lifetime will reduce the incentives for wind power developers to invest. To ensure needed investments take place, the current price-setting mechanisms will need to be reviewed accordingly. A complement to the current day-ahead prices could be power purchase agreement (PPA[67]) auctions, which have been adopted particularly for renewable capacity in several other European countries and will be piloted in Finland in late 2018.

Biogas, biofuel and biomass use will require demand and supply measures

On the pathway, biogas use will increase from the current 1.1 to 4.5 TWh, driven by industry. To meet the significant demand increase, cost-efficient processing of biogas should be developed. Processing of, for instance, manure and waste sludges could unlock up to 10 TWh of biogas potential in the long run.[68] Biogas use in the 60 per cent pathway in industrial applications is mostly within the span of the current natural gas network, limiting the need for network extensions. Use in transport provides additional demand potential for biogas.

The biofuel blending rate will increase to 30 per cent by 2030, but further increases have not been considered on the pathway. Given the rapid electrification and ICE energy efficiency improvements, the impact of a higher blending requirement will decrease rapidly and the total biofuel need to fulfil a 30 per cent blending mandate in transport could remain close to 2020 levels.[69] However, further biofuel use in transport, machinery and heating oil provides potential for further decarbonisation beyond the abatement accounted for on the pathway. These opportunities are especially interesting if in practice some of the industry measures on the pathway are not feasible in terms of being implemented by 2030.

Biomass use in the power and heat sector will increase by 5.6 TWh in terms of electricity generated. This corresponds to approximately 17 TWh of power and heat combined, and roughly 10 million m^3 of solid wood fuels use increase in CHP. This poses a challenge with regard to Finland's LULUCF

---

66 The pathway assumes large-scale projects with improving cost-efficiency – current project pipeline cost-effectiveness has not been assessed in detail, but notably the 2023–2030 capacity additions should be more efficient and preferably come from offshore wind. The current onshore wind pipeline might be able to generate enough wind power if realised in full, but cost-efficiency might remain below modelled pathway economics.
67 Also called renewable energy auctions.
68 Sitran selvityksiä 111: Biokaasusta kasvua (2016).
69 Government draft proposal of 29 June 2018 on increasing biofuel use.

carbon sink balance. This challenge and the options for CHP conversions to biomass as a decarbonisation lever are discussed further later in this chapter.

The 2030 potential of hydrogen has not been explored in detail in this report other than in the context of ethylene production feedstock conversion and a potential steel plant conversion to hydrogen-based DRI-EAF. With increasing availability and decreasing production costs, hydrogen may become a significant alternative measure for industry and transport decarbonisation beyond 2030. Examples of hydrogen applications could include use as an industry feedstock, fuel for ships and road vehicles, balancing power in power generation, or use in heating systems within the gas grid.

Finland will face the challenge of a reduced carbon sink regardless of the pathway

The Finnish land use, land use change and forestry (LULUCF) sector currently forms a sizeable carbon sink. However, the planned increases in industrial biomass use combined with the pathway power and heat emissions reduction with biomass use would considerably increase biomass use and become a challenge for the forest carbon sink size. This sub-chapter describes the current carbon sink, sustainability of future biomass use and some potential options to limit biomass use.

Finnish LULUCF carbon sink accounts for nearly half of Finnish GHG emissions

Today, the Finnish LULUCF sector forms a sizeable net carbon sink in Finland. The carbon sink was –26 $MtCO_2e$ in 2015, equivalent to 47 per cent of the total CO_2e emissions in Finland. The size of the carbon sink varies significantly from year to year, primarily due to variable levels of wood harvesting. The forest sink has increased significantly from the 1990s, driven partly by a continuous increase in forest growth rates since the 1970s.[70]

Over 90 per cent of the carbon sink is formed by forests, both the trees and the soil. The remaining 10 per cent comes from harvested wood products. Agriculture (including only land emissions) and other land use offset part of the negative sink as net emitters at around +7.5 $MtCO_2e$.

LULUCF has a dual role as a carbon sink and a source of economic activity. The forestry sector accounted for 21.5 per cent or 11.6 billion euros of physical goods exports out of Finland in 2015.[71] This underlines the need for collaboration between different interest groups to find a common framework that enables Finland to reach its climate commitments.

Future biomass use will exceed the levels allowed in the second commitment period of the Kyoto Protocol

Until 2020 the regulatory environment for LULUCF is the second commitment period of the Kyoto protocol, where the required size of the forest carbon sink is set at roughly –20 $MtCO_2e$ for Finland. After 2020, LULUCF will be integrated into the EU climate policy framework, and new reference levels will be set. The new required reference level for the forest management sink will be defined in 2019 both for Finland and the EU, with Finland giving its suggestion for its own reference level by the end of 2018. If too much forest is harvested, the effort sharing sector would need to abate more to reach the target net emissions, or a corresponding amount of sink units would have to be

[70] Luke: Puuston vuotuinen kasvu (2017).
[71] Customs Finland: Metsäteollisuuden ulkomaankauppa vuonna 2017.

purchased from another member state above its own reference level. Hence, abatement through the use of domestic biomass as an alternative fuel beyond the defined limits is problematic. Under the current accounting, the use of imported biomass does not face the same restrictions and is not considered as an emission in the importing country. However, importing biomass may decrease the carbon sink elsewhere.

The National Climate and Energy Strategy (TEM 4/2017)[72] has set a yearly harvesting target of 79 million m^3 of roundwood, which is 11 million m^3 higher than the realised harvesting in 2015. This increase is projected to decrease the forest carbon sink to –13.5 $MtCO_2e$ by 2030, already far below the Kyoto reference level.

Knowing this, the projected biomass use in the BAU presents a challenge. In the BAU, roundwood use would grow from the current 68 million m^3 to approximately 82–87 million m^3, driven by a 14–19 million m^3 increase in the pulp and paper industry. In addition, BAU requires 7–9 million m^3 of thinning wood, logging residue and forest industry side streams for the CHP conversions in the power and heat sector (6 million m^3) and for biofuels in the transport sector (1–3 million m^3), if biofuels are to be produced from forest biomass.[73] With these projections, the carbon sink could be reduced to zero[74] if no additional imports are used.

This report acknowledges the challenges related to the availability of biomass. Furthermore, if emissions from land use and land use change increase as projected,[75] it will pose additional challenges and should be reflected in the forest management part of the sector. Further work at the national level should be conducted to assess the resource constraints for proposed uses of both roundwood and side streams. A joint effort by industry and government would be needed to create a national strategy on biomass use.

There are no easy options to limit biomass use in cogeneration plants

On the 60 per cent pathway, the biomass use is escalated. The power and heat sector will consume roughly 4 million m^3 more biomass than the BAU due to the additional conversions of CHPs from fossil fuels to biomass. In total, the 60 per cent pathway will require roughly 12 million m^3 additional biomass for CHP and industrial fuel use in 2030 compared to 2015.

Given the limitations in the availability of sustainable biomass, such a large-scale conversion of CHPs to biomass could be problematic. A feasible solution to limiting the biomass need would be to electrify district heating together with building energy efficiency measures. However, if the biomass use in CHPs were limited, a large part of the Finnish district heating-based system would need to be radically rethought.

In an electrified heating system, large-scale heat pumps would collect waste heat from industry, commercial buildings and sewage, as well as heat from the ground, air and sea to provide most of the heating (and selectively cooling needs) of the network.[76] Biomass-based CHPs could provide the necessary flexibility in times of winter peak loads, while solar collectors and seasonal heat storage could be at the core of providing

---

72 TEM: Government report on the National Energy and Climate Strategy for 2030 (2017).
73 Most of the transport biofuel need is likely to be covered with non-wood based HVO, according to a study assessing the possibility of a 30 per cent blending requirement (Sipilä et al. 2018).
74 Luke: Skenaariolaskelmiin perustuva puuston ja metsien kasvihuonekaasutaseen kehitys vuoteen 2045 (2016) presents a scenario where an annual roundwood harvesting of 89 million m^3 turns the forest sink into an emission source by 2030.
75 Statistics Finland: Finland's Seventh National Communication under the United Nations Framework Convention on Climate Change (2017).
76 Smart Energy Transition Project, Clean energy district heating and cooling vision.

back-up capacity and managing the seasonally variable heat demand and supply. Increased heat pump use would also drive an increase in power demand, resulting in a higher need for clean electricity production, but electricity-based heating also has the potential to balance peak electricity grid load and supply through smart grids. The economics and technical feasibility of a system like this especially for larger cities remains an open question and has not been addressed in this analysis.

The changes on the 60% pathway have wide-ranging impacts on the structure of the economy.

Looking beyond 2030, alternative technologies for heat production could become available and increasingly competitive. Deep geothermal heat, i.e. geothermal heat that exploits temperature at depths of over a kilometre, could provide an alternative that would also suit densely populated areas.[77] Furthermore, VTT has conducted a study to assess the potential of small modular nuclear reactors in district heating.[78] These new technologies could further support long-term emissions reduction; provision of heat without biomass (or fossil fuels) would have a positive contribution to the carbon sink in the coming decades.

Despite the apparent challenges, Finland needs to reach its upcoming forest carbon sink reference levels. A package of measures ranging from heat demand reduction to imports of biomass may be required. Land use and agriculture could provide opportunities to further balance the increasing forest biomass use, but this opportunity is limited. Available measures include improvements in irrigation systems, tillage, fallow land use and reforestation.

Implications for the Finnish economy

While the impacts of the pathway on the Finnish economy were not within the scope of this report, some tentative implications for the Finnish economy are discussed in this chapter. Additionally, the changes on the 60 per cent pathway such as mass-scale adoption of EVs and their batteries, associated infrastructure and broader shift towards a carbon-neutral circular economy have wide-ranging impacts on the structure of the economy and public finances. Some opportunities arising from these changes are also discussed.

Decarbonisation requires increased capital investments and a redistribution of costs and savings to finance the measures

The pathway will require high capital investment spend and solutions for the arising financing needs. Although the proposed measures are cost-efficient ways of reducing emissions from the total cost of ownership (TCO) point of view and several of them result in TCO cost savings, they require increased upfront investments. Consumers need to invest in vehicles, heating and appliances, and companies need to invest in technology switches and energy efficiency improvements. The government needs to focus on building the infrastructure for decarbonisation and assessing the impacts of all the changes on public finances. The finance sector needs to stand up and find solutions to fund these long-term infrastructure investments.

---

[77] Deep geothermal heat could also potentially become economical before 2030.
[78] VTT: District heat with Small Modular Reactors (2017).

Development in the financial sector during the past decade has been favourable. Investors' appetite for long-term, stable, lower-return investments to deploy capital effectively has increased in an environment characterised by low interest rates, easy access to capital and few opportunities to find alternative investments. Public-private partnerships, still fairly uncommon in Finland, could be explored further. At the consumer end, the barrier to upfront investments could potentially be alleviated through the private leasing of vehicles, which is still underdeveloped compared to many other countries.

As the TCO savings do not accrue evenly across different sectors, organisations or individuals, the accrued costs and savings needs to be redistributed fairly. There is a lot of room for government to redistribute these savings to ensure the short-term switches happen and to balance government budget in the long term.

Decarbonisation could provide opportunities for broader value creation

The proposed measures in the 60 per cent pathway could also create opportunities for new economic activity in Finland. Major investments in power and heat generation, grids, charging networks and load balancing require design, installation, operations and maintenance services and naturally a wide range of components and products.

Electrification of the economy could also provide Finnish companies with broader indirect value creation opportunities, driven by initial local demand that could provide a platform for further growth outside the country – in line with what the Danish wind energy commitment enabled for the Danish wind turbine manufacturers.[79] For instance, there is already today activity in most parts of the electric vehicles value chain from battery raw materials to car assembly and electric bus production. Similarly, Finnish companies have existing know-how in grid management, smart grids, mobility services, biomass-based fuels and technologies, and industrial technology provision.

At the same time, it is important to note that the window of opportunity for broader value creation is closing soon. As the rest of the world rushes to electrify and decarbonise, the competitive environment will tighten, highlighting the importance of decisive action by the policy makers and sufficient growth appetite by Finnish companies as we speak.

> *Pursuing the 60% pathway could also create opportunities for new economic activity in Finland. However, decisive action by the policy makers is needed.*

[79] IEA: Danish Energy Agreement for 2012-2020 (2012).

5. Charting a way forward

If Finland continues without employing further abatement measures, the emissions reduction will not be sufficient to reach the current EU ambitions, Paris commitments nor long-term abatement targets. Immediate, targeted actions by the government are needed to correct the course. Even though 2030 is still over a decade away, many decisions that determine our emission reduction pathway and response to the climate crisis need to be taken during the next government term starting in 2019.

Effective decarbonisation requires several measures to be considered, implemented and taken into account when crafting the national Long-term Climate Policy Plan. Critical enablers include securing the needed infrastructure that allows individuals and companies to shift to low-carbon solutions, creating economic conditions that steer investments towards these solutions, and providing long-term visibility to minimise the regulatory risk of these investments. A national decarbonisation plan is required to ensure that the policies and incentives come into effect timely and at the required scale.

Framework for the change: national decarbonisation plan

A national decarbonisation plan, embedded into the Long-term Climate Policy Plan, is needed to:

1. Create a broad commitment to the 60 per cent reduction target by 2030 as a milestone towards decarbonisation and negative emissions.
2. As for the LULUCF sector and sustainable biomass use, clear targets should be in place alongside a joint fact base, acknowledging both the sustainability concerns related to the use and availability of biomass and the importance of carbon sinks in the pursuit of carbon neutrality over time.
3. Create a common understanding of the necessary abatement actions and their timing for all sectors. It is important to have a clear insight of when and at what pace the enabling infrastructure (for instance grid investments enabling wind buildout or charging networks enabling increased EV use) will be needed, and how to fit industry decarbonisation measures into plant-specific investment cycles.
4. Define key guiding principles, for example assessing how the costs and benefits of decarbonisation actions should be distributed between all relevant sectors and stakeholders.

The plan should also identify priority areas for technology development and cross-sector and cross-stakeholder collaboration and identify possible opportunities to redirect public R&D funding.

Policies and support schemes to enable and drive the change

To capture the abatement opportunities on the pathway, policies and support schemes are needed to provide the right environment for businesses, local authorities and individuals to make the low-emission choices attractive. The key principle is the "polluter pays". In practice, this means setting a price for carbon to capture the external cost for society, allowing markets to find the least-cost measures to cut emissions. Potential additional tax revenue from increased emission taxes can be used to lower other distortionary taxes (such as labour taxes) or to support further investment and R&D in low-carbon solutions.

Power system transformation

A significant power system shift is needed to enable emission-free electrification of both transport and industry. The main changes, described in more detail in Chapter 4, that need to be ensured by enabling regulation are:

- Securing land and building permits needed for new wind power plants along a timeline that matches the demand build-up.
- Developing the national transmission grid to match the increasing volumes of wind power. This will require modestly higher capital investments than currently planned. Preparations need to be started soon given the long timeline involved.
- Ensuring financing of the required power investments even with potential downward pressure in power prices in the long term, including reviewing the current price-setting mechanisms in the power markets.
- Ensuring that the regulation of electricity distribution grids enables distribution companies to develop and use their networks appropriately to accommodate large volumes of EVs and to leverage them to balance overall load. Distribution grid regulation should ensure that the required investments can be made in a timely and cost-effective manner, building on a plan for wind capacity uptake.

Rapid adoption of electric vehicles

Although the total cost of ownership turns in favour of EVs compared to ICEs around 2025, this will not automatically lead to mass adoption of EVs. On a tax-neutral basis, the initial investment for an EV will remain higher until the turn of 2030. For mid-range EVs, taxation and reimbursements will therefore play a vital role in allowing car buyers to bridge the gap of the last few thousand euros. Once the pre-tax capital investment for new EVs starts to reach parity with ICEs, incentives can be reassessed.

Examples of policies to support EV uptake include:

- a regulated shift of corporate leasing vehicles from ICEs to EVs
- a strict emission-based standard setting for new car sales
- the regulated phase-out of ICE car sales
- investment and information support for EV charging stations
- in addition to incentives related to the upfront investments, EV adoption supported by a range of additional measures making EV usage more attractive; for example, privileged access to bus lanes and parking spaces.

Several countries have made EV adoption a priority. Countries such as China, Norway and Sweden can provide examples for Finland on setting new policies and incentives, for example in supporting EV adoption, the development of local infrastructure or battery recycling.

Industry decarbonisation

The industry decarbonisation levers along the 60 per cent pathway are generally site and company-specific. While some of them appear cost-negative or cost neutral on the cost curve, the actual typical capital cost and payback time requirements with weighted average cost of capital of 8-10 per cent for industrial companies may be such that the investments do not automatically materialise even at ETS prices above 30 euros per tonne of carbon dioxide. These investments typically have long lead times due to technical complexity, and they also need to be fitted into the site-specific refurbishment cycles. All of this suggests that long-term policies and/or incentives that create the right economic conditions for the costlier industry decarbonisation efforts will need to be shaped early on, building on top of ETS as the primary mechanism for industry emissions control. As ETS plays a crucial role in guiding industry emission reduction investments economically, a national or regional floor price for emissions within the ETS sector could be considered to ensure and reinforce the impact of the emission trading scheme. A precondition for the policies is a framework (such as a national decarbonisation plan) that defines the principles for cost and benefit sharing across sectors.

Accelerated phase-out of oil heating and improving energy efficiency in buildings

The continued phase-out of oil heating and improvements in energy efficiency should be accelerated with a broad range of measures that can address specific challenges for different building types, including the following.

- A regulated phase-out of oil heating use in central and local government-owned buildings.[80]
- A package of measures to phase out oil heating in detached housing, making the continued use of oil less attractive: promoting the cost-efficiency of heat pumps, regulating refurbishments of oil boilers and creating subsidies or other financial incentives and information support for oil boiler replacements.
- Supporting improvements in energy efficiency to reduce heat use and loss, with e.g., stricter building and renovation standards, information, voluntary schemes and financial incentives.

In addition, indirect emission reduction in the buildings sector could be driven through standards and regulation for material efficiency in buildings, for example through designs and practices that make reuse and recycling of materials and elements easier.

Changing the course

Decisions that Finland now needs to take to further reduce its greenhouse gas emissions are truly course-altering. Changes will not be incremental but will involve major transformations, especially in the transport and energy sectors. They will shape the country for generations to come. Making such significant decisions requires courage and leadership.

Critical decisions need to be based on robust analyses and evidence. The chosen path has to be cost-efficient and comprise a consistent set of actions. This report shows that the pursuit of the 60 per cent emission reduction goal is not only technically feasible but also economically viable. Significant reductions could be achieved by simply leveraging proven low-carbon solutions that other countries are already harnessing, electric vehicles and wind power being the two central solutions. There will also be significant room for the government to apply policy measures to accelerate the change and redistribute costs and benefits.

The time to make these decisions is now. Many of the measures require long periods of preparation, co-ordination and implementation, and the medium-term milestone of 2030 is approaching fast. Taking these decisions is critical to shift Finland in the direction of the trajectory mandated in the Paris Agreement. The sooner the shift is initiated, the less dramatic and costly it will be.

---

[80] In line with the With Additional Measures scenario from the TEM Government report on the National Energy and Climate Strategy for 2030 (2017).

Appendix

Methodology

Business-as-usual scenario

The current trajectory, or business-as-usual scenario (BAU), describes a pathway towards 2030 where a neutral approach towards the adoption of new technologies is taken. In other words, the BAU expects the current trends to continue at the same pace as in the past and for current policies to realise the anticipated impacts. It is based on the outlooks outlined by reputable sources such as the International Energy Agency, Statistics Finland and the International Council on Clean Transportation. The BAU was modelled for this report to project what would happen if no further abatement measures were taken but the development continued as business as usual. It acts as a comparison point for the outlined pathway. While it shares similar characteristics with national baselines, BAU is not strictly the same as the With Existing Measures (WEM) scenario in Finnish national climate reports.[81]

In short, in the BAU energy consumption is expected to increase, driven by the anticipated trends of macroeconomic factors such as population and economic growth. Meanwhile, energy and resource efficiency in the different consumption segments counteract the demand uptake. For instance, fuel efficiency of diesel and gasoline vehicles are expected to improve by 11-26 per cent, with differences according to the type of vehicles and the powertrain, following the trends reported in various studies from the International Council on Clean Transportation. Also, in the buildings sector, anticipated efficiency improvements in appliances and lighting technologies, and a reduction in heating needs driven by building envelope improvements, have all been estimated based on trusted local and external sources (see below).

On the other hand, no major outbreaks of innovative technologies or political interventions are emerging, besides what is already set in current government plans and regulations (for instance, the impact of additional nuclear units on the decarbonisation of electricity generation).

The key assumptions in the BAU are listed below, as are the pathways built on these assumptions.

Pathway

Scope

The report focuses on abatement in the transport, buildings, industry, and power and heat sectors, which cover about 80 per cent of total emissions in Finland (Figure 15). This leaves the other 20 per cent of emissions from non-CO_2 greenhouse gases, waste management CO_2 and agriculture and LULUCF CO_2 out of scope. In the analysis, they are set to follow the With Existing Measures (WEM) scenario[82] up to 2030, reducing emissions by ~2 $MtCO_2e$ from 2015 to 2030. Potential opportunities for abatement in waste management and agriculture are outlined in this appendix.

Moreover, within the considered sectors technology-specific abatement levers have not been applied for i) domestic aviation,

---

81 The BAU scenario predicts 2030 emissions to be 46.8 $MtCO_2e$ and the WEM scenario predicts 48.8 $MtCO_2e$ (according to an April 2017 EIONET submission).

82 TEM: Government report on the National Energy and Climate Strategy for 2030 (2017).

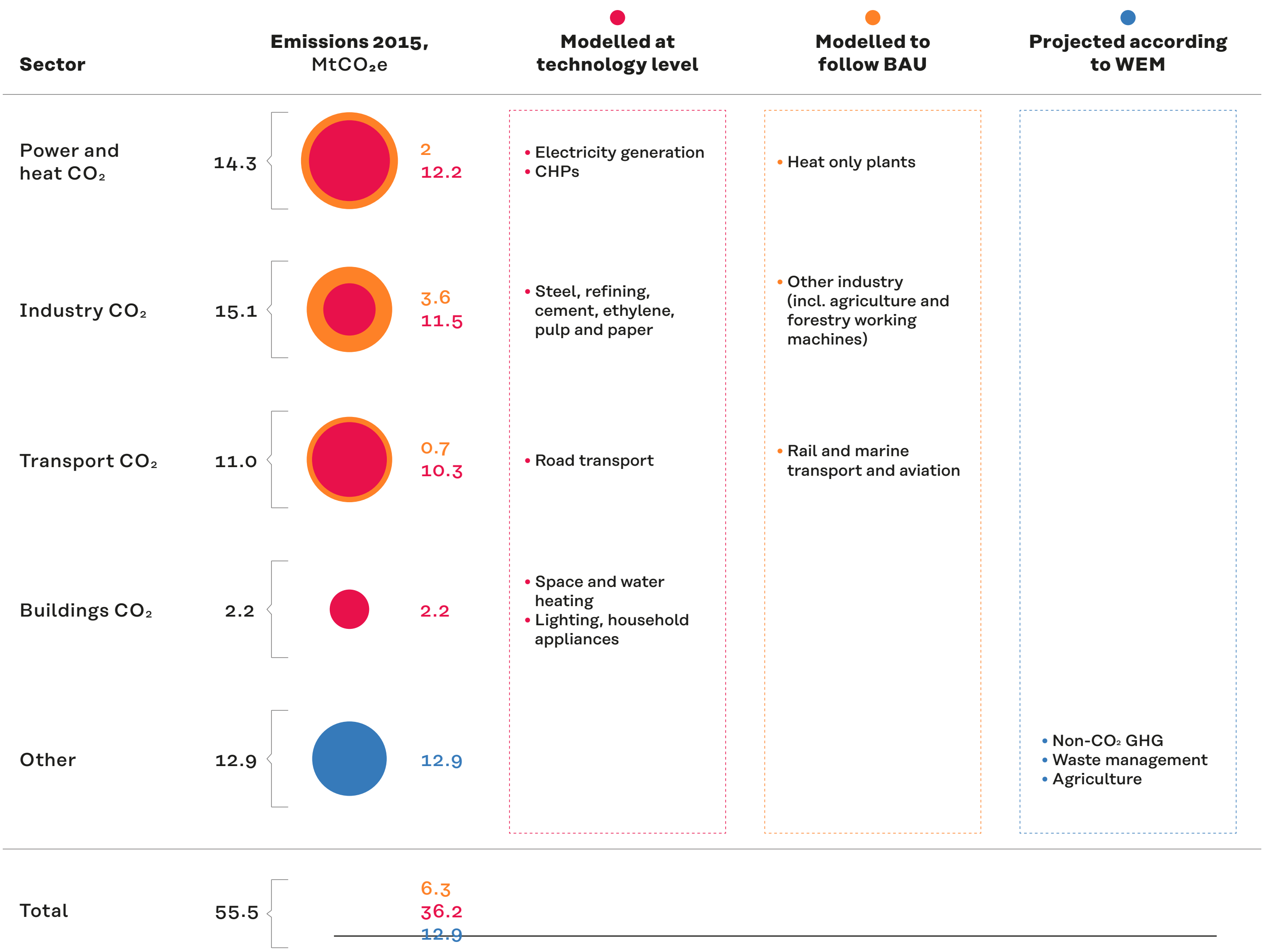
marine and rail; ii) heat-only plants[83] and iii) other industries.[84] These account for 18 per cent of the CO_2 emissions within the considered sectors. These emissions are modelled to follow the BAU and projected to remain relatively stable until 2030 as a result of efficiency increases offsetting growth, and consequently the emissions remain on a similar level to 2015 at 8 $MtCO_2$. In total, technology-specific abatement levers have been analysed for roughly 65 per cent of Finnish GHG emissions.

Implied abatement need

As shown in Figure 16, this approach of modelling Finnish emissions implies that in the 60 per cent pathway, the sectors modelled at technology level must abate 25 $MtCO_2$ out of the total 27 $MtCO_2e$. The

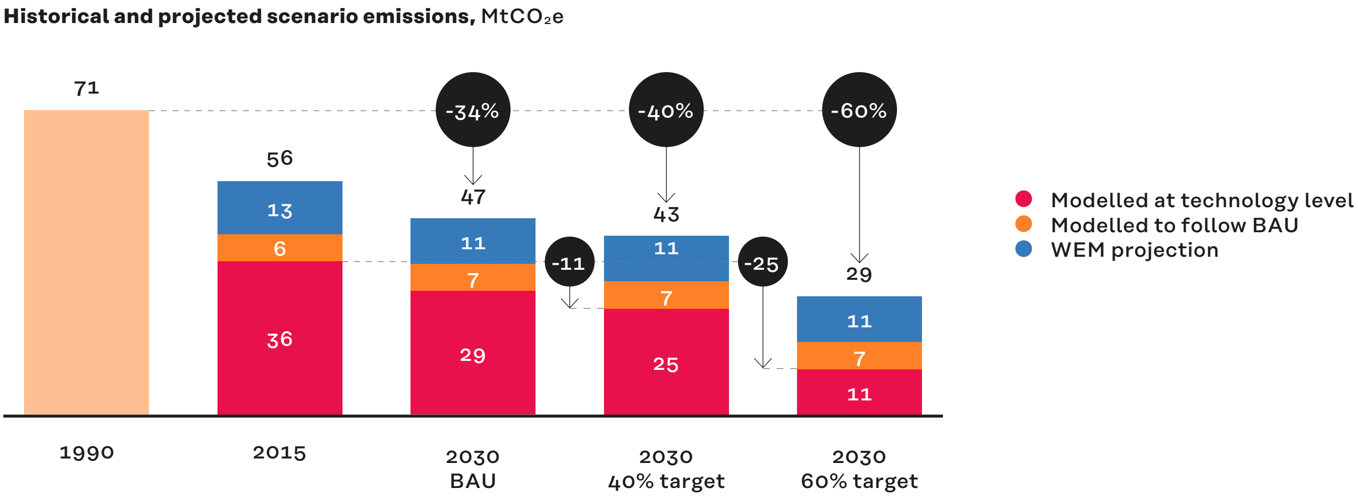
Figure 15: Scope of the analysis

Modelled sectors power & heat, industry, transport and buildings cover approximately 80% of Finland's GHG emissions, and the emissions within these sectors modelled at technology level cover 65%.



[83] Both district heating and industrial steam production.
[84] Primarily: agriculture/forestry fuel combustion for machinery; the food and tobacco industry; other material and mineral production (besides chemicals, cement, iron and steel).

Figure 16: Abatement needed for emissions reduction targets
The 40% and 60% targets imply respectively 11 and 25 $MtCO_2$ abatement in the emissions modelled at technology level.



remaining approximately 2 $MtCO_2e$ abatement is covered by the out-of-scope emissions, which are projected to decline in line with the WEM scenario.

Modelling

To find a coherent and cost-effective pathway to meet the emission reduction objectives, the analysis undertaken here is based on full-system optimisation. The approach is selected to show a logical sequence of choices made year by year and to take into account the interdependencies between sectors. For instance, the link between an increase in electricity demand due to electrification in sectors such as transport and corresponding changes in power price is one of the core interdependencies that are modelled directly. In other words, an increase in the number of electric vehicles would increase electricity demand, which the power and heat sector would need to supply. Additional electricity production might then affect the electricity prices, as well as increase the challenge for the power and heat sector to reduce emissions. Other interdependencies considered include increased heat production from increased industrial activity, which can be used for district heating. As a result, the pathways emerging from this full-system optimisation represent a mutually consistent set of measures to reach the given abatement target.

The set of measures in a pathway can be broadly divided into two groups:

- Measures that directly abate CO_2 (e.g. moving from oil boilers to biomass boilers).
- Measures that enable abatement or make abatement easier (e.g. grid infrastructure for electrification, more efficient household appliances).

The measures that directly abate CO_2 are visualised on an abatement cost curve; a graph where each column represents one specific technical measure for emissions abatement. The width of each column represents the realised reduction of annual CO_2 emissions by 2030 when compared to 2015, and the height of each column the average cost of abating one tonne of CO_2. The columns are organised from the most economical to the most expensive measure, expressed in EUR/tCO_2 abatement. The curve gives a view of how much abatement can be realised at what cost. It considers the total cost of ownership (TCO), taking into account both the costs of the initial investment as well as the costs of operation for the full lifetime of the measure. The cost of abatement on the cost curve is the difference in the TCOs between the low-emission technology or fuel and the incumbent technology or fuel that is replaced. The difference in the TCOs can be both positive (i.e. the measure leads to more costs over its lifetime) or negative (i.e. the measure saves money over its lifetime compared to what it replaces). Costs are calculated as the annualised average cost of implementing the measure over its full lifetime.[85]

While the abatement cost curve allows for objective, quantitative comparisons of different abatement options, it should not be considered as a stand-alone representation of the pathway. The curve only shows the direct abatement measures but does not show measures that enable this abatement and/or make this abatement easier. The costs for the enablers are mostly not included in the curve as they cannot be allocated to certain measures (for instance, additional transmission lines to enable electric heating versus those needed for electric vehicles). These enablers and their costs are discussed in Chapter 4.

Solution space

In the analysis, only solutions that are switches from one technology or fuel to another are considered (e.g. switching from an ICE vehicle to an EV or switching a cogeneration plant from coal to biomass). Behavioural changes, such as consumers reducing animal-based food consumption or opting to use public transport instead of private cars, have not been considered.

The modelling leverages over 300 business cases on deployable technologies across sectors. These cover business cases including more efficient fridges, 16 types of electric vehicles and different steel-making technologies. A business case compares a low-emission technology or fuel to currently prevailing technologies or fuels in terms of costs, taking into account all associated costs. These include the initial investment, cost of daily operations and cost of maintenance.

For more detailed information on the included transport business cases, see the section Additional detail on transport assumptions and constraints below.

In our analysis, we have only included abatement technologies that are either proven today or appear likely to become viable in the near term. For simplicity, emissions reductions from emerging technologies with more uncertainty in the development path or timing, such as oxyfuel carbon capture and storage power plants, deep geothermal heat and micro nuclear plants, have not been considered. While the analysis has excluded emerging technologies with the most associated uncertainty, some uncertainty still remains in terms of estimated costs, the timing and the volume of levers that have been considered. For instance, there are numerous differing views on how the costs and consequently the adoption of electric vehicles will unfold.[86] Additionally, rapid cost decreases have been seen in solar photovoltaic, wind and battery technologies and more recently in electrolysers. While the cost outlooks used in the report leverage the most recent information, it is possible that the prices will fall faster (or slower) than in the projections.

---

[85] The costs are calculated as the average cost of implementing the measure, weighted by how much – and when – a measure is used (e.g. if two equally emitting industry sites get electrified at a cost of 50 EUR/tCO_2 in 2020 and a third identical one in 2029 for 30 EUR/tCO_2, the weighted average cost of electrification is given by 2/3 x 50 + 1/3 x 30 = 43 EUR/tCO_2). For some measures, their lifetime exceeds the year 2030 (for instance the investments in industrial assets in the late 2020s will continue to be used for several years and into the decades beyond 2030). For these measures, the cost of the initial investment is split into parts allocated to the years before 2030 and the years after 2030, and only the costs for the years before 2030 are considered. For instance, if initial investments for an industrial asset with 10-year lifetime cost one million euros and the measure was applied in 2028, only (2030-2028)/10 x 1 million euros = 0.2 million euros of initial investment costs would be considered.

[86] The vehicle analysis is based on a proprietary McKinsey database consisting of a global car demand database, a total cost of ownership database and a battery cost development model.

Assumptions and constraints

Underlying assumptions and commodity prices

The analysis is built on the business-as-usual assumptions on demand outlooks presented in the tables of the sub-chapter Business-as-usual scenario. They are used as inputs for the model.

Figure 12 illustrates the resulting projections of when different technologies and fuels and their enablers would start large-scale adoption, i.e. when the technologies and fuels would reach TCO parity with the incumbent technologies or fuels, on the 60 per cent pathway. Changes in power price or fossil fuel assumptions would affect the cost parity points; for instance, considerably higher electricity prices would delay EV cost parities by a few years.

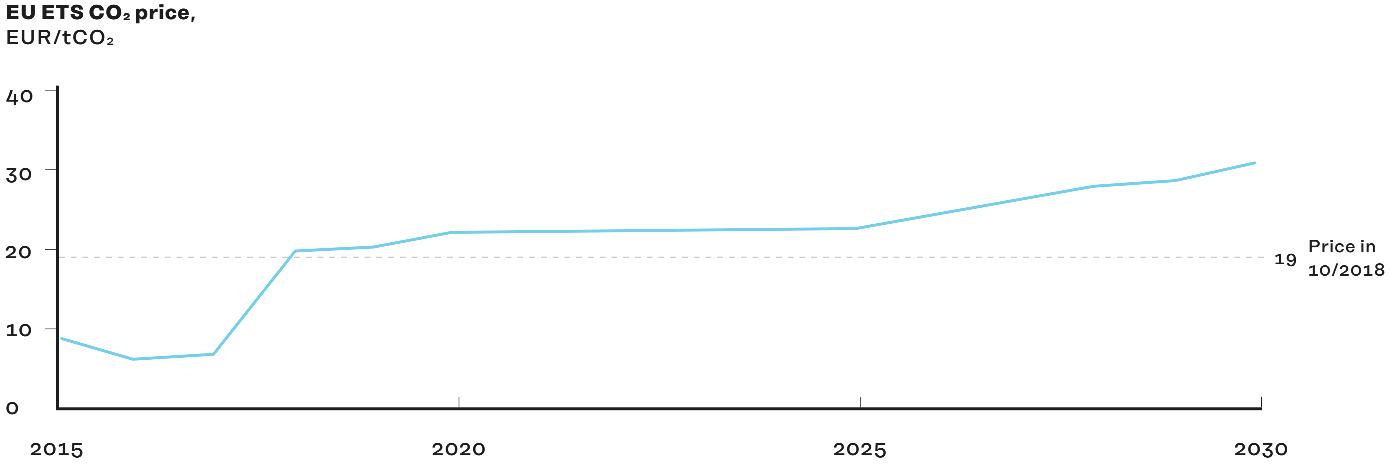
Discount rate

The analysis takes a level playing field perspective to the abatement costs, which means it excludes taxes and subsidies and assumes equal capital costs across sectors equal to a social rate of 4 per cent.[87] This approach allows for a fair comparison of abatement measures across sectors and opportunities. In practice this means that the calculated costs differ from those that a consumer or a company would experience and base their decisions on. Therefore, the curve cannot be used in isolation to determine the exact investment cases for a specific technology or fuel switch or to forecast CO_2 prices.

ETS price

For the industry and power and heat sectors, an ETS price of ~8 EUR/tCO_2 in 2015 increasing up to 31 EUR/tCO_2 in 2030[88]

Figure 17: Projected ETS price development
ETS price will steadily increase to approximately 31 EUR/tCO_2 by 2030.



[87] The analysis assumes a 4 per cent social discount rate, which is at the lower end of the empirical results of social discount rates of 4–7 per cent (Michael Pollitt/Cambridge University) and closest to the discount rates of roughly 1.5–2.5 used in other climate analyses and in line with discount rates proposed by the OECD in Impact Assessment of European Commission Policies: Achievements and Prospects (2006), despite them also acknowledging the possible need for a lower discount rate in long-term climate modelling. This study recognises that the low discount rate will disproportionately favour options with high capital investments, and that in reality the required Weighted Average Cost of Capital within industry is considerably higher and should be taken into account when moving from a system view to an individual view.

[88] Historical data: European Emission Allowances, projections an average of Bloomberg NEF, Energy Aspects and Thomson Reuters on 9 August 2018.

(Figure 17) is included in the costs presented in the pathway and deducted from the full cost of the measure – i.e. the costs presented are on top of the ETS price.[89]

Assumption on rational consumer and company behaviour

The modelling primarily assumes rational consumer and corporate behaviour, meaning that consumers and corporations would start choosing available technologies as soon as the TCO for these drops below that of the incumbent technology.

However, this assumption has been limited by certain constraints outlined in the transport-specific assumptions and constraints elaborated on below to ensure realistic adoption rates of technology.

Additional detail on transport assumptions and constraints

The passenger car fleet renewal rate has been capped at 120,000 cars per annum. This keeps the fleet size roughly stable at 2.7 million cars between 2015 and 2030 and the vehicle lifetime at the current 20 years. Battery electric vehicle adoption is capped at a maximum of 85 per cent of the car renewal rate to reflect potential inertia for BEV adoption in the countryside. For the remaining 15 per cent, PHEV is allowed as a modelling option. Without these constraints the model would pick more ICEs to be replaced before their natural refurbishment time, driven by the low TCO.

The passenger vehicle TCO includes the upfront cost of the car including a home charging station (cost at roughly 1,000-2,000 euros), maintenance costs with two battery changes over the lifetime and fuel costs per kilometre. Electricity prices will decrease by roughly 30 per cent by 2030 as low-cost wind power reduces average prices.

Vehicle TCO calculations on capital investment and operating estimates also leverage following assumptions and sources:

- Vehicle CAPEX (capital expenditure) costs are based on a proprietary model from McKinsey, applied to multiple segments – cars, trucks and buses. The model compares EV powertrains (BEV, PHEV and HEV) to ICE vehicles (diesel, gasoline) at the sub-segment level (e.g. C/D class for passenger cars or HDT (heavy duty trucks) for trucks), analysing multiple applications and daily distances. The data leverages car cost breakdowns and powertrain cost modules for internal combustion engine and battery cost development, forming the annual capital expenditure outlook. This outlook is grouped into various vehicle classes such as A/B, C/D, E/F and J -type passenger cars and light, medium and heavy-duty trucks[90] (with different typical driving ranges of urban, regional and long-haul).
- Battery pack cost is expected in the modelling to reach the following milestones: 160 USD/kWh by 2020, 110 USD/kWh by 2025 and 100 USD/kWh by 2030 with typical battery sizes of 50-75 kWh by passenger vehicle with increasing power density

---

[89] The cost of emission allowance (ETS price) is reduced from the total cost of the measures in the industry and the power and heat sectors. For these sectors, the actual cost of the measures is the cost shown on the curve on top of the ETS price. The reason for this is that companies in these sectors would have to pay the cost of an ETS price for each tonne of CO_2 emissions they emit (or alternatively the companies would occur the opportunity cost of not being able to sell the emission allowance). Therefore, when these companies reduce their emissions, they no longer have to pay for the emission allowances. This cost saving is treated as a "subsidy" for the total cost of abatement on the curve.

[90] Truck sizes are <7 tonnes for LDT (light-duty truck), 7-16 for MDT (medium-duty truck) and >16 for HDT (heavy-duty truck).

over time and longer driving ranges.[91] No major technology breakthroughs in battery technology such as zinc-air are expected during the timeframe.

Battery cell production capacity or raw material constraints are not expected to become a bottleneck for vehicle demand in Finland. It has already been announced that over 300 GWh of global battery capacity will be online by 2022, with new sites achieving efficiency of scale and potentially driving battery pack costs even faster.[92]

The EV infrastructure assumptions leverage VTT[93] estimates, but the costs of charging stations could also be lower based on more recent estimates.[94]

- One home charger has been assumed for each new EV. This cost has been included in the EV cost.
- One public space charger (workplaces and other public areas) has been assumed per 10 vehicles with the potential to service multiple cars at a time, at an average cost of 10,000 euros per charger. These costs have not been allocated to vehicle TCOs and are discussed in Chapters 3 and 4.
- One high-speed charger has been assumed per 100 vehicles at an average cost of 40,000 euros, also discussed in Chapters 3 and 4.

Biogas, flexi-fuel (E85)[95] and hydrogen have not been included as options for passenger vehicles in the modelling. In practice some of these could gain popularity in Finland in the long run, given political support, but their adoption may be constrained by available car models and the car industry moving to electric vehicles in scale. There is also some promising development in fuel cell cars, but this technology is in a clear minority compared to electric vehicles. Truck technology options considered include fuel cell, ICE, PHEV, BEV and CNG. For buses, only ICE and BEV have been considered.

Reflecting the modelling exclusions, no E85 car uptake post-2025 has any underlying logic that could apply to a post-2045 society: these cars too would have to be phased out before 2045 (as E85 cars still emit CO_2) while the average lifetime of a passenger vehicle in Finland is roughly 20 years. However, refurbishing existing ICE cars to make them E85-ready could be a way to reduce emissions from ICE vehicles even post-2025 while being better compatible with fully decarbonised transport by 2045. Refurbishment would come at lower costs than buying a new E85 car and would not create the lock-in of investing in a CO_2-emitting technology with a 20-year lifetime (which will have to be scrapped by 2045). While the economics of this option might be better than for new E85 cars, they are not compared to electric vehicles (post-2025). An additional 0.5 $MtCO_2$ abatement could be achieved with E85 car refurbishments, but these are not covered on the pathway.

91 For some details on the recent development of electric vehicles, see link 1: or link 2. For details on truck electrification TCO outlook.
92 For more details on the battery value chain and materials supply.
93 Nylund et al. (2015): How to reach 40% reduction in carbon dioxide emissions from road transport by 2030: propulsion options and their impacts on the economy.
94 For more details on charging infrastructure needs.
95 Fuel containing 85 per cent ethanol fuel and 15 per cent gasoline or similar fuel.

Abatement opportunities in agriculture and waste management

As discussed in Chapter 2, the abatement pathway does not consider agriculture and waste management since they mainly produce emissions other than CO_2 and have a very fragmented landscape of potential measures. However, there are abatement opportunities in these segments and can substantially contribute to abatement targets. Some key levers in these sectors are briefly described below.

Agriculture

In 2015, 97 per cent of emissions in agricultural activities (excluding fuel combustion for agricultural machines and land use emissions) originated from methane (CH_4) and nitrous oxide (N_2O). More than 85 per cent of these emissions were caused by using nitrogen fertilisers in agricultural soil management (3.4 $MtCO_2e$) and by enteric fermentation of livestock (2.1 $MtCO_2e$).

Possible abatement measures currently available or in a research and development phase include the following.

Abatement of CH_4

- Use of additives and supplements (either synthetic or natural, currently under development) in cattle feed to reduce methanogenic digestive processes. Most common supplements are nitrates and dietary additives, with a potential CH_4 emissions reduction of 15–20 per cent.[96]
- Natural supplements are currently being researched. Preliminary results from a recent study show that mixing cattle food with a small amount of seaweed can lead to 99 per cent reduction in methane emissions from dairy cows in a laboratory environment. This solution could provide a natural-based alternative to synthetic supplements. Moreover, it is relatively easy to grow as seaweed cultivation does not require land, fresh water or fertiliser.[97]
- Livestock anti-methanogenic vaccinations have progressed in recent years and some of these vaccines can provide a reduction of between 25 and 30 per cent in emissions from cows.
- Genetic manipulation or selective breeding to breed cows with low emissions and high production capability could also provide some abatement potential, but this approach is likely to be more relevant in the long term given the high degree of complexity of genetic research.[98]
- Meat and dairy demand reduction by a shift to a more plant-based diet.

Abatement of N_2O

1. Improved fertiliser application in terms of quantity, timing and placement.
2. Crop selection and reduction of tillage, which can lead to an up to 50 per cent reduction in emissions, and have an impact also on CO_2 emissions reduction.
3. Usage of mixes of organic soil improvers that can enhance the capability of binding more emissions to the soil.
4. Meat and dairy demand reduction by a shift to a more plant-based diet – a decrease in meat demand also decreases the needed feed produced, which utilises fertilisers.

---

[96] Government of Western Australia, Department of Primary Industries and Regional Development, Carbon farming: reducing methane emissions from cattle using feed additives.
[97] Gabbatiss J., Feeding cows seaweed cuts 99 per cent of greenhouse gas emissions from their burps, research finds (2015).
[98] Luke: Cows in a glass tank help to reduce methane emissions (2016).

In order to enable effective emission reductions in agriculture, the following barriers should be considered.

- It is technologically difficult to reduce the main sources of emissions and the strong correlation between agricultural measures and their outputs that end up on the consumers' plates makes it challenging to smoothly deploy innovative solutions (e.g. synthetic additives and their possible impact on livestock health).
- Few levers come at negative cost, and a true change would likely require a reduction in demand.
- Most of the levers require collaboration and significant changes in mindset among farmers.

Therefore, one of the important drivers of potential agricultural abatement is the policymakers' actions towards creating opportunities for farmers to benefit from improved agricultural practices and from greater awareness of the problem. Also, the promotion of research and development projects to advance the pursuit of more climate-friendly agricultural management measures should be a top priority for a government that aims to curb GHG emissions in this sector.

Waste management

Waste management emissions in Finland mainly originate from landfill methane emissions, which have already decreased substantially in the last two decades. A key driver has been the improved practices that have followed legislation and the restrictions that have entered into force in the period 2010-2016. Going forward, many of the available measures in the sector require either policies or incentivisation. Potential abatement measures include:

- A continuous reduction of biodegradable waste disposal at landfill and the use of this for aerobic composting or incineration.[99]
- An increase in the recycling rate of municipal solid waste and a shift towards a more circular economy.
- An increase in consumer and producer awareness of the importance of waste minimisation at source.

[99] Waste incineration leads to an increase in emissions accounted for in the energy sector. However, according to the WEM estimations this increase will be less than 0.2 $MtCO_2e$ between 2015 and 2030.

Background interviews

Sitra would like to thank the different parties that have participated in the process of writing this report by providing commentary on assumptions and emerging results.

However, the results may not represent the views of these organisations or individuals. The following organisations have provided their insights:

- Elinkeinoelämän keskusliitto (Confederation of Finnish Industries)
- Energiateollisuus (Finnish Energy)
- Fingrid
- Finnsementti
- Fortum
- Gasum
- University of Helsinki
- Neste
- SSAB
- ST1
- Suomen ympäristökeskus (Finnish Environmental Institute)
- Teknologiateollisuus (Technology Industries of Finland)
- Työ- ja elinkeinoministeriö (Ministry of Economic Affairs and Employment)
- UPM

Key underlying assumptions for developing BAU 2030

SECTOR	SUB-SECTOR	KEY ASSUMPTION	SOURCE
Buildings	**Residential**	**Demand drivers** Number of households grows from 2.7m in 2015 to 3.05m by 2030, aligned with population growth Average floor space per household from 75.29 m^2 to 80.34 m^2 by 2030	Number of households from the Economist Intelligence Unit Total floor space 2013-2023 based on Navigant Research, Global Building Stock Database and forecast, 2023-2050 forecasts based on team analysis
		Efficiency gains 7-139% increase in brightness per Watt of lighting technologies 4-10% increase in energy efficiency of different types of space heating equipment Appliance performance improves at an average rate of 1.7% p.a.	IEA – Transition to Sustainable Buildings (2013); Ecofys – EU pathways towards a decarbonized building sector (2016); EIA – Annual Energy Outlook 2017
		Technology mix Frozen penetrations of space heating technologies to 2015 levels (i.e. 18% heat pumps, 24% biomass heaters, 39% district heating, 8% oil heaters) Adoption levels of lighting technologies frozen at 2015 levels Water heating technology mix follows space heating mix	Technology mix based on 2015 fuel mix from IEA and efficiency assumptions Based on Strategies Unlimited dataset
	Commercial	**Demand drivers** Commercial floor space grows from 66m m2 to ~85m m^2 by 2030	2013-2023 based on Navigant Research, Global building Stock Database and forecast, 2023–2050 forecasts based on team analysis
		Efficiency gains Same technology performance improvements as in residential buildings	IEA – Transition to Sustainable Buildings (2013); Ecofys – EU pathways towards a decarbonized building sector (2016); EIA Annual Energy Outlook 2017
		Technology mix Penetrations of space heating technologies frozen at 2015 levels	Technology mix based on 2015 fuel mix from IEA WEO 2017 and efficiency assumptions
Industry	**Iron and steel**	**Demand drivers** Iron and steel production increases of 5.5% by 2030, up to 4.21 Mt	McKinsey Basic Material Global Steel Model
		Efficiency gains 6% in energy efficiency improvements by 2030, no reduction in energy intensity of the process	Interviews with McKinsey experts
		Material reduction No reduction currently assumed in material usage	
	Chemicals	**Demand drivers** Total ethylene production capped at 0.41 Mt	ICIS Supply and Demand database for chemicals
		Efficiency gains 8% in efficiency gains for derivatives production and 4% for ethylene production by 2030	Interviews with McKinsey experts
		Material reduction Share in ethylene derivatives production coming from recycled sources increases on average by 40% by 2030	Interviews with McKinsey experts and team analysis

SECTOR	SUB-SECTOR	KEY ASSUMPTION	SOURCE
Industry	**Pulp, paper and print**	**Demand drivers** Pulp and paper production grows from 10.2 Mt in 2015 to 12.5 Mt in 2030	Bottom-up model based on RISI Mill Asset Database for production forecasts Fisher Database for historical energy demand data
		Efficiency gains No efficiency gains	
		Electrification of heat No electrification of heat processes assumed	
	Agriculture	**Non-energy emissions estimate** Extrapolate 10-year historical trend for Finland, i.e. flat emissions (6.5 Mt) to 2030. Triangulate with: Ministry of Economic Affairs and Employment of Finland (TEM): expecting limited changes to emissions to 2030 EU Agricultural Outlook: emissions expected to decline 1.5% from 2008 levels in 2030 in EU28 countries mainly due to projected decrease in EU livestock numbers Other local sources	Ministry of Economic Affairs and Employment of Finland (TEM) EU agricultural outlook 2017–2030 Luke, other local sources
		Energy emissions estimate From 1.18 Mt in 2015 to 1.22 Mt in 2030	McKinsey Global Energy Perspective model
		Efficiency gains No efficiency gains	
	Other (construction, mining, cement)	**Demand drivers** GDP and population	GDP and population growth from TEM and Statistics Finland Base year for GDP and population however differ by ~0.2–0.5%, based on IHS and UN World Bank to allow consistent regressions – less than 0.5% difference in 2030 to SF Historical values aligned with Statistics Finland
		Electrification of heat processes No further electrification assumed	
Transport	**Rail**	**Demand drivers** GDP	IEA WEO 2017 for historical energy demand, forecast aligned with GDP
		Efficiency gains No efficiency improvements assumed	
		Fuel Mix Constant product mix assumed (66% electricity, 34% oil)	IEA WEO 2017
	Road	**Demand drivers** Ownership rates by different vehicle types grow ~0.3–17% by 2030 Passenger cars: from 476 vehicles per 1,000 capita to 478.1 by 2030 Trucks: from 17.5 vehicles per 1,000 capita to 18.1 by 2030 Buses: from 2.3 vehicles per 1,000 capita to 2.7 by 2030 Two and three-wheelers: to stay constant at 83.8 vehicles per 1,000 capita (instead of increasing) Vans and pick-ups: from 56.4 vehicles per 1,000 capita to 61.8 by 2030	International Road Federation (IRF) World Road Statistics and team analysis VTT expert view

SECTOR	SUB-SECTOR	KEY ASSUMPTION	SOURCE
Transport	**Road**	Average vehicle km travelled differentiated by power-train and type of vehicle in line with IRF and ICCT and assumed constant Passenger cars: ~15,000 km/a in 2017 Trucks: ~35,500 km/a on average in 2017 Buses: between ~50,000 km/a in 2017 Vans and pick-ups: ~17,500 km/a in 2017 ~5-10% scrap rate for different types of vehicles (cars, buses, trucks) Lifetime: 20 years for passenger cars 10–14 years for others depending on the vehicle type	KAISU Trafi VTT expert view International Road Federation (IRF) and International Council on Clean Transportation (ICCT) and team analysis
		Fuel efficiency Increase in new car fuel efficiencies, 11% for EVs and 21% for diesel and gasoline cars by 2030; 13–26% for trucks	ICCT (various reports) and inter-views with McKinsey experts
		Biofuel blend rate 20% target reached in 2020, fixed after that	ALIISA
	Aviation (NIR value, excluding international bunkers)	**Demand drivers** Revenue passenger kilometres from 18 billion km in 2015 to 45.3 billion km in 2030; revenue tonne kilome-tres from 713 million km to 810.4 million km in 2030	Historical values from the International Air Transport Association (IATA) and World Bank, projections in line with GDP/capita
		Fuel efficiency 14% energy efficiency improvements by 2030	International Civil Aviation Organization
	Marine (NIR value used excluding international bunkers)	**Demand drivers** Global fleet size by type of vessels: Dry bulkers grow from 27,770 in 2015 to 38,830 in 2030 Number of containers increases from ~4,900 to ~7,800 by 2030 Tankers increase from ~15,400 to ~19,400 by 2030	
		Efficiency gains No efficiency improvements assumed by 2030	
		Fuel mix Reduction in HFO from 60% to 45% in fuel mix by 2030	MGI and McKinsey GEP team analysis
Power and heat	**Electricity generation**	**Demand drivers** Electricity consumption grows from ~80.1 TWh to ~86.5 TWh by 2030	McKinsey Global Energy Perspec-tive model
		Technology efficiency improvements Technology efficiency improvements: gas from 53 to 54% by 2030; coal from 43 to 44%; wind capacity factor improves from 28 to ~36%	McKinsey Global Energy Perspec-tive team analysis
		Future fuel mix By 2030, ~90% of domestic electricity supply will be carbon neutral	McKinsey Global Energy Perspec-tive model
		Demand drivers GDP and population growth	GDP and population growth from TEM and Statistics Finland Base year for GDP and population differ, however, by ~0.2–0.5%, based on IHS and UN World Bank to allow consistent regressions – less than 0.5% difference in 2030 to SF Historical values aligned with Statistics Finland
		Technology efficiency improvements No energy efficiency improvements assumed	

Commodity prices

SECTOR	PRICE 2017 (INCLUDING AVERAGE TAXES, REAL)	PRICES 2030 (INCLUDING AVERAGE TAXES, REAL)	ASSUMPTIONS	SOURCE
Natural gas – industrial, EUR/MWh	47.5	54.8	Gas follows trend of EU/ Russian gas prices	Base number from Statistics of Finland, trend based on World Bank EU gas price outlook
Electricity – industrial, EUR/MWh	70.0	modelled	Taxes and T&D cost assumed to be stable	Base number from Statistics Finland, trend based on power model
Coal, EUR/MWh	13.0	11.1	Coal price follows EU price	Base number and trend from World Bank, EU coal outlook
Biomass, EUR/MWh	20.0	20.0	No price change assumed	Base price from IEA, trend assumed stable
Crude oil, EUR/bbl	65.0	74.8	Oil prices slightly increase	Base price and trend from World Bank
Naphtha, USD/GJ	10.8	10.8	No price change assumed	Base price from World Bank, trend based on World bank crude oil outlook
Hydrogen, EUR/MWh	57.2	57.2	No price change assumed	Base price from IEA, no price changes assumed
District heating EUR ct/kWh	8.6	8.6	Price weakly coupled to gas price	Base number from Statistics Finland, trend based on gas price increase
Natural gas – residential, EURct/m^3	46.2	51.3	Taxes and T&D cost assumed to be stable	Base number from Statistics Finland, trend based on World Bank EU gas price outlook
Electricity – residential, EURct/kWh	16.0	modelled	Modelled in power model, taxes and T&D stable	Base number, taxes and T&D from Statistics Finland, trend modelled in power model
Heating oil, EURct/l	91.0	100.1	Price coupled to oil price	Base price from P&B Finland, trend based on World bank crude oil outlook
Wood pellets, EURct/kg	25.1	25.1	No changes in price expected	Base price from Statistics Finland, no price change assumed
Gasoline, EURct/l	142	156	Biofuel blending assumed not to change price (i.e. biofuel remains subsidised) Prices coupled to oil price	Base price from P&B Finland, trend based on World bank crude oil outlook
Diesel, EURct/l	130	143	Biofuel blending assumed not to change price (i.e. biofuel remains subsidised) Prices coupled to oil price	Base price from P&B Finland, trend based on World bank crude oil outlook

References

Anna Sahari. (2017). Essays on Households' Technology Choices and Long-Term Energy Use. Aalto University School of Business.

Baltic Sea Region Energy Co-oparation. Conditions for deployment of wind power in the Baltic Sea Region.

BASF. Important raw material price developments.

Climate Analytics and Sitra: Rocha, M., Sferra, F., Schaeffer, M., Roming, N., Ancygier, A., Parra, P., & Hare, B. (2016). What does the Paris Climate Agreement mean for Finland and the European Union.

Customs Finland. Metsäteollisuuden ulkomaankauppa vuonna 2017.

Finnish Climate Change Panel. (2018). Ilmastopaneelin näkemykset pitkän aikavälin päästövähennystavoitteen asettamisessa huomioon otettavista seikoista.

Fortum. Investor presentation September 2018.

Frandsen, T. Q. Rodhe, L., Baky, A., Edström, M., Sipilä, I., K., Petersen, S.L. & Tybirk, K. (2011). Best Available Technologies for pig Manure Biogas Plants in the Baltic Sea Region. Published by Baltic Sea 2020, Stockholm.

Government of Western Australia, Department of Primary Industries and Regional Development. Carbon farming: reducing methane emissions from cattle using feed additives.

International Energy Agency. (2012). Danish Energy Agreement for 2012-2020.

Kinley R., de Nys R., Vucko M., Machado L. & Tomkins N. (2016). The red macroalgae Asparagopsis taxiformis is a potent natural antimethanogenic that reduces methane production during in vitro fermentation with rumen fluid. Animal Production Science 56, 282-289.

Luke. Puuston vuotuinen kasvu 2017.

Luke. (2016). Cows in a glass tank help to reduce methane emissions.

Luke: Lehtonen, A., Salminen, O., Kallio, M., Tuomainen, T. & Sievänen, R. (2016). Skenaariolaskelmiin perustuva puuston ja metsien kasvihuonekaasutaseen kehitys vuoteen 2045: Selvitys maa- ja metsätalousministeriölle vuoden 2016 energia- ja ilmastostrategian valmistelua varten.

Material Economics. (2018). The circular economy - a powerful force for climate mitigation.

McKinsey: de Pee, A., Pinner, D., Roelofsen, O., Somers, K., Speelman, E. & Witteveen, M. (2018). How industry can move toward a low-carbon future. McKinsey Sustainability & Resource Productivity Practice July 2018.

Ministry of Economic Affairs and Employment. Hallituksen esitys eduskunnalle laeiksi biopolttoöljyn käytön edistämisestä, biopolttoaineiden käytön edistämisessä liikenteessä annetun lain muuttamisesta sekä biopolttoaineista ja bionesteistä annetun lain 2 §:n muuttamisesta. 29.6.2018. TEM/1334/03.01.01/2018.

Ministry of Economic Affairs and Employment: Riku Huttunen. (2017). Government report on the National Energy and Climate Strategy for 2030. Publications of the Ministry of Economic Affairs and Employment 12/2017.

Ministry of Transport and Communications. Alternative fuels infrastructure — a proposal for a national framework until 2020/2030. Publications of the Ministry of Transport and Communications 4/2015.

Mirja Mutikainen, Kai Sormunen, Heli Paavola, Turo Haikonen, Mirva Väisänen. (2016). Biokaasusta kasvua: Biokaasuliiketoiminnan ekosysteemien mahdollisuudet. Sitran selvityksiä 111.

Motiva. Lämmitystapojen vertailulaskuri.

Nylund, N., Tamminen, S., Sipilä, K., Laurikko, J., Sipilä, E., Mäkelä, K., Hannula, I. & Honkatukia, J. (2015). How to Reach 40% Reduction in Carbon Dioxide Emissions from Road Transport by 2030: Propulsion Options and their Impacts on the Economy. VTT Research Report VTT-R-00752-15.

Petroleum & Biofuels Association Finland. Consumer price update.

Petroleum & Biofuels Association Finland. World market prices of crude oil.

Pöyry management consulting. (2018). Kivihiilen käytön kieltämisen vaikutusten arviointi.

Pöyry management consulting. EU:n 2030 ilmasto- ja energiapolitiikan linjausten toteutusvaihtoehdot ja Suomen omien energia- ja ilmastotavoitteiden toteutuminen. Valtioneuvoston selvitys- ja tutkimustoiminnan julkaisusarja 28/2016.

Sipilä, E., Kiuru, H., Jokinen, J., Saarela, J., Tamminen, S., Laukkanen, M., Palonen. (2018). Cost effective pathways of biofuels until 2030. Publications of the Government´s analysis, assessment and research activities 63/2018.

Smart Energy Transition Project. Clean energy district heating and cooling vision.

Statistics Finland, The Natural Resources Institute Finland, The Finnish Environment Institute, VTT Technical Research Centre of Finland Ltd, Finavia, the Energy Authority, The

Ministry of Employment and the Economy, The Ministry of Foreign Affairs of Finland. National Inventory Report (2016).

Statistics Finland. Energy prices [e-publication]. ISSN=1799-800X. 1st Quarter 2018, Appendix figure 2. Consumer prices of principal oil products.

Statistics Finland. (2017). Finland's Seventh National Communication under the United Nations Framework Convention on Climate Change.

Statistics Finland. 111k Greenhouse gas emissions in Finland, 1990-2016.

Statistics Finland. Energy prices [e-publication]. ISSN=1799-800X. 1st Quarter 2018, Appendix figure 5. Price of electricity by type of consumer.

Statistics Finland. Energy prices [e-publication]. ISSN=1799-800X. 1st Quarter 2018, Appendix table 2. Energy prices in heat production in March 2018.

Suomen Tuulivoimayhdistys ry. Wind power in Finland.

Trafi. Ajoneuvojen ensirekisteröinnit maakunnittain 2001-2018.

Trafi. Liikennekäytössä olevat ajoneuvot ajoneuvoluokittain ja kunnittain 30.7. 2018.

Trafi. Maaliskuun henkilöautorekisteröinnit hieman viime vuotta pienemmät.

World Nuclear Association. Nuclear Power in Finland.

VTT. ALIISA vehicle fleet model. (2017).

VTT: Keränen J., Manninen J. (2012). Tonni, Onni & Inno – kolme erilaista kaverusta. Skenaariotyö metsäteollisuuden kehityksestä vuoteen 2050.

VTT: Tulkki, V., Pursiheimo, E. & Lindroos, T. (2017). District heat with Small Modular Reactors.

SITRA STUDIES 140
Sitra Studies is a publication series which focuses on the conclusions and outcomes of Sitra's future-oriented work.

ISBN 978-952-347-082-8 (paperback)

SITRA.FI
Itämerenkatu 11–13,
P.O. Box 160, 00181
Helsinki, Finland
Tel +358 294 618 991
@SitraFund