The Danish Government's Climate Partnerships

Energy and Utilities Sector

Powering Denmark's Green Transition

Roadmap for a near carbon neutral energy sector to achieve Denmark's 70% reduction target by 2030

MAY 2020

A new dawn in Danish climate and business policy: Energy corporations join forces with the government to secure green transformation

Climate change is the greatest challenge of our time. The choices we make today will impact the planet we leave behind for future generations. We must be aware of our responsibility and stop global warming, which is already posing an alarming threat to our life on this planet. This calls for unprecedented action.

In line with the rest of Europe, Denmark must be climate neutral by 2050. In summer 2019, the Danish government and the Danish parliament raised their ambitions and announced a 2030 target to cut carbon emissions by 70% below the 1990 level as a step towards achieving full climate neutrality by 2050. The Danish government also invited Danish businesses to come up with ideas on how the government can achieve this target. The invitation is a unique opportunity for the Danish government and green Danish businesses to show global leadership and contribute to national and international emission cuts in line with Denmark's commitment to the Paris Agreement and the global target of keeping the global temperature increase below 1.5°C.

The Danish Prime Minister Mette Frederiksen has selected 13 climate partnerships across Danish businesses to help the government realise its 70% reduction target by 2030:

The 13 climate partnerships cover a broad range of businesses and include climate partnerships for land transport, service, IT and consultancy, aviation, waste, water and circular economy, construction, life science and biotech, trade, manufacturing, finance, shipping, energy-intensive industry, food production and energy and utilities.

All 13 partnerships have been tasked with formulating each sector's contributions to carbon reductions towards 2030 in a so-called sector roadmap. The partnerships may propose initiatives in their own sector and initiatives that contribute to reductions in other sectors as well as to international reductions.

The Danish Prime Minister has appointed Ørsted CEO Henrik Poulsen to head the climate partnership for the energy and utilities sector, and as chairman he has set up an Advisory Board consisting of leading companies in the sector, which have assisted the chairman in putting together the sector roadmap.

"All parties of society must contribute to achieving the government's ambitious climate target. I am confident that people with different interests can work together to find common solutions if they want to. Every single day, businesses and organisations do just that, taking responsibility for the society in which they operate."

– Danish Prime Minister, **Mette Frederiksen**

In addition, the energy and utilities climate partnership comprises a wide range of companies and organisations in the sector which are involved in the production of power, heat, biogas, oil, natural gas and hydrogen and the related infrastructure on a daily basis. As part of its work on the sector roadmap, the climate partnership has also involved numerous relevant stakeholders and received input from industry associations, businesses, NGOs, trade unions, scientists, etc.

What is a sector roadmap?

In November 2019, the Danish government asked Danish businesses to draft a sector roadmap which includes:

a) ambitions for carbon reductions in their own sector
b) contributions to reductions in other sectors
c) contributions to international reductions and reductions in international value chains.

This report was first published in Denmark (in Danish only) on 16 March 2020 when the magnitude of the COVID-19 pandemic was still unknown. Besides reducing carbon emissions, many of the initiatives outlined in this roadmap can also contribute to the necessary economic recovery in the wake of the global pandemic. To improve the overall understanding of the Danish context among an international audience, this report is a slightly adjusted English version of the original Danish report.

Introduction

Climate change is the greatest challenge of our time. The choices we make today will have a profound impact on the planet we leave behind for future generations. We must be aware of our responsibility and stop global warming, which is already posing an alarming threat to our life on this planet. This calls for unprecedented action.

In summer 2019, the Danish government and the Danish parliament raised their ambitions and announced a 2030 target to cut carbon emissions by 70% below the 1990 level as a step towards achieving full climate neutrality by 2050. The Danish government also invited Danish businesses to come up with ideas on how the government can achieve this target. The invitation is a unique opportunity for Denmark and strong Danish businesses to show global leadership. If we work together, we are in the best position to succeed.

It has never been clearer that a green future based on 100% renewable energy is within reach. We know that a radical green transformation is achievable – without having to compromise our fundamental prosperity and society as we know it. Since 2014, the price of offshore wind has plummeted, green power from onshore wind and solar farms is almost subsidy-free, biogas is becoming cheaper, sustainable biomass has helped us phase out coal, Danes are guaranteed security of supply, and Danish energy efficiency solutions are keeping energy consumption down. This has been possible thanks to sustained political efforts to drive green investment in Danish businesses. We need to keep up the good work.

The Danish energy and utilities sector has undergone a major transformation from fossil fuels to green energy in record time. This has provided us with a strong platform – which is why we need to keep raising the bar. We are aiming for the energy and utilities sector to be virtually fossil-free by 2030, but that will not be enough. Denmark will not be able to achieve this target unless transport and industry cut their fossil fuel consumption in half and agriculture reduces its emissions. The answer to this monumental change is not to close down businesses and agricultural entities, nor to prevent consumers from owning a car. The answer is rather to replace fossil energy with green and renewable energy. The energy and utilities sector is capable of making this happen. We just need to get started now. Over the next decade, this transformation will make green energy the catalyst of Denmark's future growth and prosperity, strengthening the competitiveness of Danish businesses. Danish energy technology is already sold to customers all over the world. Danish skills and resources also enable Denmark to export large quantities of green energy, providing a significant contribution to the green transformation in Europe. Cheap, green energy also offers ample opportunities for new sector couplings and enables the development of an entirely new industry based on new, hydrogen-based fuels to replace fossil fuels. Danish energy technology combined with Denmark's ample green energy resources can create new and comprehensive industrial activity in Denmark.

The Danish transformation to a sustainable green society will require comprehensive decisions in all parts of Danish society. With the selection of 13 climate partnerships across Danish businesses, the Danish government and the Danish parliament have a historic opportunity to realise a comprehensive transformation of society in cooperation with Danish businesses. The 70% reduction target calls for a new partnership between business, government and parliament. A partnership based on a mutual agreement that businesses contribute substantial investments in new technology and infrastructure, while policymakers provide the necessary framework conditions to realise the transformation.

We need to make clear, long-term decisions now.

This first outline of a sector roadmap describes how the energy and utilities sector will crack the climate code in a partnership with policymakers and businesses. In Denmark, we have the potential to succeed if we want to.

Enjoy your reading.

CHAIRMAN OF THE CLIMATE PARTNERSHIP
FOR THE ENERGY AND UTILITIES SECTOR

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CEO Ørsted

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1.0 The Danish energy and utilities sector's tasks and approach

In order to deliver the 70% reduction target, all sectors must reduce their total carbon emissions by 26 million tonnes by 2030, corresponding to more than the total reduction achieved from 1990 to 2019. This will require significant efforts in all sectors. The sector roadmap of the Danish energy and utilities sector is first and foremost based on Denmark's Energy and Climate Outlook, then on a displacement model providing estimates of the impact of a number of reduction initiatives. The sector roadmap assumes that the 70% reduction target must be realised and provides an estimate of the future green energy demand across sectors. This approach was chosen to be able to assess the initiatives and not least the level of investment required in the energy and utilities sector to support the green transformation in other sectors. Such an assessment, however, is subject to several uncertainties and factors; it is for example difficult to estimate which technologies will be preferred by the market in 2030. The displacement model and actions will thus have to be adjusted along the way, as technologies and consumer preferences develop, and after completion of the work of the 13 climate partnerships. In return, the model offers a detailed proposal on a cost-effective path to achieve the reductions required for Denmark to achieve the 70% reduction target.

2.0 Denmark halfway to meeting target by ensuring a fossil-free energy and utilities sector by 2030

Through energy efficiency improvements that have reduced the energy demand significantly, the Danish energy and utilities sector's carbon emissions have already been cut by 58% from 32 million tonnes in 1990 to 13 million tonnes in 2019. With continued energy efficiency improvements and further initiatives to phase out fossil energy, the energy and utilities sector may be able to reduce its emissions to approximately 1 million tonnes by 2030. This translates to a reduction of more than 95% compared to the 1990 level. The initiatives include phasing out the remaining coal used for power stations and natural gas for district heating production, phasing out natural gas and oil in individual heating systems, carbon capture at large point sources, reduction of the use of plastics in waste-to-energy systems and reduction of the amount of natural gas used for energy production in the North Sea. The reductions achieved in the energy and utilities sector are expected to account for approximately half of the total reductions required in Denmark from 2019 to 2030.

3.0 The green transformation of other sectors will help Denmark reach its target

Of the 47 million tonnes of carbon emissions in Denmark today, 33 million tonnes come from other sectors than the energy and utilities sector. Of these, 19 million come from the use of fossil fuels, while 14 million tonnes of carbon emissions are non-energy-related emissions from agriculture, environmental and industrial processes. Even with a potential further reduction of 13 million tonnes of carbon emissions in the energy and utilities sector and an estimated reduction in non-energy-related emissions of 4 million tonnes, the remaining sectors need to cut their use of fossil fuels more or less in half, corresponding to 9 of 19 million tonnes, in order for Denmark to reach its 70% reduction target.

4.0 The energy and utilities sector can supply green energy to power the full transformation of Denmark

Phasing out fossil fuels in the energy and utilities sector will lead to increased demand for renewable energy, which must be met by the energy and utilities sector in order to achieve the full transformation of Denmark. The need for production capacity and infrastructure can be reduced with energy efficiency improvements, demand-side response and storage. The total demand for renewable energy is expected to grow by 64% to 125 TWh by 2030. Meeting the increased demand for renewable energy requires a build-out of offshore wind from 1.7 to 7.6 GW, of onshore wind from 4.4 to 6.1 GW and of solar energy from 1.2 to 8.8 GW. Biogas production must be increased from 4.4 TWh in 2019 to 13.3 TWh by 2030, and Power-to-X must be increased to full-scale production. The power grid must be upgraded to be able to transport more green power. It is expected that the final consumption from the distribution grid will increase from 34 TWh in 2019 to 58 TWh in 2030, and the final consumption from the transmission grid will increase from 1 TWh to 13 TWh. Demand-side response and smart solution will reduce the necessary infrastructure upgrades. Nevertheless, the increased power generation from fluctuating renewable energy sources will require more interconnections. Furthermore, the gas and heat infrastructure will change and we need to establish an infrastructure to support the development of Power-to-X fuels. Initiatives must be implemented to ensure security of supply during times with limited power generation from flexible energy sources.

5.0 Green energy exports from Denmark can support the international transformation

Denmark is in a unique position to support the international transformation by exporting large quantities of green offshore wind power and Power-to-X products to replace fossil fuels in international transport and industry. An increase in exports will build on Denmark's long-standing position as a green pioneer nation and could contribute significantly to the EU target of climate neutrality by 2050. At the same time, Denmark can increase its already significant global exports of technologies and consultancy services within energy efficiency improvements and renewable energy production. Increased exports will not only contribute to reducing carbon emissions, they will also create export revenues and create jobs across Denmark. Export of energy commodities will require a build-out of the power export infrastructure and the establishment of a Danish Power-to-X production framework during the 2020s. An increased export infrastructure to neighbouring countries will also play a significant role in reducing risks, both economic as well as in relation to security of supply, if the build-out of renewable energy does not match the Danish energy demand all the way to 2030.

6.0 The transformation requires significant investments, but the cost for the individual is manageable

When Denmark reaches its 70% reduction target in 2030, the energy sector and its energy customers will have made significant investments in renewable energy, energy infrastructure and new energy-efficient technologies. The energy and utilities sector estimates that these additional and extra investments will total approximately DKK 32 billion annually towards and including 2030. These investments can be made if the political framework supports the right investment decisions. Investments must be made in our shared energy infrastructure, and, not least, the power grid must be prepared to handle twice the power consumption and the many additional wind turbines and solar panels that will be connected to the grid. The gas and heating systems will also undergo major changes.

The total additional costs to society are estimated at around DKK 15 billion in 2030. This corresponds to approximately DKK 5,000 per year per household. Even though this is a significant amount for the individual household, the average gross income of a Danish household is expected to have increased by DKK 90,000 by 2030. All in all by 2030, the Danish energy consumption will be more climate-friendly, and Danes will be spending less of their total household budget on energy compared to today.

If left unchanged, the current energy tax regime, which imposes heavy taxation on fossil fuels, will lead to lost government revenues of approximately DKK 23 billion in 2030. In addition, the Danish government will have to allocate support funds in the form of subsidies and targeted tax remissions to ensure that immature technology can be developed and scaled and potentially negative effects on Danish competitiveness mitigated. Subject to the recommendations of other partnerships, the need for funding is estimated to be in the range of DKK 5-7 billion annually towards 2030.

7.0 A new green social contract on the path to climate neutrality

A new partnership between business, the Danish government and the Danish parliament will secure the investments and policies necessary to take Denmark all the way to a 70% reduction by 2030 and to full climate neutrality by 2050. Investments in competitive and novel and immature technologies must be made ahead of an increase in demand under the assumption that policy will drive demand. Attracting new capital is only possible when people are willing to share the risks that come with it, for example, by entering power purchase agreements. The energy and utilities sector is requesting a mutual, green social contract in line with the 70% reduction target.

From target to national strategy **to action** in 18 months

Implementing the energy and utilities sector's roadmap towards 2030 will entail a pervasive transformation of the way the sector supplies energy to the Danish society. In order to succeed, we need a collective and strategic approach to decision-making and the necessary resolve from policymakers and business executives. The government's coming climate action plan is expected to build on the 2018 Energy Agreement, meaning that the scope and timeline of already decided plans for onshore wind, solar and offshore wind will be adhered to.

We need a national climate strategy. The Climate Act sets an ambitious target. Denmark is to reduce its total carbon emissions by 70% by 2030. This means that over the next ten years, Denmark must reduce carbon emissions by almost the same amount as in the past 30 years. All parts of Danish society will have to contribute if this target is to be met. If parts of the economy fail to deliver their reductions, others will have to realise larger reductions in order to reach the target. How much fossil energy needs to be replaced with renewable energy depends on which specific initiatives we decide to implement. To be able to develop an energy and utilities sector capable of supplying green energy to Denmark in 2030 and 2050, the energy and utilities sector needs clarity of the overall climate strategy which the Danish government and the parties backing the Climate Act intend to pursue. Most investments in the energy and utilities sector have long lead times, so if we are to reach the target, we need to get started now. Energy customers also need clarity in order to commit and make decisions that support the 70% reduction target. The Danish government and parliament should realise that making too many non-green investment decisions in the coming years may result in significantly increased costs. So while 2030 may seem far into the future, the decisions we make in the years to come will be decisive for Denmark's ability to reach its climate ambitions.

It calls for a national climate strategy based on input from all of the 13 climate partnerships. The energy and utilities sector requires the strategy to build on five fundamental actions.

Action 1. Set an a guiding target of reducing carbon emissions from the energy and utilities sector by at least 95%

Action 2. Set an a guiding target of reducing the total use of fossil fuel for buildings, transport and industry by 50%

Action 3. Prepare a guiding 10-year roadmap for hydrogen-based fuels, focusing on how government and industry can work together to reduce start-up costs and costs of use.

Action 4. Set a target for build-out of renewable energy ensuring sufficient capacity to support a complete, green transformation of Denmark.

Action 5. Define a framework for build-out of the Danish energy infrastructure to support a complete, green transformation of Denmark.

The National Climate Strategy must be decided by mid-2020

20 critical decisions to ensure action. The national strategy is the first step towards setting a clear direction. The strategy must be supported by specific decisions to ensure action. The energy and utilities sector proposes 20 critical decisions that will move the national strategy forward and create a foundation for action that is critical for Denmark to be able to reach its target. In some areas, decisions can be made quickly, because the basis for decision is already clear and the technological risk is limited. In other areas, action and decisions must be developed. The national direction and ambition to be pursued in all areas must be decided now with broad political support. The future is uncertain in any case, and the path chosen will have to be adjusted along the way. Decisions must therefore be accompanied by the political will to introduce adjustments as markets, technology and consumer behaviour evolve and change.

The 20 critical decisions must be made by mid-2021

Decisions must be backed by regulation. Decisions must be backed by regulation that supports the transformation. The energy and utilities sector makes its recommendations of the detailed regulation that can secure private investments in green alternatives, in the build-out of renewable energy and in energy infrastructure, so that we can be ready in time and ready to take on our national and international responsibility as an energy and utilities sector.

Long-term plan for funding. The government should decide long-term funding of the national climate strategy across all climate partnerships that 1) addresses the loss of revenue resulting from the transition from fossil to green energy, 2) mitigates increasing energy costs for low-income groups and the most competitive industries, and 3) provides the necessary subsidies for the maturation and implementation of new green technologies.

Ambitious international climate policy. In addition to pursuing a national climate strategy, the government should pursue an ambitious international and, not least, European climate and energy policy. An international and European climate and energy policy in line with the Danish ambitions would benefit all business sectors. It will create a level playing field, open the market to the most climate-efficient operators in all sectors and increase confidence in a much more rapid development of technological solutions. The European cooperation in particular is critical because it holds a number of regulatory constraints such as state aid framework, the European single energy market, etc. which will also impact the national climate strategy. The government should therefore continue its work to raise the European reduction target to 50-55% by 2030 and to strengthen the EU emissions trading system by reducing the amount of available carbon credits and potentially including more sectors. It is also important to help shape global rules, for example, under the auspices of international maritime and aviation organisations such as IMO and ICAO[1].

[1] International Maritime Organization, International Civil Aviation Organization.

20 climate decisions

Action 1. Set guiding target of reducing carbon emissions from the energy and utilities sector by at least 95%

1. Decide on a full and speedy phase-out of coal in the Danish combined heat and power generation.

2. Decide on how to phase out natural gas in individual heating systems by 2030 and prepare an action plan to allow customers time to prepare to switch to another heating option (heat pump, biogas or district heating).

3. Decide on new regulation for the district heating sector to support the transition to 100% green energy while considering the differences in heating areas and different technological solutions and prioritising investment in alternatives to increased biomass utilisation. Also decide that all use of biomass for energy production must comply with future statutory sustainability criteria.

4. Decide to separate plastics from waste and prepare a long-term strategy to increase recycling.

5. Decide that a national climate strategy must include carbon capture (utilisation and storage) and provide the regulatory and financial framework to establish carbon capture at one or more of the Danish point sources, including waste-to-energy plants.

6. Decide to prepare an action plan, in cooperation with the offshore industry, for optimisation and partial electrification of the oil and natural gas production in the North Sea.

Action 2. Set a guiding target of reducing the total use of fossil fuel for buildings, transport and industry by 50%

7. Decide on a new vehicle taxation scheme to support accelerated sales of green vehicles, eliminating the incentive to buy petrol and diesel vehicles before 2030, and supplement with a pro-active approach to planning and designation of areas for the establishment of recharging points.

8. Decide that all new public transport contracts – for the delivery of buses, ferries, taxis and trains – must be for fossil-free solutions.

9. Decide to remove regulatory barriers to energy efficiency as identified across climate partnerships, and make this an independent focus area in a national climate strategy.

10. Decide on a plan to phase out industrial use of coal, oil and natural gas where technically feasible and support industry in transitioning to green alternatives such as power, hydrogen-based fuels and biogas.

Action 3. Prepare a guiding 10-year roadmap for hydrogen-based fuels, focusing on how government and industry can work together to reduce start-up costs and costs of use.

11. Decide on a strategy and roadmap for the use of hydrogen-based fuels (Power-to-X). Allocate funds for industrial scale-up to encourage cost reductions towards commercial feasibility and appoint relevant locations for utilisation of, for example, waste heat.

Action 4. Set a target for build-out of renewable energy ensuring sufficient capacity to support a complete, green transformation of Denmark

12. For annual tenders from 2021 to 2024, decide that at least 5 GW of offshore wind farms are to be installed and commissioned before 2030. A capacity of 3 GW of these 5 GW is already sanctioned in the 2018 Energy Agreement, and allowance should be made for further upward adjustment towards 2030 – also through the open-door procedure.

13. Decide on a roadmap for the total build-out of renewable energy and transmission infrastructure in the North Sea and the Baltic Sea towards 2050, also determining that one of the first public tenders of offshore wind before 2024 must include the construction of one or more energy islands, which are to be connected to other countries before 2030 and form part of a North Sea grid and/or a Baltic Sea grid after 2030.

14. Decide on an action plan allowing for an ambitious build-out of onshore wind and solar energy which caters to the overall demand for renewable energy and grid capacity. Carry through the already agreed upon technology-neutral tenders. Enter binding agreements with local authorities to secure the required land lease agreements.

15. Decide to increase the amount of biogas in the Danish energy supply by 2030 and make requirements for an increasingly cost-effective production either backed by 'fixed-volume offtake requirements' or by production subsidies.

Action 5. Define a framework for build-out of the Danish energy infrastructure to support a complete, green transformation of Denmark

16. Decide that economic regulation of distribution system operators and Energinet must enable cost-effective build-out of the distribution and transmission grids to accommodate increased power consumption.

17. Decide to implement time-differentiated tariffs and to make data available for market players to develop attractive demand-side products, energy storage, etc. for the energy customers, contributing to peak-shaving and reduction of power consumption to balance the demand.

18. Decide that the Danish security of supply target must allow for an energy system designed to support the 70% reduction target, comprising more fluctuating energy production and significantly reduced power plant capacity.

19. Decide on a plan for expanding the transmission infrastructure (on- and offshore), supported by efficient decision-making processes to ensure investments are not delayed.

20. Decide on a gas infrastructure plan, including which of the gas network to retire and when as well as how the gas infrastructure's transport and storage capacity can be used to support Power-to-X fuels and green gases.

Roadmap from climate strategy to climate action

2019 — **Mid-2020 at the latest** — **Mid-2021 at the latest**

Climate target

Climate target adopted

June
The Danish government and its supporting parties decide on a climate target: 70% reduction of carbon emissions by 2030.

Climate Act

December
Broad agreement between the Danish government and the Danish parliament to pass a climate act confirming and providing the framework for the climate target.

Climate strategy

5 actions

Action 1. Set a guiding target of reducing carbon emissions from the energy and utilities sector by at least a 95%

Action 2. Set a guiding target of reducing the total use of fossil fuel for buildings, transport and industry by 50%

Action 3. Prepare a guiding 10-year roadmap for hydrogen-based fuels, focusing on how government and industry can work together to reduce start-up costs and costs of use

Action 4. Set a target for build-out of renewable energy ensuring sufficient capacity to support a complete, green transformation of Denmark

Action 5. Provide a framework for development of the Danish energy infrastructure that supports a full, green transformation of Denmark

20 decisions

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Other climate partnerships

Policy

Regulations

2021+ 2021+ 2030

Climate action

70%

Detailed regulation

The five actions and the 20 decisions must be supported by detailed regulation.

Investments

Demand and risk sharing support mobilisation of the necessary investments from households and private businesses, including the energy and utilities sector. This is elaborated in Chapter 6.

The result of many decisions made by many parties in a very short time

Households and private businesses

Vision The climate challenge represents a historic opportunity for Denmark

Denmark has all the prerequisites to realise an ambitious green transformation that will benefit the climate, businesses and the Danes. However, Denmark depends on its resolve and its ability to carry through large changes in all parts of Danish society. Elected officials must set the direction with the necessary ambitions, decisions and framework conditions. Businesses must demonstrate their willingness and ability to innovate and invest, and translate change into solutions that can be exported to the rest of the world. The Danes must be prepared to invest in housing, energy and transport solutions that support the ambition.

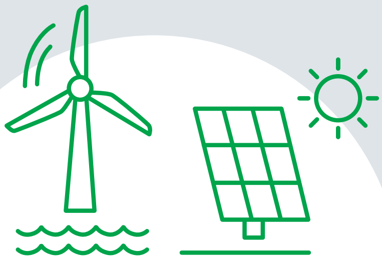
This formula has already placed Denmark among the global leaders in green technology, and Denmark has a historic opportunity to develop and capitalise on this position. Facing the changes head on with a better social cooperative spirit and greater strategic courage and resolve than other countries, Denmark can lead the way, combat climate change and strengthen our long-term competitiveness.

The goal is to build a country with access to large amounts of green energy at competitive prices. A country where homes, transport solutions and the entire business sector run on green energy, and *Made in Denmark* is synonymous with sustainability. A country selling green energy, technology and knowledge to the whole world, while attracting investments from companies looking for access to our green energy, innovation power and stable framework conditions. A country that creates green growth and green jobs, where Danish workers form a world-class green workforce. A country where security of supply remains best in class.

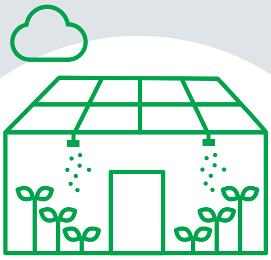
Add to this the potential to export large amounts of green power and green fuels to make up for the large revenue historically obtained from Danish oil and natural gas production in the North Sea. We can maintain our healthy economy while contributing to significant carbon emission reductions in the other European countries lacking the wind and solar resources to power a full green transformation.

Today, this vision of Denmark may appear abstract, but it is definitely within reach. If we have the courage and resolve to make the Danish society work together towards this common goal, we will be able to make headway in the right direction over the next ten years.

The energy and utilities sector is ready to get to work. We look forward to the future and to helping future-proof Denmark's competitiveness and position as a pioneer in the fight for a sustainable world.

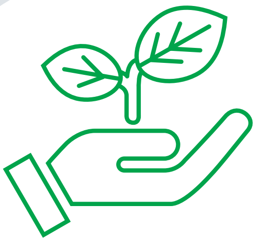


Ample amounts of green energy, technology and knowledge to benefit the whole world

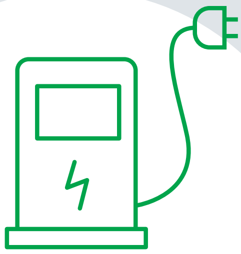


Green growth and green jobs – a world-class green workforce

High security of supply and competitive prices



***Made in Denmark* is synonymous with sustainability – regardless of industry**



Energy efficiency, demand-side response and smart solutions

1.0 The Danish energy and utilities sector's tasks and approach

In order to deliver the 70% reduction target, all sectors must reduce their total carbon emissions by 26 million tonnes by 2030, corresponding to more than the total reduction achieved from 1990 to 2019. This will require significant efforts in all sectors. The sector roadmap of the Danish energy and utilities sector is first and foremost based on Denmark's Energy and Climate Outlook, then on a displacement model providing estimates of the impact of a number of reduction initiatives. The sector roadmap assumes that the 70% reduction target must be realised and provides an estimate of the future green energy demand across sectors. This approach was chosen to be able to assess the initiatives and not least the level of investment required in the energy and utilities sector to support the green transformation in other sectors. Such an assessment, however, is subject to several uncertainties and factors; it is for example difficult to estimate which technologies will be preferred by the market in 2030. The displacement model and actions will thus have to be adjusted along the way, as technologies and consumer preferences develop, and after completion of the work of the 13 climate partnerships. In return, the model offers a detailed proposal on a cost-effective path to achieve the reductions required for Denmark to achieve the 70% reduction target.

Since 1990, Denmark has reduced its carbon emissions by 34%, corresponding to a reduction of carbon emissions of approximately 24 million tonnes from 1990 to the present day. Reaching the target of reducing carbon emissions by 70% by 2030 requires Denmark to reduce its carbon emissions by an additional 26 million tonnes between now and 2030. This means that over the next ten years, Denmark must reduce carbon emissions by almost the same amount as in the past 30 years, see Figure 1.

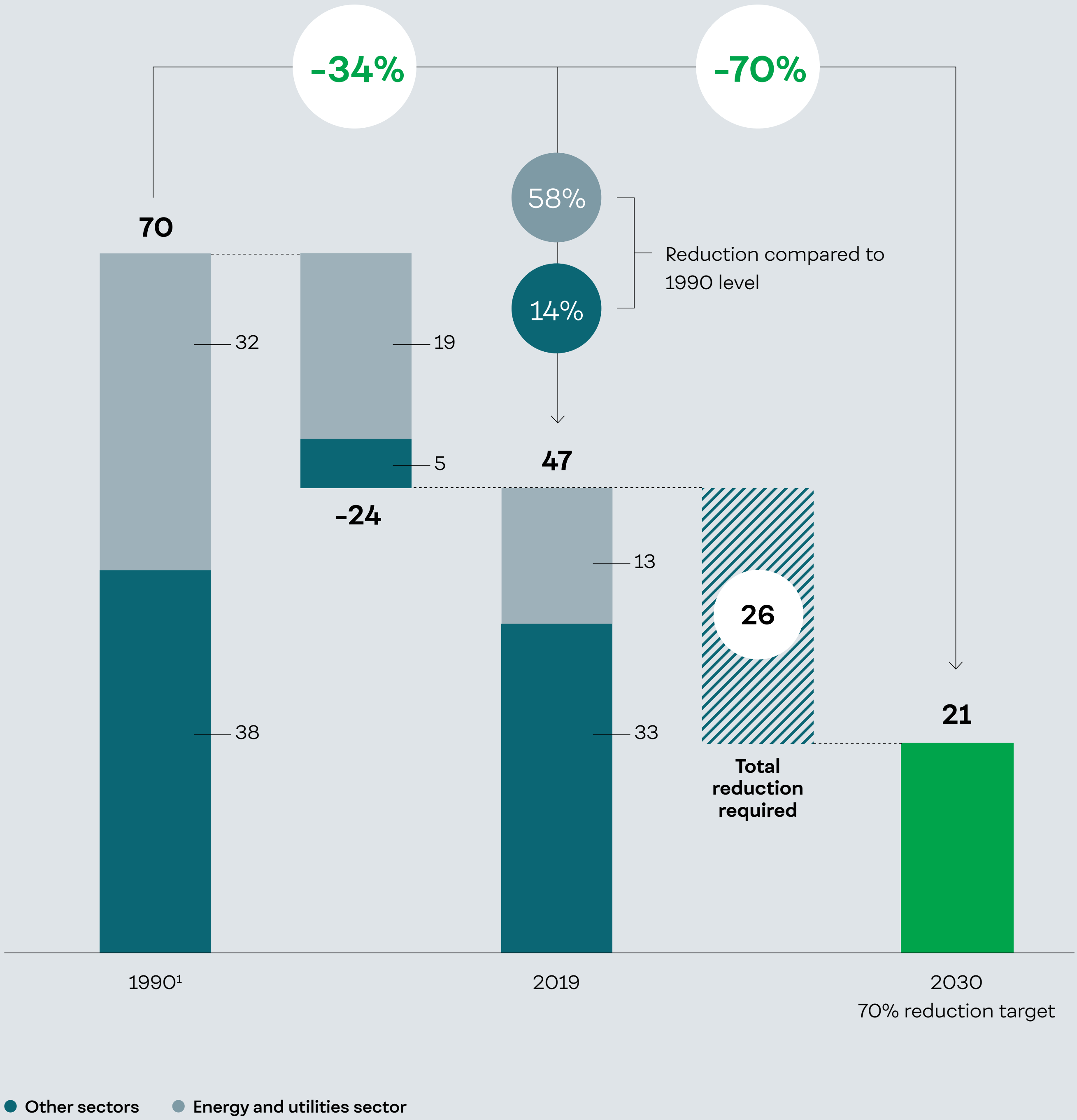
The 70% reduction target requires realisation of a comprehensive, green transformation of the entire Danish society with considerable contributions from all sectors. The transformation will require phasing out the remaining fossil fuels in the energy and utilities sector and significant reductions in the use of fossil fuels in other sectors. In addition, energy efficiency improvements may contribute significantly to reducing the overall energy demand, which will facilitate the task of producing and supplying the necessary amounts of new, green energy.

Denmark is facing a monumental task. Fortunately, we are in the best position to succeed. Today, Denmark is much better equipped to realise an accelerated green transformation towards 2030 than we were back in 1990. Since then, the energy and utilities sector has reduced its carbon emissions by 58%. More than 20 years of experience with the green transformation has paved the way for green technologies becoming not only the green alternative but the economically most attractive one. Renewable energy is now cheaper than its fossil counterparts, and a large share of Danish households are heated using green energy. Danish technologies have significantly improved and reduced energy consumption, and sustainable biomass and biogas have replaced coal.

Figure 1.

The 70% reduction target means that over the next ten years, Denmark must reduce carbon emissions by almost the same amount as in the past 30 years

Million tonnes of carbon dioxide equivalents (CO_2e)



[1] The baseline of the government's climate target.
Note: The emission numbers shown are actual emissions excluding LULUCF (Land Use, Land-Use Change and Forestry) as measured in Denmark's Energy and Climate Outlook 2019.
Note: The emissions of the energy and utilities sector include emission produced during extraction, conversion to power and heat and finally during heating.
Source: Denmark's Energy and Climate Outlook 2019, Energy Statistics 2017, QVARTZ analysis.

The energy and utilities sector's approach

The sector roadmap of the energy and utilities sector uses the 70% reduction target as the absolute premise of the analysis forming the basis of the proposed reduction initiatives for the sector. The energy and utilities sector wants to supply Danish society with renewable energy corresponding to the amount of fossil energy that will have to be phased out in order to achieve this target.

The analysis is primarily based on Denmark's Energy and Climate Outlook. In addition, the energy and utilities sector has identified several initiatives within the sector itself that could contribute to further reductions. In order to present a specific estimate of how much renewable energy it takes to replace enough fossil energy for Denmark to reach its overall target, the analysis further uses a displacement model developed by Ea Energy Analyses. The model shows how cross-sectoral initiatives can contribute to reducing carbon emissions towards 2030 and provides an assessment of the related costs.

There are several paths to achieving the 70% reduction target. In its sector roadmap, the energy and utilities sector assumes that the 70% reduction target will be achieved without imposing significant restrictions on the Danish consumption or on activities in agriculture, industry and the transport sector. For example, the model does not assume that agriculture will transition to a much larger proportion of plant-based production or that the total number of vehicles in Denmark will be significantly reduced. The overall assumptions of the sector roadmap are described in more detail in the methodology section.

According to the displacement model (Figure 2), Denmark will be capable of reducing its carbon emissions by 64% by 2030 using relatively well-known and scaled solutions. These include energy efficiency improvements, replacing fossil fuels with electric heat pumps and replacing vehicles powered by fossil fuels with electric vehicles as well as increased use of biogas.

The remaining 6% must be achieved by exploring technologies that are currently relatively immature or by scaling more mature technologies to a level which currently seems difficult to reach. These include immature technologies such as Power-to-X and carbon capture and phasing in significantly more electric vehicles by 2030 (500,000) than assumed (1 million) in the 64% reduction estimate. If one or more of the proposed initiatives are not implemented, they will have to be replaced by other initiatives with equivalent reduction potential in order for Denmark to reach its 70% reduction target by 2030.

Reaching a reduction of 64% is in itself a great task, and going the extra mile to reach 70% with 1.5 million electric vehicles, Power-to-X and carbon capture is even more ambitious. But all of the proposed initiatives can be implemented. At the same time, all three initiatives are absolutely vital to achieving further reductions beyond 2030 and achieving the target of full climate neutrality by 2050. The amount of reductions produced by each of the three initiatives towards 2030 is not as important as it is to include all three initiatives in the strategic and political planning towards 2050. The reduction measures are presented in Figure 2.

Our path towards 2030 will lead us through an accelerated green transformation resulting in significantly increased complexity and variability. The displacement model cannot, of course, predict the state of the world in 2030, it is merely a cost-effective estimate of what a green Denmark might look like in 2030. In particular, it is very difficult to estimate which technologies will be preferred by the market in 2030. The sample space of technologies that can help Denmark achieve its 70% reduction target is vast, and great care must be taken not to make any firm decisions on use of specific solutions. This is particularly true of the Power-to-X fuels because it is still uncertain which green fuels will be preferred by heavy transport, aviation and shipping. As these modes of transport extend beyond Denmark's borders, the demand for Power-to-X fuels will also depend on the international market. Similarly, new research may lead to significant reductions of non-energy-related emissions in agriculture and from environmental and industrial processes, which may impact the 'building blocks' of the displacement model. Moreover, it cannot be ruled out that the green transformation will lead to a reduction in private motoring which will in turn reduce the number of electric vehicles compared to the assumption. The displacement model and actions will thus have to be adjusted along the way as technologies, markets, businesses and consumer preferences develop.

In return, the model provides a detailed estimate of a cost-effective way to achieve the reductions necessary for Denmark to meet its 70% reduction target. The upside is that it can contribute to making an ambitious target more tangible by proposing specific initiatives and actions. The model provides a basis for understanding the necessary trade-offs and priorities, while offering a starting point that can be adjusted as technologies and markets develop in the coming years.

Figure 2.

Known initiatives can push Denmark towards a 64% reduction. Further initiatives are needed to achieve a 70% reduction and a 100% reduction

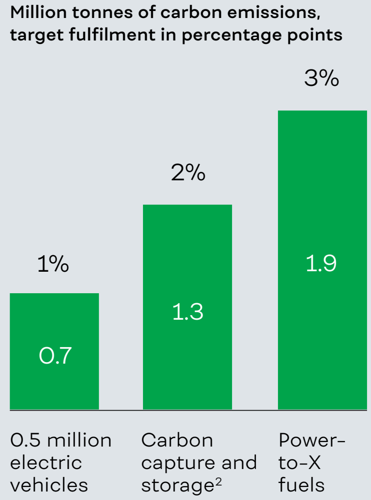
Initiatives to achieve 64% reduction by **2030**[1]

64%

- Heat pumps for heating and industry
- 1 million electric and hybrid vehicles
- Electrified public and heavy transport
- 15% blending of biofuels
- Biogas for housing, industry and heavy transport
- Separation of plastics from waste-to-energy systems
- Energy efficiency improvements (building insulation, manufacturing, transport, etc.)

Further initiatives to achieve 70% reduction by **2030**

70%



- Additional 0.5 million electric vehicles
- Carbon capture and storage[2]
- Power-to-X fuels

Initiatives to achieve 100% reduction by **2050**

100%

All initiatives are necessary to achieve further reductions beyond 2030 and full climate neutrality by 2050

64% — 70% — 100%

[1] The solutions shown are not exhaustive in order to achieve a 64% reduction.
[2] Here shown for the energy and utilities sector. Additional carbon capture and storage may also be necessary in heavy industry.
Source: Ea Energy Analyses; QVARTZ analysis.

The aim of the energy and utilities sector in estimating the actions to be taken, including in other sectors, is to estimate the energy demand in 2030. This is done to answer the question of how much fossil energy it is possible to replace with green energy and if the infrastructure – power, heating and gas – will be able to handle a future, increased energy demand.

Notwithstanding all of the uncertainties, if the energy and utilities sector must be capable of meeting the future energy demand, we need a reliable estimate of the future energy demand now to provide a basis for the energy and utilities sector's future strategy and planning. Investment decisions in the sector do not only require a lot of capital, they also have a very long lead time. For example, investments in power infrastructure typically have an investment horizon of 30-50 years, and it generally takes eight years to plan, procure and construct an offshore wind farm. Similarly, it takes several years to plan and implement significant changes in the heating sector.

Once the work of all 13 climate partnerships has been completed, the estimate of the future energy demand must be updated based on all of the initiatives in the sector roadmaps. Ultimately, the decisions made in other sectors will decide the build-out of green energy forms and infrastructure to be delivered by the energy and utilities sector. Furthermore, the other 12 sector roadmaps may recommend new solutions that could lead to technological leaps, more energy-efficient technologies or greater emissions reductions from agriculture than assumed in this analysis.

The following chapter describes how the energy and utilities sector, through six specific initiatives, may reduce its carbon emissions by approximately 13 million tonnes between 2019 and 2030, delivering about half of the carbon emission reductions necessary for Denmark to reach its 70% reduction target.

It generally takes eight years to plan, procure and construct an offshore wind farm

2.0 Denmark halfway to meeting target by ensuring a fossil-free energy and utilities sector by 2030

Through energy efficiency improvements that have reduced the energy demand significantly, the Danish energy and utilities sector's carbon emissions have already been cut by 58% from 32 million tonnes in 1990 to 13 million tonnes in 2019. With continued energy efficiency improvements and further initiatives to phase out fossil energy, the energy and utilities sector may be able to reduce its emissions to approximately 1 million tonnes by 2030. This translates to a reduction of more than 95% compared to the 1990 level. The initiatives include phasing out the remaining coal used for power stations and natural gas for district heating production, phasing out natural gas and oil in individual heating systems, carbon capture at large point sources, reduction of the use of plastics in waste-to-energy systems and reduction of the amount of natural gas used for energy production in the North Sea. The reductions achieved in the energy and utilities sector are expected to account for approximately half of the total reductions required in Denmark from 2019 to 2030.

2.1. Since 1990, the energy and utilities sector has reduced its carbon emissions by 58%

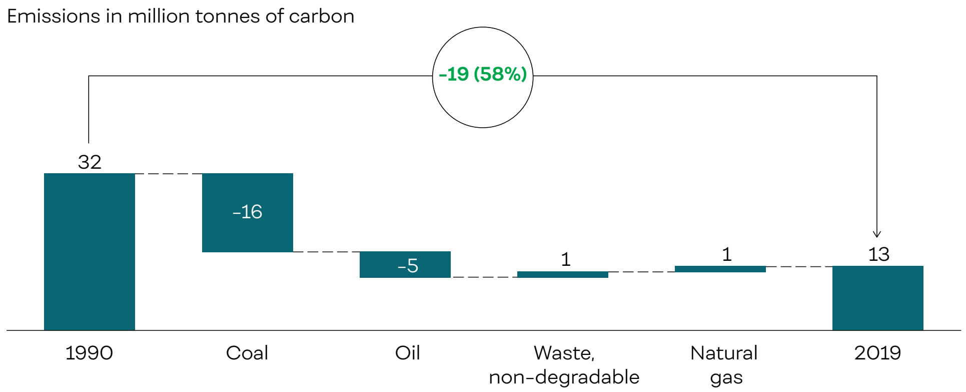
The energy and utilities sector has reduced its carbon emissions from 32 million tonnes in 1990 to 13 million tonnes in 2019, corresponding to a reduction of 19 million tonnes or 58%. The reduction is mainly achieved by means of energy efficiency improvements which have reduced the overall energy need and by means of significant replacement of fossil fuels with renewable energy in the overall energy mix. This has resulted in a significant phase-out of coal and oil, see Figure 3.

Phasing out coal has reduced carbon emissions by 16 million tonnes, which has primarily been realised at a number of power stations, e.g. Studstrup, Avedøre 1 and Stigsnæs. Phasing out oil has reduced carbon emissions by 5 million tonnes, primarily from residential boilers where energy efficiency has been improved and oil replaced by, for example, district heating. Concurrently with phasing out coal and oil, non-degradable waste (1 million tonnes) and natural gas (1 million tonnes) have been introduced in energy production, resulting in a slight increase in carbon emissions. However, both have been introduced as direct substitutes for coal and oil, thereby reducing total carbon emissions. The 19 million tonnes reduction in carbon emissions achieved in the energy and utilities sector between 1990 and 2019 constitutes approximately 80% of the total Danish carbon emissions reduction since 1990.

Energy efficiency improvements remain a critical parameter

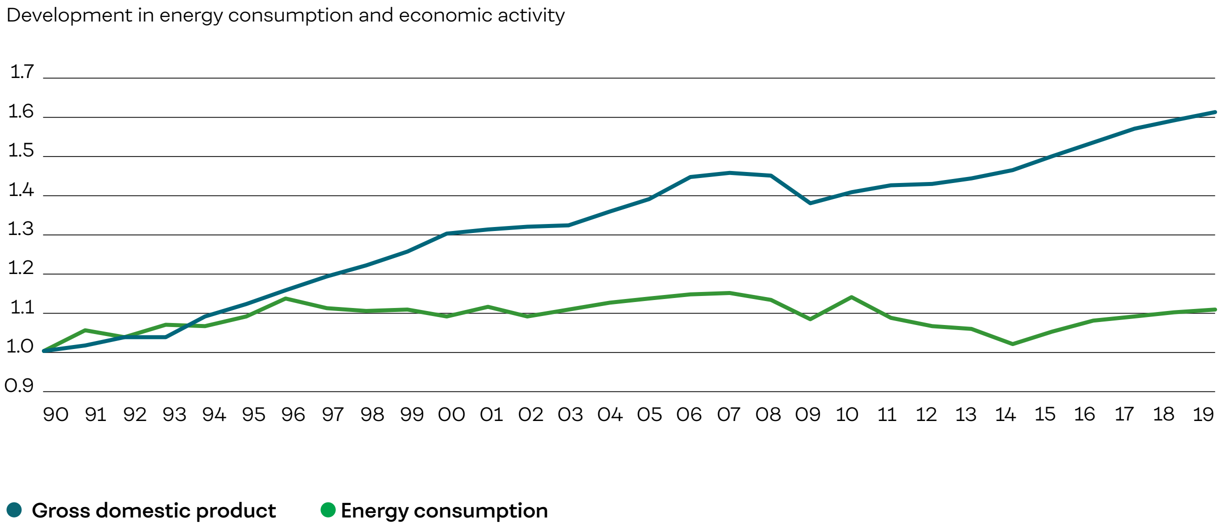
Since 1990, Denmark has managed to create economic growth and prosperity without significantly increasing energy consumption. This development is driven by Danish businesses which have led the way and invested in energy-efficient technologies that have significantly reduced the energy demand. At the same time, building regulations have improved the energy performance of buildings. From 1990 to 2019, Denmark's gross domestic product increased by approximately 61%, while the total energy consumption, including transport, only increased by 10%. Seen in isolation, the energy consumption in buildings and businesses only increased by 2% over that period of time. The energy efficiency improvement efforts have also reduced the amount of energy to be supplied by the energy and utilities sector

Figure 3. **Carbon emissions by energy source in the energy and utilities sector from 1990 to 2019**



Source: The Danish Energy Agency (2019): Denmark's Energy and Climate Outlook; Danish Energy; QVARTZ analysis.

Figure 4. **Energy consumption and economic activity in Denmark**



Note: Indexed development; 1990=100.
Note: GDP 2010 price level, Statistics Denmark (NAN1), fixed prices.
Source: The Danish Energy Agency (2019): Denmark's Energy and Climate Outlook; Danish Energy Agency (2018): Energy statistics; Statistics Denmark; Danish Energy; QVARTZ analysis.

by approximately 6% between 1990 and 2018[2.1], even in a period of marked social and economic growth.

The significant energy efficiency improvements are primarily the result of energy savings in business, for example, production process optimisation, new building energy performance standards, energy renovation of existing buildings and energy optimisation of building installations and building operations. Leading Danish businesses, such as Danfoss, Grundfos, Rockwool, Velux and others, have supported the energy efficiency improvements in Denmark and globally.

Towards 2030, there is still potential to pursue energy efficiency improvements in industrial processes, buildings and housing to reduce the energy demand. A report prepared by Danfoss in 2020 states that *"Between 2020 and 2030, energy efficiency investments are estimated to result in socio-economic savings of around DKK 14 billion compared to the cost of an increased build-out of renewable energy (…), including saved costs for the expansion of power grid and energy storage"*[2.2].

Going forward, continued energy efficiency improvements, choosing efficient green solutions in combination with demand-side response and digitisation will be part of the solution to limiting the need to build out renewable energy and expand the energy infrastructure. Furthermore, the future will also see the development of new interaction patterns across supply forms, energy suppliers and energy customers. A closer connection between different supply forms will play an important role in limiting the need for build-out and expansion.

For example, district heating producers will become large power customers with a unique chance to use fluctuating power prices to produce district heating for their heat stores whenever the price is low.

Replacement with renewable energy sources

Seen in isolation, replacing fossil fuels with renewable energy has reduced carbon emissions in the energy and utilities sector. The share of renewable energy in the energy produced by the energy and utilities sector has increased from 9% in 1990 to 59% in 2018, see Figure 5. Over the same period of time, we have seen a significant reduction in particularly the share of coal and oil.

We have succeeded in realising a major transformation from fossil fuels to renewable energy without compromising the high Danish security of supply and with limited energy expenditure increases (excluding taxes) for Danish consumers and businesses. At the same time, the transformation has happened at a speed and a level of ambition which means that Denmark today is internationally recognised for its sustainable energy system[2.3].

The great carbon reductions achieved in the energy and utilities sector mean that the most cost-efficient initiatives have already been implemented. How further reductions towards 2030 can be implemented is described in the next section.

2.2. The energy and utilities sector can reduce its carbon emissions by more than 95% towards 2030

The energy and utilities sector's 2030 vision is to reduce its carbon emissions by at least 95% compared to 1990. The energy and utilities sector has identified six overall reduction initiatives with a total technical reduction potential of almost 13 million tonnes. A full implementation of the initiatives can reduce the energy and utilities sector's emissions by more than 95% compared to 1990, see Figure 6.

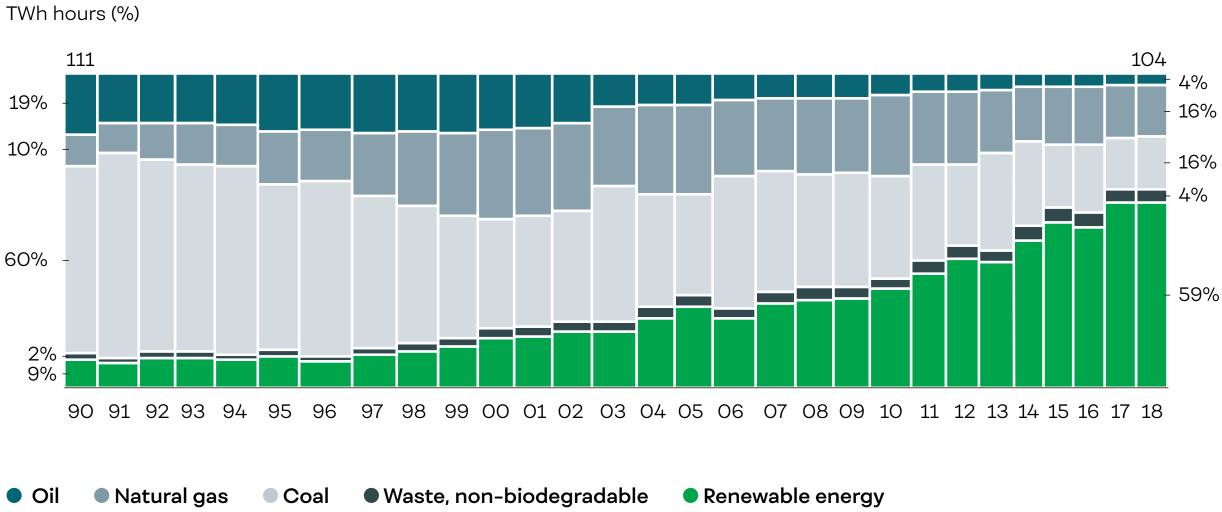
Most of the reductions (10 million tonnes) are achieved by phasing out fossil fuels in power and district heating production and in individual heating. Other reductions are achieved through improved plastics separation and recycling from waste which can potentially reduce emissions from waste-to-energy plants (1 million tonnes). Furthermore, carbon capture systems must be established to capture carbon directly from large emission sources (1 million tonnes), and the production of oil and natural gas in the North Sea which is currently based on gas turbines must be optimised and partially electrified to reduce the use of natural gas in the production (1 million tonnes).

2.1 From 111 TWh in 1990 to 104 TWh in 2018, as illustrated in Figure 5. Converted from petajoule. The total Danish energy consumption was reduced by approximately 5% from approximately 228 TWh in 1990 to approximately 223 TWh in 2018. Energy statistics 2018, Danish Energy Agency.

2.2 Socio-economic savings of DKK 14 billion is calculated on the basis of other reduction assumptions than those used in this report, which is why the figure may not necessarily be reproduceable.

2.3 World Energy Trilemma Index, (2018): The World Energy Council has named Denmark as having one of the world's best energy systems in terms of how safe and reliable it is, how affordable and accessible it is, and how environmentally sustainable it is.

Figure 5. **Fuel sources for energy production in the energy and utilities sector from 1990 to 2018**



Note: Column widths vary with fluctuations in total annual energy consumption.
Note: Biomass accounted for 57% of renewable energy in 2018.
Source: Denmark's Energy and Climate Outlook 2019: Energy statistics. Actual gross energy consumption; Danish Energy; QVARTZ analysis.

Of these 13 million tonnes, the Danish Energy Agency's projection of the energy development towards 2030 already includes reduced emissions of 7.5 million tonnes in the energy and utilities sector, see Figure 7. The remaining 5.4 million tonnes of emission reductions will be achieved through the additional identified initiatives that the energy and utilities sector can contribute towards achieving the 70% reduction target.

All of the reduction initiatives are considered technologically feasible and financially justifiable compared to the costs of reductions in other parts of the Danish society, e.g. industry, agriculture and transport. This does not mean that these reductions will materialise on their own. On the contrary, the 13 million reduction corresponds to about half of what is needed in Denmark towards 2030 and will require a significant transformation of the Danish energy and utilities sector. In order to support this transformation and secure the necessary investments, certain technologies must be further matured and the necessary framework conditions must be in place. The following sections describe six reduction initiatives that can take the energy and utilities sector all the way to a reduction of more than 95% by 2030.

2.2.1. Phasing out coal in CHP plants

Phasing out coal in CHP plants is expected to contribute to a reduction of almost 6 million tonnes towards 2030. The first 2.5 million tonnes of reductions were achieved in 2019 through replacement of coal at Asnæs and Amagerværket power stations. At the beginning of 2020, three Danish CHP plants remain that use significant amounts of coal. They are Nordjyllandsværket power station, Esbjerg power station and Fynsværket power station. When these CHP plants phase out coal, the energy and utilities sector's carbon emissions will be reduced by a further approximately 3.3 million tonnes. Phasing out coal in CHP plants is also included in the Danish Energy Agency's basis projection of energy consumption towards 2030, except phasing out coal at Fynsværket power station[2.4].

Plans for phasing out coal are already available at all three CHP plants:

- Esbjerg power station will phase out coal by 2023. Investigations are ongoing into the possibility of replacing coal with commercial-scale seawater heat pumps combined with biomass boilers.
- Fynsværket plans to phase out coal by 2025. Plans for replacing coal are not final, but heat pumps, increased use of waste heat and biomass are being considered.
- Nordjyllandsværket plans to phase out coal by 2028 and is investigating the possibility of replacing coal with geothermal energy, commercial-scale heat pumps and waste heat from Aalborg Portland's production.

The power stations' ambitions to phase out coal are all challenged by the task of establishing new production capacity to replace the capacity of the current large power plant units. At the same time, power stations are often located in densely built-up areas where it is difficult and expensive to find suitable sites for new and often space-demanding production facilities.

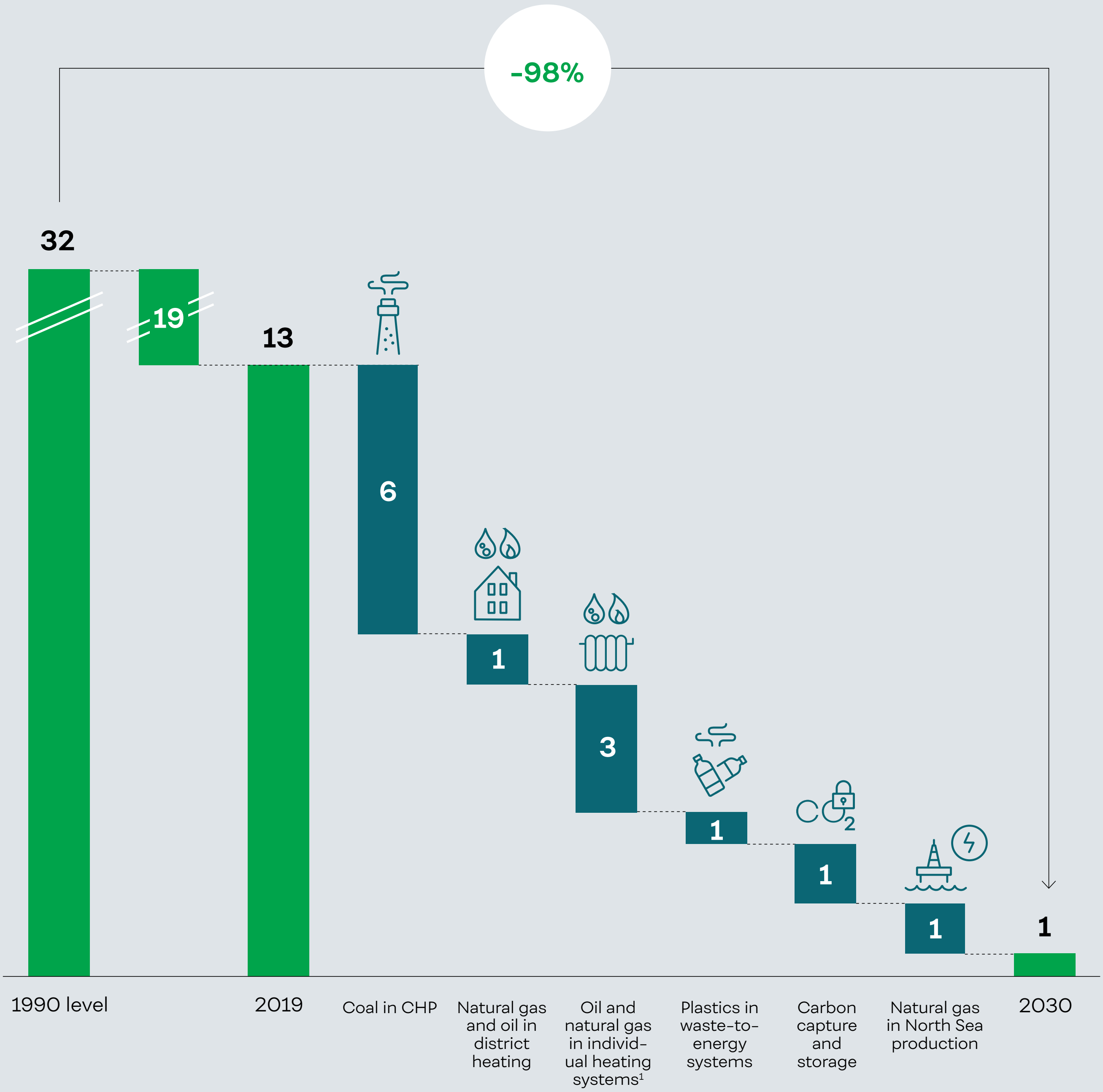
Future heating solutions in major cities are expected to be more diverse than earlier. The trend is to invest in several small distributed systems to replace coal-fired power plant units. Local conditions and possibilities will decide the alternative production capacity to be established. Examples of production capacity are waste heat from e.g. industry, data centres, cold stores or Power-to-X plants. It may also be areas with the right geological conditions for geothermal energy or areas with large heat storage capacity. Finally, waste-to-energy or biomass-fired plants may also be used for heat production. Depending on the alternative production capacity installed, district heating networks will in some places have to be converted to integrate new heat producers as described in Chapter 4.

2.4 Denmark's Energy and Climate Outlook 2019.

Figure 6.

The energy and utilities sector may reduce its emissions by more than 95% towards 2030

Million tonnes of carbon emissions



[1] Individual heating systems in homes and businesses.

Note: The residual value shown in the figure is 1 million tonnes, although the combined impact of initiatives is 13 million tonnes due to rounding off. Remaining emissions of around 0.4 million tonnes from individual heating systems are expected to be displaced through energy efficiency improvements in other sectors (buildings and industry), reducing the need for heating. Remaining emissions comprise North Sea natural gas production (0.6 million tonnes), waste (0.4 million tonnes) and oil in oil-fired boilers as well as for start-up and emergency load (>0.1 million tonnes). Remaining emissions from fossil fuels exceed the residual shown as some of the CCS reduction (0.8 million tonnes) comes from biomass and therefore counts as negative emissions.

Source: Denmark's Energy and Climate Outlook 2019; Ea Energy Analyses; calculations made by Danish Energy; QVARTZ analysis.

In order to phase out coal, geothermal energy and heat pump technologies must be sufficiently matured to produce at larger scale than previously seen in Denmark. Seawater and air-to-water heat pumps are feasible in most places, but their installation poses some challenges and none of these types of heat pumps are currently used in large-scale plants. As both types are driven by ambient heat, their efficiency decreases significantly in cold weather when the need for heating is largest. Several challenges will therefore need to be addressed before the technologies have matured sufficiently, e.g. icing when heat is extracted from cold seawater as well as problems with large cold areas on large air-to-water heat pumps.

The framework conditions of the transformation must be clarified if we are to be able to realise our ambitions of phasing out coal. The phasing out of coal may also lead to increased prices of heating for individual business customer groups.

2.2.2. Phasing out natural gas and oil in district heating

Phasing out natural gas and oil in district heating production is expected to contribute to a reduction in carbon emissions of around 1 million tonnes towards 2030. Natural gas for production of district heating is mainly used at plants outside the major cities (decentralised areas) for combined heat and power production. At the same time, the majority of the Danish district heating companies are used for peak loads and as peak reserves which also involves a minor oil volume.

Phasing out natural gas in district heating

Replacing natural gas in decentralised district heating production with public heat pumps and solar power could displace 0.6 million tonnes of carbon emissions[2.5]. In decentralised areas this would mainly be achieved by air-to-water heat pumps which are currently sufficiently mature to be implemented at the necessary scale. Heat pumps based on groundwater or waste water are also a viable option in areas where these heat sources are available. Also, the build-out of heat pumps in decentralised areas will not be limited by space issues as will be the case in larger cities. However, a large build-out of heat pumps requires that businesses acquire specialised knowledge and competences within operation of these new technologies, which may be a challenge especially for small district heating providers. The large demand for heat pumps has also proven to be a challenge in the current market situation, but this is not expected to be an issue in the long term. The 0.6 million-tonne reduction in carbon emissions is also included in Denmark's Energy and Climate Outlook 2019.

Phasing out remaining natural gas in combined heat and power production

In addition to the 0.6 million tonnes of reduced carbon emissions, it is possible to achieve reductions of a further approximately 0.2 tonnes[2.7]. This is the remaining natural gas consumption used for district heating and power generation at the CHP plants contributing to maintaining security of supply[2.6]. This natural gas consumption can be phased out if the remaining power plants switch to biogas or invest in small batteries for power storage and increased use of other production units for heat production (e.g. heat pumps). Even though the price of batteries is expected to be reduced towards 2030, this technology is not sufficiently mature to provide an independent means to ensure security of supply until after 2030. For this reason, the energy and utilities sector considers cost-effective phase-out of natural gas in the remaining part of the combined heat and power production to be achieved by replacing 14% of the power capacity with batteries, while converting the remaining 86% to biogas.

Natural gas and oil for peak load and peak reserve

The last natural gas and oil are used for peak load and peak reserve. Phasing out gas and oil for this application will reduce carbon emissions by another 0.3 million tonnes[2.7]. In replacement, electric heating elements or biogas can be introduced in existing natural gas-fired boilers. Phasing out natural gas will therefore either require investing in new production

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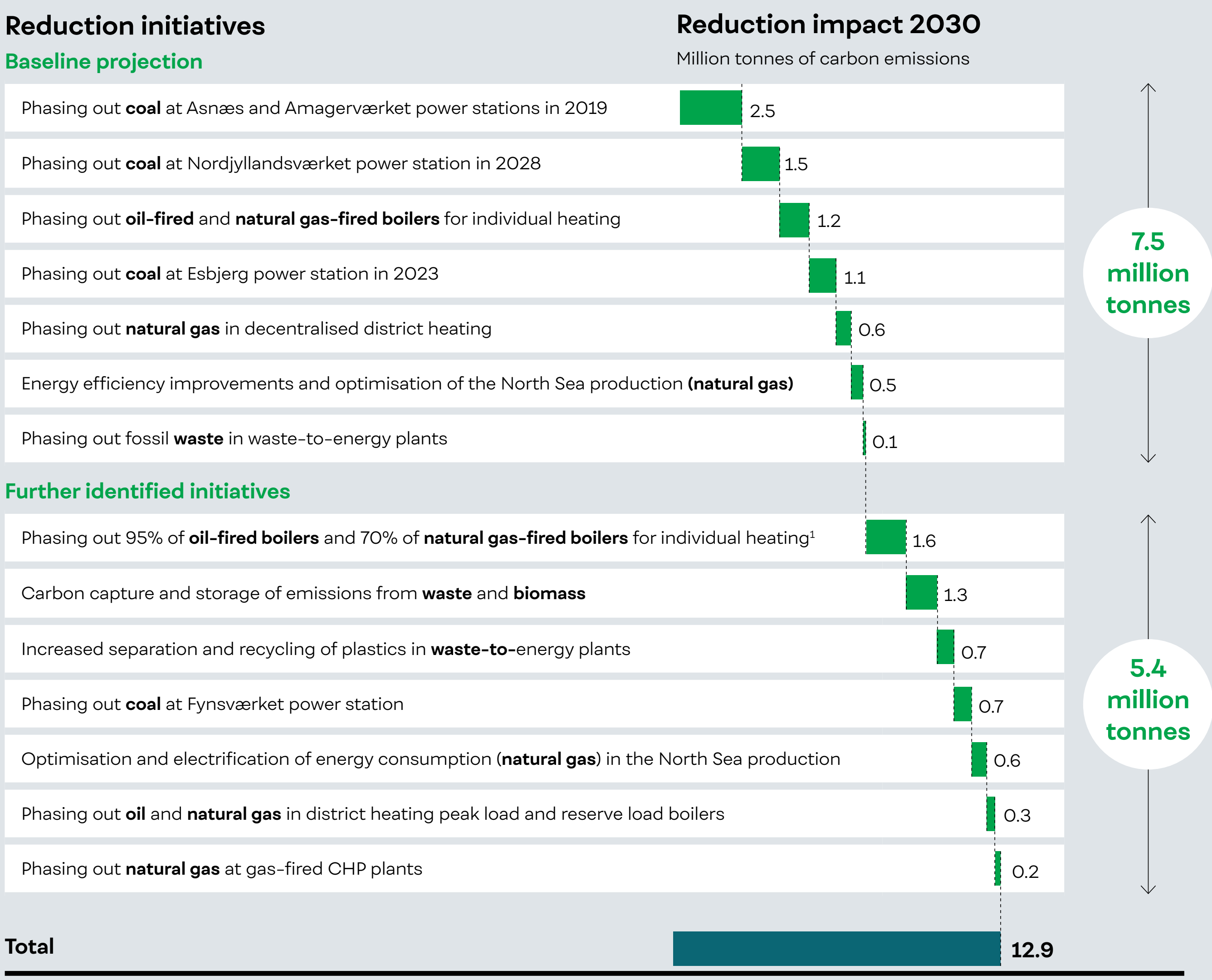
2.5 Denmark's Energy and Climate Outlook 2019.

2.6 Denmark's Energy and Climate Outlook 2019.

2.7 Denmark's Energy and Climate Outlook 2019; Danish Energy analysis based on Denmark's Energy and Climate Outlook 2019; QVARTZ analysis.

Figure 7.

Carbon reductions in the energy and utilities sector towards 2030



[1] Remaining gas-fired boilers use biogas.
Source: Denmark's Energy and Climate Outlook 2019; Ea Energy Analyses; calculations made by Danish Energy; QVARTZ analysis.

capacity or lead to increased fuel costs after switching to the more expensive biogas. The energy and utilities sector estimates that phase-out can be achieved using approximately 70% electric heating elements and 30% conversion to biogas. In addition, in order to ensure cost-effective phase-out of natural gas and oil, it is essential that district heating companies combine the use of electric heating elements and/or biogas boilers with the use of heat storage. Heat storage allows businesses to increase their consumption flexibility, using power when it is cheap and when there is spare grid capacity. In this way it is also possible to limit the need for expanding the power grid. The use of heat storage can also reduce the district heating company's general demand for peak load capacity. Smart operation of the district heating system and customer flexibility through digitisation can reduce this need even further.

2.2.3. Phasing out natural gas and oil in individual heating systems

Phasing out natural gas and oil in individual heating systems can reduce carbon emissions by approximately 3 million tonnes towards 2030. There are currently approximately 375,000 natural gas-fired boilers and 80,000 oil-fired boilers in Denmark used for heating in households and businesses located outside district heating areas, i.e. for individual heating. The reduction is achieved by replacing 70% of all natural gas-fired boilers for individual heating with alternative heating, for example, heat pumps or district heating, and by replacing natural gas with green biogas in the remaining 30% of natural gas-fired boilers. In addition, about 95% of all oil-fired boilers will have to be replaced with alternative heating sources such as heat pumps. Unlike natural gas there is no green alternative to domestic fuel oil in oil-fired boilers. Therefore, it is expected that there will still be a small amount of oil used for individual heating in 2030. Replacing 70% of natural gas-fired boilers with other energy sources corresponds to reducing the total number of households using natural gas-fired boilers from 375,000 households today to 100,000 households in 2030. Reducing the number of oil-fired boilers by 95% corresponds to reducing the total number of households using oil-fired boilers from 80,000 today to approximately 4,000 in 2030. District heating is assumed to replace approximately 140,000 oil or natural gas-fired boilers, while heat pumps will replace approximately 210,000 boilers. Of the approximately 3 million tonnes of reduced carbon emissions, 1.2 million tonnes are included in Denmark's Energy and Climate Outlook.[2.8]

In certain areas, the accelerated replacement of individual natural gas-fired boilers with heat pumps or district heating will entail substantial additional costs. Therefore, biogas will be used as replacement instead. The role of biogas in heating beyond 2030 is uncertain.

Phasing out 95% of oil-fired boilers can only be realised through a significantly accelerated replacement of boilers as some boilers will have to be phased out before they reach the end of their service life. Consequently, it is not realistic to replace 100% of all boilers by 2030. The accelerated replacement increases the cost of replacement.

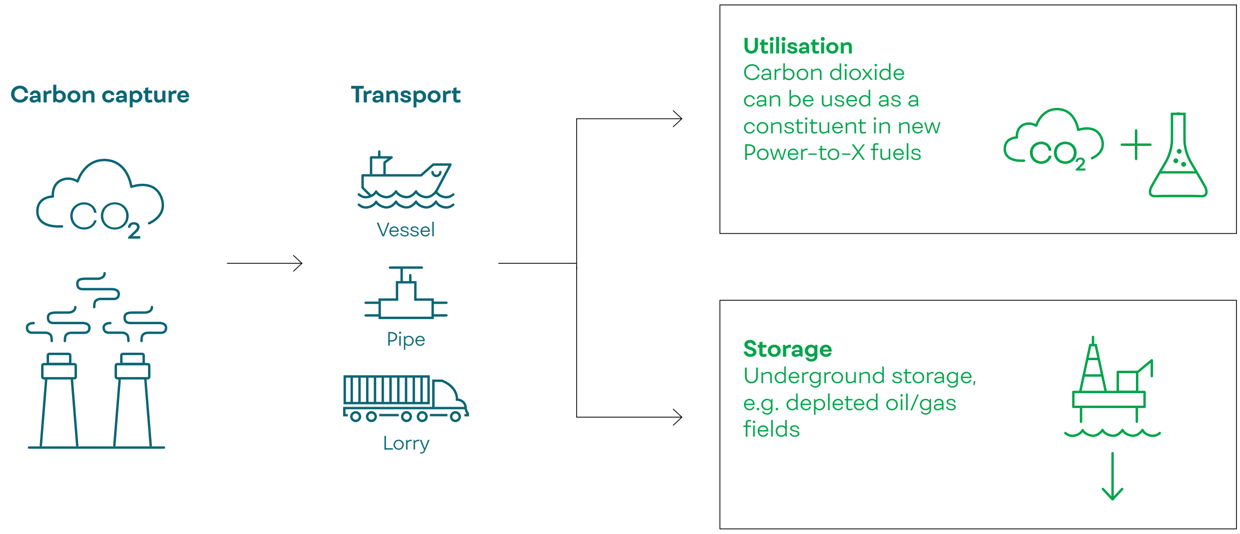
Realising this replacement of boilers requires financial framework conditions encouraging conversion to alternative heating from either heat pumps or green district heating before the boilers reach the end of their service life, and the framework conditions must allow for the remaining natural gas customers to use biogas in their natural gas-fired boilers. Beyond 2030 and towards 2050, it is assumed that only a minor share of biogas resources will be used for residential heating.

2.2.4. Reducing plastics in waste-to-energy plants

Incineration of waste in energy production results in carbon emissions from fossil waste fractions – mainly plastics. These emissions can be reduced through improved separation and recycling. Improved separation and recycling of plastics is estimated to reduce the emissions from waste-to-energy plants by approximately 0.7 million tonnes towards 2030. This reduction can also be achieved through increased use of biogenic (i.e. non-fossil) plastics to replace fossil plastics because incineration of biogenic plastics does not produce carbon emissions.

2.8 Denmark's Energy and Climate Outlook 2019: Further acceleration of the replacement can reduce emissions by 1.6 million tonnes towards 2030 (Ea Energy Analyses (2019): Muligheder og omkostninger ved drivhusgasreduktionstiltag frem mod 2030).

Figure 8. **Carbon capture (storage and utilisation)**



Note: The figure shows storage and utilisation potential for carbon capture. The identified reduction initiatives in the energy and utilities sector towards 2030 only include storage of 1.3 million tonnes of captured carbon.

Figure 9. **Remaining carbon emissions in the energy and utilities sector by 2030**

Source of carbon emissions	Expected carbon emissions 2030 (Million tonnes of carbon emissions)
Residual carbon emissions from rigs **(natural gas)** in the North Sea	0.6
Fossil **waste** (plastics, etc.) in waste-to-energy plants	0.4
Oil consumption for start-up and emergency load in CHP plants	0.07
Oil-fired boiler for individual heating (last 5%)	0.03
Total	1.1

Source: Denmark's Energy and Climate Outlook 2019; Danish Energy analysis based on Denmark's Energy and Climate Outlook 2019; QVARTZ analysis.

Denmark's Energy and Climate Outlook projects emissions from fossil waste to be reduced by approximately 0.1 million tonnes towards 2030[2.9] The energy and utilities sector estimates that improved separation and recycling can reduce emissions from waste to energy with an additional 50%[2.10], equivalent to 0.7 million tonnes of carbon emissions a year[2.11]. The separated fossil fractions are replaced with equivalent volumes of biogenic fractions. This means that the expected amount of energy produced at waste-to-energy plants remains unaffected by the improved separation.

Improved separation is achieved through further separation of plastics from other waste in households and in businesses[2.12]. Separation options and information should be standardised across local authorities to ensure that the plastics are separated efficiently ensuring a high quality. Separated plastics are then sent to a separation system for further separation before being resold and recycled. Such separation systems can be established in Denmark, but the separated plastics may also be sent abroad, for example to Germany where several systems are already in operation.

2.2.5. Capturing carbon

Carbon capture, storage and utilisation is expected to reduce emissions from the energy and utilities sector by 1.3 million tonnes towards 2030. As described in the previous section on plastics in waste, not all fossil waste can be separated, making it impossible to completely eliminate carbon emissions from waste-to-energy plants. However, carbon emissions from incineration of fossil waste can be captured and either stored underground or used as a carbon source for the production of, among other things, Power-to-X instead of being discharged into the atmosphere. These methods are also referred to as Carbon Capture and Utilisation (CCU) or Carbon Capture and Storage (CCS). When installing carbon capture at a waste-to-energy plant, the carbon capture system will capture all carbon emissions from the plant, i.e. carbon emissions from both fossil waste and biogenic waste. Carbon capture in other sectors, e.g. heavy industry, may also hold great potential, making the total reduction in carbon emissions across sectors far greater than the 1.3 million tonnes included in the sector roadmap for the energy and utilities sector.

Carbon emissions from incineration of organic sources such as biomass and biogenic waste that are captured and stored will count as negative carbon emissions because the organic sources absorbed carbon dioxide while growing which is then permanently stored in the ground after incineration.

Denmark has no commercial-scale carbon capture systems, but on a global scale there are approximately 20 commercial-scale carbon capture systems in operation with more than 30 new systems planned and under construction. This technology is thus known but not yet fully mature.

Introducing the technology in Denmark will make it possible to achieve the 1.3 million-tonne reduction in carbon emissions in the energy and utilities sector. This requires carbon capture to be installed at one of the largest waste-to-energy plants and at one unit at a central biomass-fired CHP plant, respectively. Alternatively, the technology can be implemented in several smaller units if this proves cost-effective. The total reduction potential is expected to be greater after 2030 when the technology is expected to be much more mature.

Although the technology is not yet used in Denmark, the energy and utilities sector estimates that design and installation could, in principle, commence in the near future and be operational by 2030. The construction of a cost-effective, overall system for the utilisation and storage of carbon dioxide – including transport infrastructure – requires coordination across investors and operators. Furthermore, regulation of the supply sector must not constitute a barrier to carbon

2.9 Denmark's Energy and Climate Outlook 2019 expects emissions from fossil waste to constitute 1.6 million tonnes in 2030. This corresponds to 56% of total emissions from heat and power generation in 2030.

2.10 This does not include waste-to-energy plants processing special or hazardous waste (0.2 million tonnes of carbon emissions annually). The remaining emissions from incineration of waste come from dedicated or multi-fired waste-to-energy plants, producing heat and power from waste, corresponding to carbon emissions of 1.4 million tonnes a year.

2.11 Ea Energy Analyses (2019): Muligheder og omkostninger ved drivhusgasreduktionstiltag frem mod 2030.

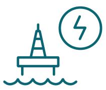
2.12 For further details on separation, please refer to the climate partnership on waste, water and circular economy.

capture at point sources, and funding must be provided in the form of investment aid to ensure that waste or heating customers are not expected to pay all of the investment costs.

Geological formations in the Danish underground are particularly suitable for storing captured carbon[2.13]. The Danish sector of the North Sea holds great potential for storing captured carbon in depleted oil/gas fields. The Danish oil and gas industry assesses the total potential for development and storage to be 5 million tonnes of carbon emissions annually by 2030[2.14], potentially storing captured carbon from the energy and utilities sector and further approximately 4 million tonnes of captured carbon from other sectors. In addition, plans for establishment of storage capacity in Norway are advanced. This storage capacity would also be able to accommodate captured carbon from Danish sources.

Costs remain relatively high, but are expected to decrease as the technology develops. Developing the method to commercial scale and using the same storage and transport infrastructure for storage of carbon emissions from many sources would allow for significant advantages of scale and reduced unit costs. However, in order to do this, regulations must promote incentives for further development and scaling of the method.

Utilisation of captured carbon in the production of green fuels in Power-to-X plants is described in detail in Chapter 4.



2.2.6. Optimising and electrifying the North Sea oil and natural gas production

Optimisation and electrification of the North Sea oil and natural gas production could potentially reduce carbon emissions by approximately 1 million tonnes towards 2030. The extraction of oil and natural gas from the Danish sector of the North Sea requires large quantities of power for operation of the oil rigs. Currently this power is produced locally using gas turbines. Today, the energy used to power the extraction produces 1.6 million tonnes of carbon emissions in total. The Danish Energy Agency projects that it is possible to reduce these emissions by approximately 0.5 million tonnes[2.15] through optimisation and introduction of efficiency measures in operating production[2.16]. This can be achieved by optimising and simplifying existing infrastructure, including the ongoing construction of the Tyra Hub facilities and the reduction of methane emissions from production facilities and tankers. Integrated digital solutions and data-driven operation and maintenance, as well as supply chain optimisation (helicopters, supply vessels, warehouses, offices, etc.) are expected to further contribute to reducing emissions.

The water depths in the southern part of the North Sea, where a significant part of the Danish oil and natural gas installations are located, are approximately 35 metres. This enables installation of offshore wind turbines and thus electrification. This in combination with ongoing and planned cable and energy hub projects by other market operators can enable conversion to electrical operation at the oil and natural gas installations. The energy and utilities sector estimates a technical reduction potential of up to 0.6 million tonnes by 2030 in addition to the 0.5 million tonnes already estimated by the Danish Energy Agency. Partial or full electrification of Tyra could potentially reduce carbon emissions by 0.1-0.4 million tonnes alone. Natural gas displaced by electrification can instead be exported, potentially displacing other fossil fuels with a higher carbon footprint than natural gas and generating export revenues.

Electrification of offshore installations using wind power requires the production to be connected to renewable energy systems. The total reduction potential of 13 million tonnes from the sector's six initiatives can, under the right circumstances and framework conditions, bring Denmark halfway towards meeting the 2030 target.

2.13 GEUS (2019): Carbon storage in Denmark.
2.14 Oil Gas Denmark analysis.
2.15 Denmark's Energy and Climate Outlook 2019 projects 0.46 million tonnes of carbon emissions.
2.16 Oil Gas Denmark analysis.

2.3. Reducing remaining carbon emissions requires technological innovation

Even with the implementation of the six reduction initiatives, emissions from the energy and utilities sector will have to be reduced by a further 1 million tonnes. At this stage, there is no clear path to reducing carbon emissions from the energy and utilities sector by another approximately 1 million tonnes. Achieving this reduction by 2030 will either require potential replacement technologies that are yet unknown or measures involving restrictions or burdens on individuals and businesses. The plan for achieving the remaining reduction must therefore be adjusted along the way as existing technologies mature and new ones develop.

The remaining 1 million tonnes are distributed on four categories, see Figure 9.

Of the remaining 1 million tonnes, 0.6 million tonnes come from the residual emissions produced by natural gas extraction in the northern part of the North Sea. Electrification of these production platforms is difficult to achieve by 2030 and requires the establishment of additional offshore wind turbines capable of supplying the production platforms with green power. These efforts must also be compared to the life expectancy of the installations.

Furthermore, 0.4 million tonnes of carbon emissions will remain from the incineration of fossil waste. Half of the fossil waste fraction is expected to be removed by separation well before 2030, and 25% of emissions from waste-to-energy plants are expected to be captured and stored. Reducing emissions from the last 25% of fossil waste requires viable solutions for completely separating all of this waste. However, emissions from waste treatment at specialised plants, e.g. for processing special or hazardous waste of approximately 0.2 million tonnes will remain. It is considered difficult to reduce these emissions through separation. Alternatively, carbon capture and storage should be implemented at the remaining waste-to-energy plants.

Finally, a minor share of the residual emissions come from the use of oil for start-up and emergency load at CHP plants as well as in the few remaining oil-fired boilers for individual heating (approximately 4,000) in 2030. Phasing out oil for start-up and emergency load requires early conversion to non-fossil start-up fuels such as synthetic oil. However, no technically viable potential replacement products have been discovered yet. In the long term, a shift in technology to fuel-free base load production can eliminate this requirement.

Phasing out the last 5% of oil-fired boilers for individual heating requires strongly accelerated replacement of oil-fired boilers by owners who cannot be expected to be alert to incentive schemes and/or who have recently invested in such boilers.

In addition to the initiatives mentioned, the energy and utilities sector may support a potential need for further carbon capture and storage in, for example, industry. Recently, Ea Energy Analyses, on behalf of Energifonden[2.17], assessed the CCS potential to be greater than what is assumed in the displacement model[2.18], which also means that the technology will be used on more point sources.

2.4. Transforming the energy and utilities sector requires more renewable energy

Implementing the six reduction initiatives will significantly change the energy sources that the energy and utilities sector relies on. Fossil energy from coal, natural gas, oil and fossil waste is phased out and replaced by heat pumps, industrial waste heat, biogas, solar energy and other renewable energy sources. The consumption of fossil fuels in the energy and utilities sector will be reduced from approximately 40 TWh in 2019 to approximately 5 TWh in 2030, corresponding to a reduction in the use of fossil fuels of approximately 89% between 2019 and 2030[2.19].

In addition to reducing the use of fossil energy sources, the use of biomass will also be reduced from approximately 41 TWh in 2019 to approximately 35 TWh in 2030, corresponding to a 15% reduction. Historically speaking, biomass has been critical in phasing out coal, thus contributing significantly to reducing Denmark's carbon emissions since 1990. Biomass will continue to play a role in 2030, as phasing out fossil energy sources will be extremely costly when it comes to recently established capacity. In addition, the electrification of heating in Denmark's major cities will put pressure on

2.17 Danish fund which supports initiatives and innovative technologies that aim to improve the environment.
2.18 Ea Energy Analyses (2020): Roadmap for electrification in Denmark.
2.19 The reduction is distributed on energy sources as follows: Coal and oil are almost completely phased out from approximately 17 and 2 TWh, respectively, in 2019 to approximately 0 TWh in 2030, natural gas is reduced from approximately 15 TWh in 2019 to approximately 2 TWh in 2030, and fossil waste is reduced from approximately 5 TWh in 2019 to approximately 2 TWh in 2030.

the power grid which will be difficult to handle without using biomass. At the same time, it is very difficult to provide enough heating in the major cities using the currently available replacement technologies as described in the previous section on phasing out coal in CHP plants.

In addition to contributing to energy production, biomass-fired central power stations are also perfect candidates for carbon capture as they will be some of the largest green point sources of carbon emissions in Denmark[2.20]. However, this requires the use of biomass in the energy and utilities sector to be covered by future sustainability criteria legislation.

Unlike biomass, the consumption of other renewable energy sources is expected to increase. This is primarily due to increased electricity demand to power, for example, heat pumps, increased demand for biogas to replace natural gas and biogenic waste to replace fossil waste, etc. The power demand in the energy and utilities sector is expected to increase from approximately 3 TWh in 2019 to approximately 10 TWh in 2030, and increase of approximately 7 TWh. This power must be produced using renewable energy sources such as offshore wind, onshore wind or solar. The increase in power demand of approximately 7 TWh means that an offshore wind farm of 1.5 to 2 times the size of the planned Thor tender must be constructed or that 400-500 new onshore wind turbines must be installed.

The biogas consumption is expected to increase from approximately 3 TWh in 2019 to approximately 7 TWh in 2030, and the consumption of biogenic waste is expected to increase from approximately 6 TWh in 2019 to approximately 7 TWh in 2030.

Chapter 2 described how the energy and utilities sector, through six specific initiatives, may reduce its carbon emissions by approximately 13 million tonnes between 2019 and 2030, delivering about half of the reduction in carbon emissions necessary for Denmark to reach its 70% reduction target. This means that the energy and utilities sector could reduce its total emissions by more than 95% compared to 1990. Achieving such a reduction requires strong cooperation across the sector as well as political framework conditions to support the transformation.

In addition to significantly reducing its carbon emissions, the energy and utilities sector will also be able to contribute to the 70% reduction target by providing the renewable energy needed to complete the full transformation of Denmark, including industry and the transport sector. The next two chapters describe the necessary transformation in other sectors, as well as the necessary build-out of renewable energy and infrastructure.

2.20 Three of four IPCC scenarios include negative emissions via CCS on biogenic point sources as a necessary component in meeting the Paris Agreement's objective of limiting the temperature increase to 1.5 degrees.

3.0 The green transformation of other sectors to help Denmark reach its target

Of the 47 million tonnes of carbon emissions in Denmark today, 33 million tonnes come from other sectors than the energy and utilities sector. Of these, 19 million come from the use of fossil fuels, while 14 million tonnes of carbon emissions are non-energy-related emissions from agriculture, environmental and industrial processes. Even with a potential further reduction of 13 million tonnes of carbon emissions in the energy and utilities sector and an estimated reduction in non-energy-related emissions of 4 million tonnes, the remaining sectors need to cut their use of fossil fuels more or less in half, corresponding to 9 of 19 million tonnes, in order for Denmark to reach its 70% reduction target.

The previous chapter described how the energy and utilities sector can reduce its carbon emissions by 13 million tonnes, corresponding to approximately half of the required Danish reduction towards 2030. The other half – the remaining 13 million tonnes – will have to be found in other sectors such as industry, transport and agriculture. The transformation of other sectors will require large amounts of renewable energy, which the energy and utilities sector is ready to supply. It is impossible to achieve the reduction targets if the power for electric vehicles is generated from coal, or if no biogas is available to replace natural gas.

The other sectors need to present a roadmap on how they plan to achieve the reduction targets in order for the energy and utilities sector to know how much renewable energy will be needed in 2030. The sector roadmaps prepared in the 12 other climate partnerships describe the actual reduction plans, but the energy and utilities sector has estimated how large a build-out of the renewable energy production and infrastructure is required if the sector is to supply the renewable energy required to meet Denmark's 70% reduction target. The estimate will need to be updated with input from the other 12 climate partnerships and will also be reviewed continuously as technologies and markets evolve.

The technological and market-related development and the non-energy-related reductions are expected to impact the speed and volume of the reduction initiatives included in the model. Therefore, the estimate should be construed with this in mind. However, despite the uncertainties, it is clear that phasing out fossil fuels in the energy and utilities sector as well as in other sectors in order to meet the 70% reduction target will require large amounts of renewable energy in the form of power and biogas.

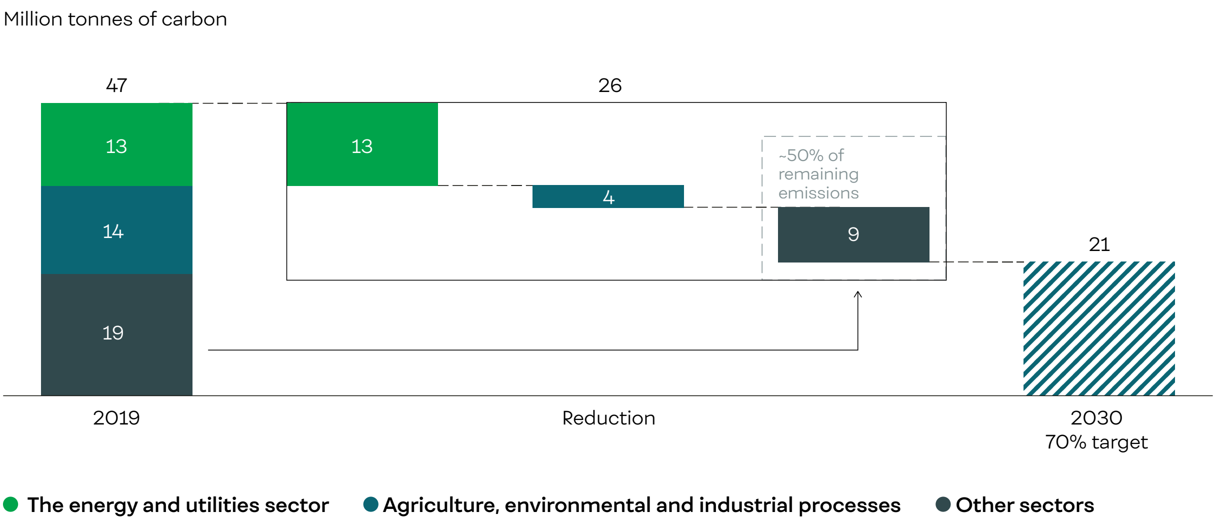
This chapter presents the energy and utilities sector's estimate of how the other sectors can reduce their carbon emissions by 13 million tonnes towards 2030 with a view to estimating the amount of renewable energy it will take to replace fossil fuels in order for Denmark to reach its reduction target.

3.1. Emissions in other sectors must be halved by 2030

In order to reach the 70% reduction target, other sectors must reduce their total annual carbon emissions by 13 million tonnes by 2030. The emissions from agriculture and environmental and industrial processes are expected to be reduced by approximately 4 million tonnes. This means that the remaining sectors, mainly transport and industry, will have to reduce their carbon emissions by 9 million tonnes, equivalent to half of the current emissions, see Figure 10[3.1].

[3.1] Ea Energy Analyses and Danish Energy based on Denmark's Energy and Climate Outlook 2019.

Figure 10. **Carbon emissions in other Danish sectors must be almost halved by 2030**



Note: Denmark's Energy and Climate Outlook 2019 expects a reduction of emissions of 7.6 million tonnes in the energy and utilities sector, 0.4 million tonnes in agriculture, environmental and industrial processes and 0.4 million tonnes in other sectors by 2030.
Source: Denmark's Energy and Climate Outlook 2019; Ea Energy Analyses; calculations made by Danish Energy; QVARTZ analysis.

Agriculture, environmental and industrial processes cover emissions that cannot be attributed to the use of fossil fuels. Agriculture includes land use management, crops, fertiliser and livestock (e.g. methane emissions from cattle) and emissions from agriculture are expected to be reduced by around 1.7 million tonnes towards 2030[3.2]. In terms of environmental gases, these come from wastewater treatment, biogenic waste and non-energy-related industrial gases. Most of the emissions from industrial gases come from the burning of lime in cement production. These emissions cannot be reduced by replacing fossil fuels with renewables, but other reduction measures such as carbon capture could be used. Reduction of emissions from environmental and industrial processes is estimated to amount to 1.4 million tonnes in 2030, which is a reduction of approximately 50% compared to today's levels and a 67% reduction since 1990[3.3]. Finally, agriculture, environmental and industrial processes are also estimated to contribute with a reduction of 0.4 million tonnes of carbon dioxide equivalents from other non-energy-related and indirect emissions such as methane and nitrogen dioxide[3.4], equivalent to about a third of today's level. Reducing carbon emissions from agriculture, environmental and industrial processes by 4 million tonnes leaves a reduction target of 9 million tonnes for the remaining sectors.

3.2. Bring into play all green energy solutions to realise the green transformation

In order to estimate the overall demand for renewable energy – to be supplied by the energy and utilities sector by 2030 – reduction initiatives amounting to a total of 9 million tonnes, primarily in the form of fuel replacement, must be identified in the remaining sectors. The Ea Energy Analyses displacement model has been used to provide a qualified and specific estimate of the energy demand.

The displacement model is based on the Danish Energy Agency's baseline projection of Danish emissions and energy consumption towards 2030 in the absence of new initiatives within climate and energy (see methodology section)[3.5]. The displacement model adds further specific initiatives across sectors bringing the total reduction to 70% by 2030. The model calculates the related costs of all potential carbon reduction initiatives towards 2030, for example, a gradual introduction of renewable energy for road transport, industrial heat pumps, etc. Ranking the initiatives from lowest to highest cost provides a qualified estimate of the most cost-effective path towards reaching the 70% reduction target, including the required shifts in technology. As no commercial-scale Power-to-X production or consumption exists in Denmark today, it remains uncertain which Power-to-X fuels will replace fossil fuels. Potential replacement fuels are hydrogen, methanol, Fischer-Tropsch diesel, demethyl ether (DME) and/or ammonia. The model will thus have to be adjusted along the way as technologies develop.

The estimated reduction initiatives amounting to 9 million tonnes in other sectors are illustrated in Figure 11 and are to be achieved through energy efficiency improvements and by replacing fossil fuels with renewable energy. Please note that reduction initiatives for other sectors are estimates serving only to assess the required build-out of renewable energy. They are not specific recommendations of reduction initiatives to be implemented in other sectors.

Energy efficiency improvements remain essential

Significant energy efficiency improvements across the energy and utilities sector and other sectors are assumed to be part of the reductions required to reach the 70% reduction target by 2030. The total energy demand is expected to be 13% more energy efficient, meaning that the energy consumption will be 13% lower than assumed in Denmark's Energy and Climate Outlook, see Figure 12[3.6].

Most of the energy efficiency improvements are achieved by replacing one technology with a more efficient one, for example, heat pumps for heat and power generation (3%), industrial heat pumps (3%) and electric vehicles (3%). The remaining energy efficiency improvements comprise energy efficiency improvements in industry (1%), e.g. optimisation of production processes, and in buildings (1%), e.g.

3.2 Ea Energy Analyses based on Danish Centre for Environment and Energy's (DCE) projection of greenhouse gas emissions from environmental and industrial processes.

3.3 Ea Energy Analyses based on DCE report (in Danish) no. 130, 2018: Virkemidler til reduktion af klimagasser i landbruget.

3.4 Ea Energy Analyses based on Danish Centre for Environment and Energy's (DCE) volatile and indirect emissions inventory, cross-border diesel trade and other corrections.

3.5 Denmark's Energy and Climate Outlook 2019.

3.6 Figures are not the same as in Figure 5, as Figure 5 only shows the energy consumption to be supplied by the energy and utilities sector, not the total Danish energy consumption.

control and operation of heating installations, insulation of technical installations and building envelope refurbishment.

Digitisation has played an important role in energy efficiency improvements, providing detailed real time energy use data and thus an improved basis for engaging customer communication and customer empowerment. The development in energy demand is the result of a combination of the transition to renewable energy, continued energy efficiency improvements and consumer empowerment through digitisation.

Using renewable energy sources to displace fossil energy

Replacing fossil energy with renewable energy sources will drive further reductions towards 2030. Reductions can be achieved through:

- **Direct electrification** where electric solutions replace fossil fuels, for example, road transport or heat pumps. It is a prerequisite that the power is based on renewable energy sources.

- **Indirect electrification, Power-to-X**, where power is used to produce hydrogen by electrolysis. The hydrogen is either used or refined into other hydrogen-based fuels. Heavy transport and industrial processes that cannot be electrified are among the areas of application. It is a prerequisite that the power used is based on renewable energy sources.

- **Biogas** as a direct substitute for natural gas in housing and industry, as fuel for heavy transport or indirectly combined with hydrogen for the production of advanced Power-to-X fuels, as mentioned above.

- **Other biofuels,** including biodiesel to be blended with fossil fuels and biogenic waste in CHP plants.

Potential reduction initiatives in the two primary sectors, transport and industry, are described in the following sections.

Transport

Carbon emissions in the transport sector could be reduced by 6.2 million tonnes by replacing fossil-fuelled vehicles with electric or biogas-fuelled vehicles. The displacement model specifically assumes that approximately 1,500,000 cars, 160,000 commercial vehicles, 5,000 buses and 3,000 lorries will be either electric or biogas-fuelled by 2030:

- In terms of passenger cars, it is assumed that more than 50% of passenger cars sold in 2024 will be electric or plugin hybrids, and by 2027 this percentage will have increased to more than 90%.
- In terms of commercial vehicles, it is assumed that 50% of all commercial vehicles sold in 2026 will be electric or plugin hybrids, and by 2030 this percentage will have increased to more than 90%.
- In terms of buses, it is assumed that by 2025, approximately 50% of all intercity buses will be powered by renewable energy, and by 2030 this percentage will have increased to more than 95% (~75% power and ~20% biogas, respectively). Furthermore, it is assumed that by 2030, 10% of tourist buses will be electric and 10% will be biogas fuelled.
- In terms of lorries, it is assumed that by 2030, approximately 2,500 lorries will be electric or biogas fuelled. To achieve this, it is assumed that by 2025, approximately 8% of all lorries sold will be either electric or biogas fuelled, and that by 2030, this number will be approximately 32% (equally distributed on electric and biogas).

In addition to the transition to electric and biogas-fuelled vehicles, reductions are expected to be achieved through commercialisation of the Power-to-X technology for production of hydrogen and hydrogen-based fuels. The reduction is estimated based on a transition to approximately 12,500 hydrogen lorries and approximately 2,000 hydrogen buses, blending 3 vol % methanol with petrol, and production of renewable diesel fuel, for example, by means of the Fischer-Tropsch synthesis or dimethyl ether (DME) to cover approximately 25% of the residual diesel demand for road transport in 2030. With Power-to-X being a relatively immature technology, the specific relative shares of Power-to-X fuels in 2030 are subject to greater uncertainty than other calculations in the displacement model[3.7].

Finally, it is assumed that reductions can also be achieved by blending second-generation biodiesel with diesel and bioethanol with petrol[3.8]. The specific share of biodiesel in diesel will be approximately 14%, and approximately 7% bioethanol in petrol[3.9] by 2030.

[3.7] For example, aviation fuel based on renewable energy will in turn require hydrogenation of carbon dioxide from Power-to-X processes. Denmark's total energy consumption.

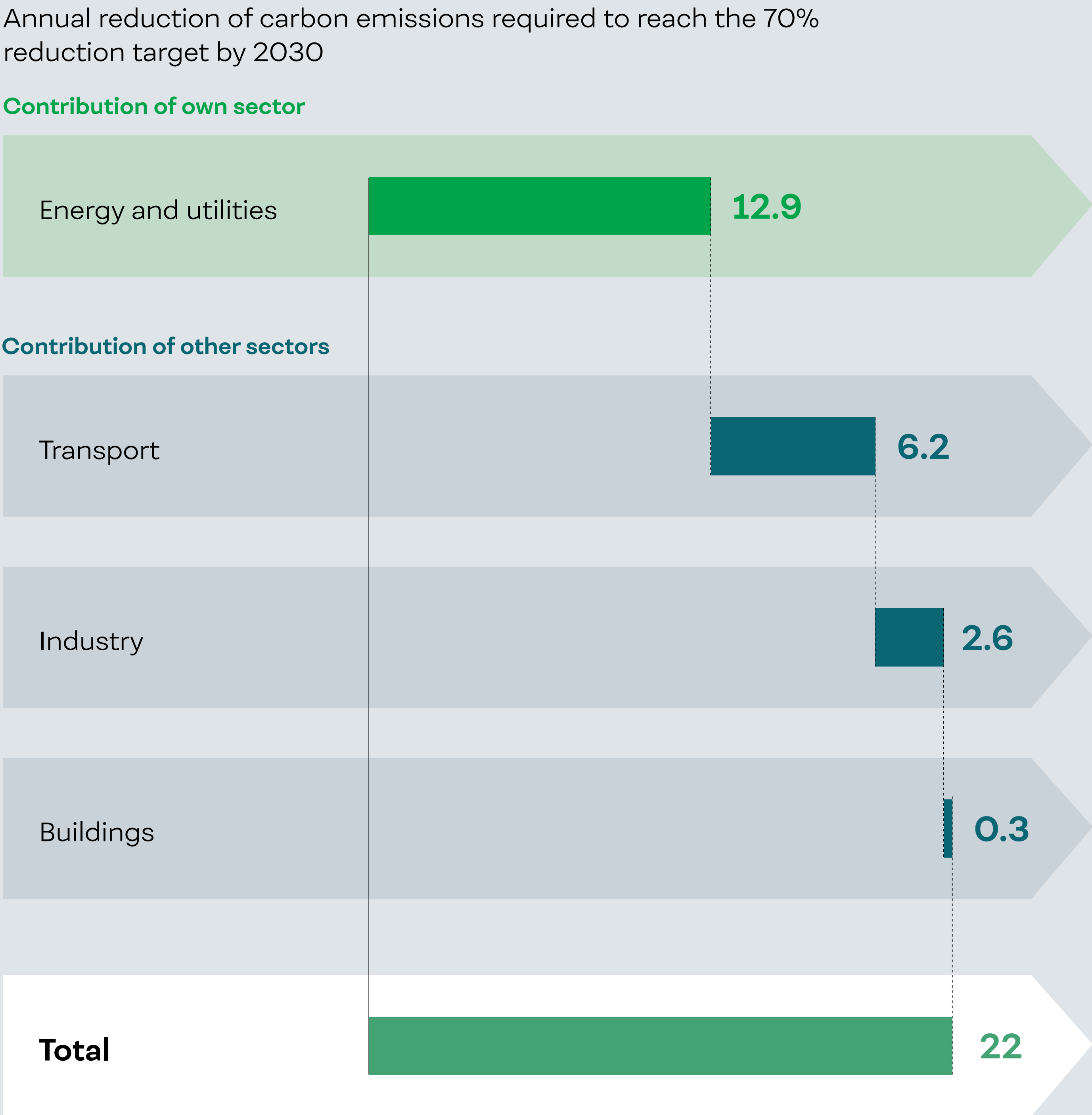
[3.8] Biodiesel and bioethanol produced from biogenic material, e.g. waste and residues.

[3.9] This is twice as much as assumed in Denmark's Energy and Climate Outlook 2019 for both biofuels.

Figure 11.

Estimated reduction of carbon emissions across sectors towards 2030

Million tonnes of carbon emissions



Displacement by sector

6.9 Renewable energy in power and district heating	**2.8** Oil and natural gas phased out of individual heating systems	**1.3** Carbon capture and storage	**0.8** Separation of plastics in waste-to-energy	**1.1** Optimisation and electrification of North Sea prod.
0.6 Adjustment of baseline projection	**2.1** 1.5 million electric or hybrid vehicles	**1.9** Power-to-X in heavy transport	**0.9** Electric commercial vehicles, electric buses and electric lorries	**0.8** Biofuel e.g. biogas and biodiesel
-0.2 Adjustment of baseline projection	**1.5** Heat pumps in process heat[1]	**0.6** Energy efficiency improvements	**0.6** Internal transport	**0.1** Biogas and biodiesel for process
– Adjustment of baseline projection[2]	**0.2** Building installations[3]	**0.1** Building insulation[4]		

It is a prerequisite that the energy and utilities sector can supply renewable energy to replace fossil energy sources

[1] Low temperature (0.7 million tonnes of carbon emissions), medium temperature (0.6 million tonnes of carbon emissions) and high temperature (0.2 million tonnes of carbon emissions).
[2] Building stock growth offsets energy efficiency gains.
[3] Energy efficiency improvements, primarily achieved by control and operation of heating installations and insulation of technical installations (e.g. heat pipes).
[4] Energy efficiency improvements achieved by renovating building envelopes (e.g. outer walls, windows, roofs).
Source: Ea Energy Analyses: Muligheder og omkostninger ved drivhusgasreduktionstiltag frem mod 2030; Danish Energy; QVARTZ analysis.

Industry

Phasing out the use of fossil fuels for process heat can reduce carbon emissions in industry by 2.6 million tonnes. It is assumed that 70% of low-temperature processes, 50% of medium-temperature processes and 25% of high-temperature processes are replaced by electric heat pumps. Energy efficiency improvements and replacing natural gas with biogas account for the remaining reduction of emissions in industrial processes. In addition to conversion of the industrial processes, it is expected that approximately one third of internal and non-road transport, such as agricultural machinery, internal warehouse transport and construction machinery, can be converted to machinery running on renewable energy evenly distributed on biofuels and power[3.10].

3.3. A green Denmark in 2030

The transformation required to meet the 70% reduction target will significantly transform all sectors, using considerably less fossil fuels for transport, heating and industry, see Figure 13.

Reaching the 70% reduction target in 2030 means almost one million fewer fossil-fuelled passenger cars on the roads[3.11], approximately 70,000 fewer fossil-fuelled commercial vehicles, approximately 7,000 fewer fossil-fuelled lorries and approximately 6,000 fewer fossil-fuelled buses compared to 2019. The displacement model also requires replacement of approximately 75,000 oil-fired boilers and approximately 275,000 natural gas-fired boilers for individual heating, and that the remaining 100,000 natural gas-fired boilers will use biogas. Finally, a considerable amount of coal, oil and natural gas for process heat in industry will be phased out.

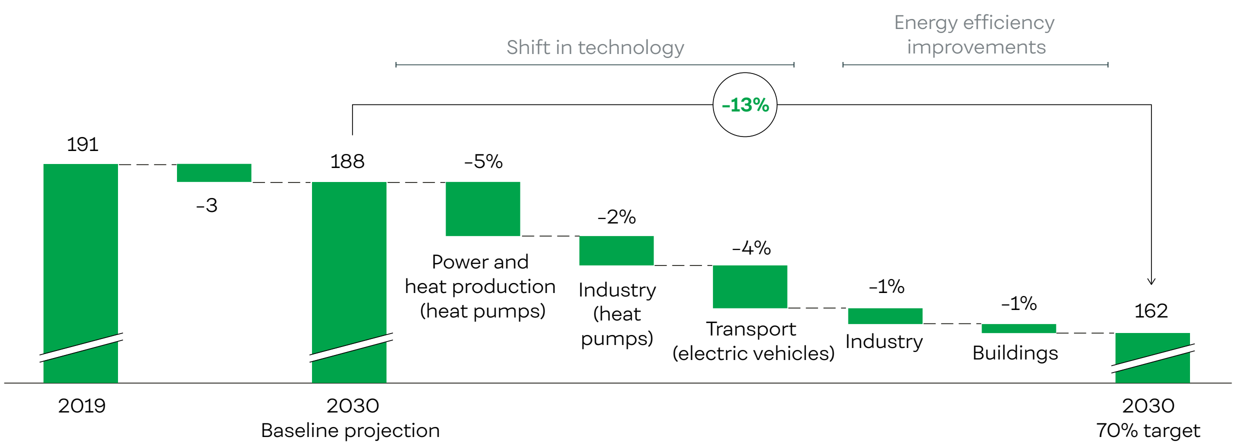
The displacement model assumes that the transformation does not change the activity level of Danish citizens and businesses predicted in Denmark's Energy and Climate Outlook. Therefore, fossil solutions will also be directly replaced by renewable alternatives. This means, for example, that when a fossil-fuelled vehicle is phased out, it is replaced by an electric vehicle. Green alternatives do not have to replace phased out fossil ones for Denmark to be able to reach the 70% reduction target. An alternative scenario would be that renewable alternatives do not take the place of fossil ones, for example that hundreds of thousands of Danes no longer own a car. In this scenario, there does not have to be 1.5 million electric vehicles on the Danish roads in 2030, as long as the required amount of fossil-fuelled vehicles is phased-out.

The initiatives presented here on how to reduce carbon emissions by 13 million tonnes by 2030 is only an estimate by the energy and utilities sector of how the required reduction can be achieved in other sectors. The aim is to estimate the total renewable energy demand to be supplied by the energy and utilities sector by 2030. The build-out of renewable energy and the required infrastructure is described in the next chapter.

3.10 Share of fuels expected to transition to renewable energy: 25% of fuels used in agriculture, 50% of fuels used in building and construction and 50% of fuels used in industry.

3.11 The demand for passenger cars is expected to increase by 0.5 million towards 2030 (the National Transport Model (DTU)). Therefore, replacing 1.5 million fossil-fuelled vehicles with electric vehicles towards 2030 will only mean 1 million less fossil-fuelled vehicles in 2030 compared to today.

Figure 12. **Energy demand in Denmark 2019-2030 (TWh)**



Note: Exclusive of energy gained from switching to synthetic fuels (Power-to-X), foreign aviation, ambient heat and energy for non-energy purposes.
Source: Denmark's Energy and Climate Outlook 2019; Ea Energy Analyses; Danish Energy; QVARTZ analysis.

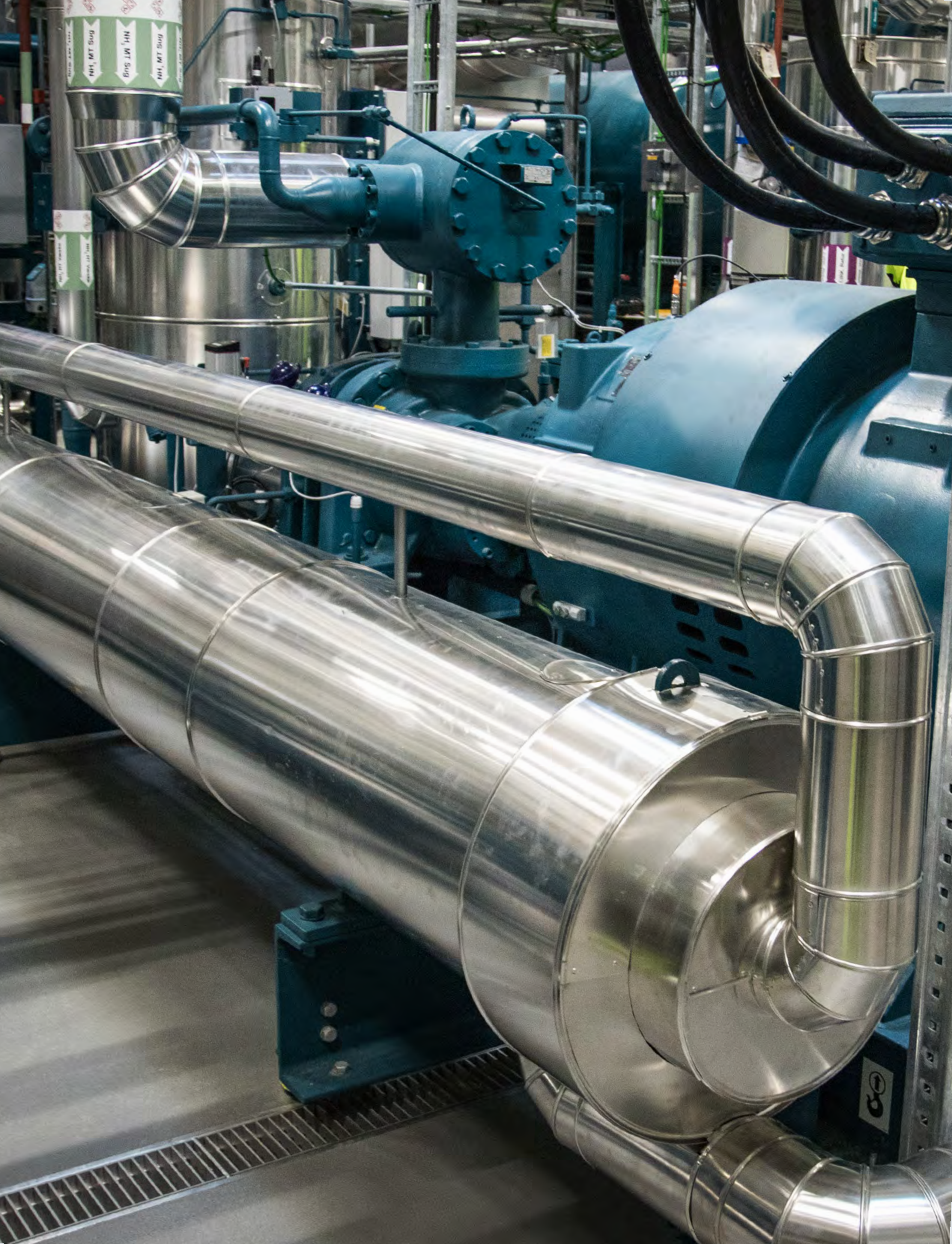
Figure 13.

Graphic presentation of the required transformation of transport and heating to reach the 70% reduction target by 2030

	Area	70% reduction target reached in 2030	Change from 2019
Transport	Passenger cars	**1,775,000** of 3,275,000 vehicles are fossil-fuelled[1] (54%)	-843,000
Transport	Commercial vehicles	**271,000** of 431,000 commercial vehicles are fossil-fuelled[2] (63%)	-71,000
Transport	Lorries	**35,000** of 50,000 lorries are fossil-fuelled (70%)	-7,000
Transport	Buses	**2,600** of 9,300 buses are fossil-fuelled (28%)	-6,200
Heating	Oil-fired boilers	**4,000** households are heated with oil-fired boilers (5%)	-76,000
Heating	Gas-fired boilers	**0** households are heated with natural gas (0%). 100,000 households use biogas in gas-fired boilers	-375,000

● Renewable energy sources ● Fossil energy sources

[1] The number of passenger cars is based on Denmark's Climate and Energy Outlook 2019, which estimates a greater number of cars in 2030 than today.
[2] Blending of biofuels (biodiesel and bioethanol) and Power-to-X fuels (methanol and Fischer-Tropsch diesel) is not included.
Source: The National Transport Model (DTU); Statistics Denmark; Ea Energy Analyses; Danish Energy; QVARTZ analysis.



4.0 The energy and utilities sector can supply green energy to power the full transformation of Denmark

Phasing out fossil fuels in the energy and utilities sector will lead to increased demand for renewable energy, which must be met by the energy and utilities sector in order to achieve the full transformation of Denmark. The need for production capacity and infrastructure can be reduced with energy efficiency improvements, demand-side response and storage. The total demand for renewable energy is expected to grow by 64% to 125 TWh by 2030. Meeting the increased demand for renewable energy requires a build-out of offshore wind from 1.7 to 7.6 GW, of onshore wind from 4.4 to 6.1 GW and of solar energy from 1.2 to 8.8 GW. Biogas production must be increased from 4.4 TWh in 2019 to 13.3 TWh by 2030, and Power-to-X must be increased to full-scale production. The power grid must be upgraded to be able to transport more green power. It is expected that the final consumption from the distribution grid will increase from 34 TWh in 2019 to 58 TWh in 2030, and the final consumption from the transmission grid will increase from 1 TWh to 13 TWh. Demand-side response and smart solution will reduce the necessary infrastructure upgrades, nevertheless, the increased power generation from fluctuating renewable energy sources will require more interconnections. Furthermore, the gas and heat infrastructure will change and we need to establish an infrastructure to support the development of Power-to-X fuels. Initiatives must be implemented to ensure security of supply during times with limited power generation from flexible energy sources.

The previous two chapters described reduction initiatives which may help to achieve the 70% reduction target. The initiatives in the energy and utilities sector can be implemented, provided that the right framework conditions are in place, while the initiatives in the other sectors provide an estimate of the total energy demand to be met by the energy and utilities sector in 2030.

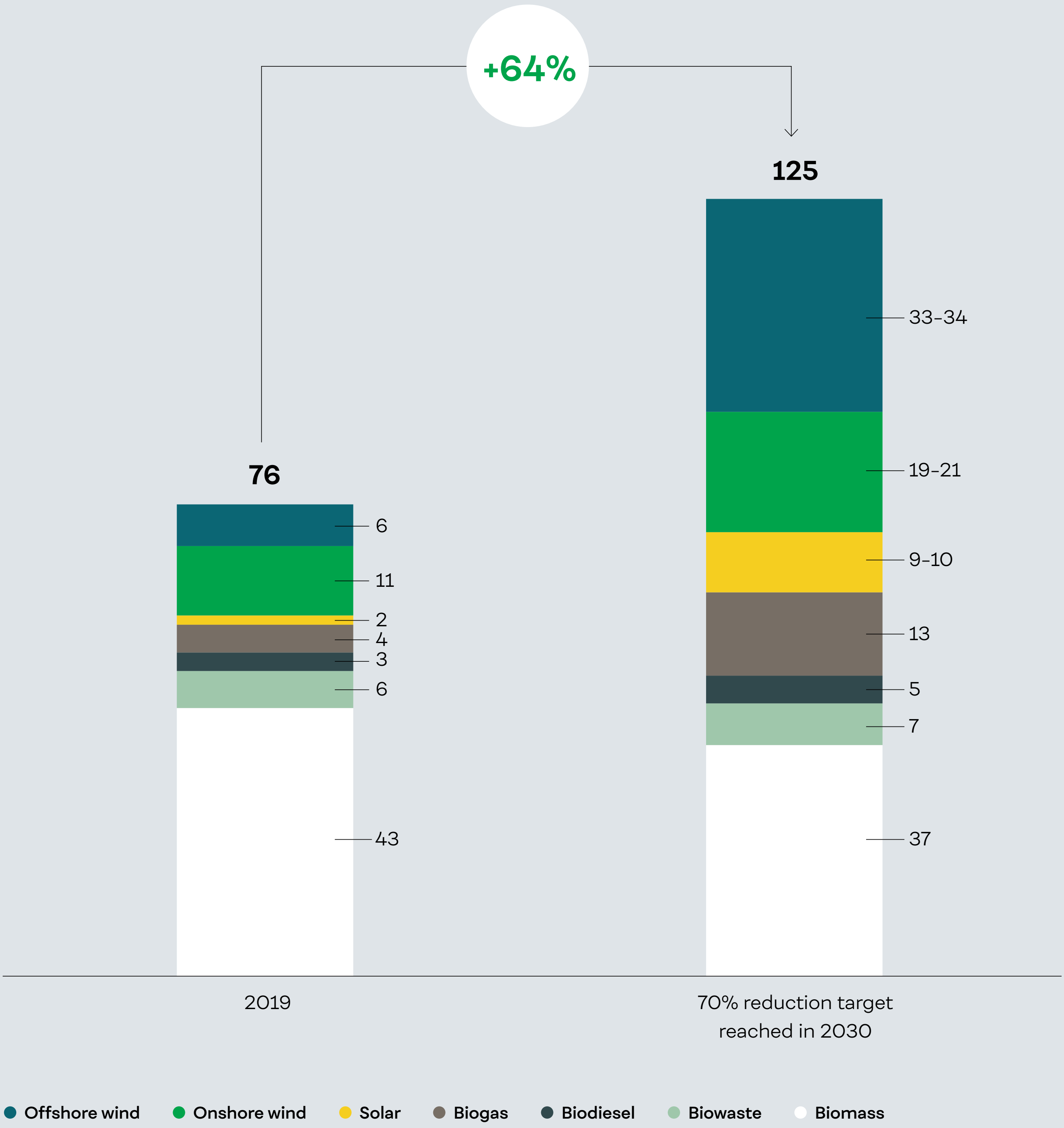
Many of the reduction initiatives involve replacing fossil fuels with renewable energy sources, leading to a sharp increase in the need for renewable energy production and associated infrastructure. However, if it were not for the significant energy efficiency improvements of the reduction initiatives, there would be an even greater need for necessary infrastructure upgrades. The efficiency improvements are expected to be achieved by switching from, for example, fossil-fuelled vehicles to electric vehicles and through more direct energy efficiency improvements such as optimisation of production processes. The energy and utilities sector estimates that by 2030 the total Danish energy demand will be 13% lower than estimated in Denmark's Energy and Climate Outlook 2019. In addition to reducing energy consumption in Danish households and businesses, the energy efficiency improvements also reduce the level of investment needed for the renewable energy and infrastructure expansion.

Furthermore, ramped-up digitisation efforts, demand-side response and energy storage will also reduce the need for infrastructure upgrades. Demand-side response makes it possible to smooth out power demand which is traditionally very high in the afternoon and in the evening over the course of the day, for example through the increased use of price signals, by charging electric vehicles at night and by using more flexible heat pumps.

Figure 14.

The transformation requires a substantial renewable energy build-out

Estimated renewable energy demand towards 2030 (TWh)



Source: Denmark's Energy and Climate Outlook 2019; Danish Energy; QVARTZ analysis
Note: Offshore wind, onshore wind and solar power are increased to meet the growing demand for power. Biogas is primarily increased as a substitute for natural gas in industrial processes, among other things, and as a substitute for fossil fuels in the transport sector as well as to a lesser extent for use in district heating production for peak and reserve loads. Biodiesel is increased for blending in the transport sector. Biowaste replaces fossil waste in waste incineration. Biomass is reduced as some of the production from CHP plants is replaced by offshore wind, onshore wind and solar power, and because heat pumps are increasingly used instead of biomass in individual heating systems.
Note: Power consumption of approximately 71 TWh and district heating production of approximately 38 TWh must be covered by renewable energy sources by 2030. The remaining energy consumption is found in industry, transport, etc.
Note: International aviation, ambient heating and energy for non-energy purposes are not included.

This chapter describes how renewable energy production can be scaled and what infrastructure changes this requires, including initiatives to promote demand-side response and mitigate the need for a infrastructure upgrades.

4.1. Green energy production must be increased significantly and the build-out must start now

The demand for renewable energy as a result of the reduction initiatives in the energy and utilities sector and other sectors is estimated to grow from 76 TWh in 2019 to 125 TWh in 2030, up 64%. Assuming that the Danish demand for renewable energy is to be met by renewable energy produced in Denmark, production must also grow by 64%. The increase in production will come from offshore wind, onshore wind, solar power and biogas, see Figure 14.

The actual energy demand in 2030 may differ from the projected demand, both in terms of scope and split between energy sources, especially because reduction initiatives outside the energy and utilities sector are estimates only. However, although other sector initiatives to achieve the 70% reduction target differ from those identified in the displacement model, overall energy demand is still expected to increase considerably. The energy and utilities sector has performed various calculations in which the reduction initiatives vary in terms of, for example, the number of electric vehicles, and the result does not significantly alter the estimated total energy demand in 2030.

It is imperative that the necessary renewable energy production is expanded to meet the growing energy demand. An inadequate build-out of green energy production will delay the phase-out of fossil energy sources or the import of fossil power from Denmark's neighbouring countries. With an inadequate build-out there is a real risk that Denmark will not be able to meet the 70% reduction target.

There may also be a risk of an excessive build-out. In that case, however, any renewable energy surplus could be exported and contribute to the green transformation in Denmark's neighbouring countries. At the same time, a temporary oversupply of renewable energy could contribute to lower energy prices, increasing the incentive to make the transition to renewable energy. Finally, an excessive build-out could also be seen to accelerate the additional energy build-out needed beyond 2030 to achieve the target of full climate neutrality by 2050.

Such a substantial build-out of renewable energy sources will require significant contributions from all parties involved. The primary contribution of the energy and utilities sector will be to ensure the development and scaling of the renewable energy sources needed, provided that the necessary framework conditions are in place.

Another important contribution from the energy and utilities sector will be to accept a considerable level of economic market risk, as the power price depends on demand which must largely be driven by policy initiatives. The electrification of Denmark and the EU over the next 10-20 years will largely be driven by policy decisions, which makes the market risk difficult to manage for private investors alone. Consequently, there is a need for regulatory models in which society assumes part of the risk, for example through tendering schemes where investors are compensated when power prices are low. The aim of all renewable energy sources is to match the market price, and as a general rule any compensation should merely match the projected market price. Generally, this applies to all the renewable energy sources addressed in this chapter, but the concrete financing models will be different.

4.1.1. Power generation must be doubled to meet the demand for power in the transformation towards 2030

As many of the major carbon reduction initiatives are expected to lead to an electrification-based transformation, the demand for power is expected to grow. Power-to-X production, heat pumps and the electrification of transport, in particular, require vast amounts of power. In addition, it is also expected that new data centres will require power. The energy and utilities sector estimates that Denmark's total power demand will almost double from 35 TWh in 2019 to 71 TWh by 2030, see Figure 15.

The increased power demand must be matched by a corresponding increase in power generation, see Figure 16. Power generation from biogas, biomass and fossil fuels is expected to fall by a total of 8 TWh towards 2030 due to a phase-out in cogeneration. As a result, the production volume from other sources must be increased by 45 TWh to reach a total power generation of 71 TWh by 2030. The increase in power generation is expected to come primarily from the build-out of offshore wind, onshore wind and solar power[4.1]. The split between offshore wind, onshore wind and solar power is proportionally distributed according to the Danish Energy Agency's expected build-out towards 2030 and will need to be adjusted on a regular basis in step with the technological development, among other things.

The 70% reduction target assumes that the necessary demand for renewable power generation is secured. In this context, the government is very much able to control the build-out of offshore wind, as it primarily takes the form of government tenders, while the build-out of onshore wind and solar power depends on municipal case management, the outcome of technology-neutral tenders and the remaining build-out that takes place outside government tenders.

A build-out of offshore wind, onshore wind and solar to the capacity needed is considered possible without leading to issues with space constraints, although there is a risk of a lack of local political support and delays due to complaints and lengthy processes. For onshore wind, the Danish Energy Agency estimates that by 2030 Denmark will have available land for the installation of 14.5 GW of onshore wind, equivalent to about 49 TWh[4.2]. Denmark also boasts large areas of farmland which are suitable for solar farms.

The offshore build-out can be expected to happen within the areas identified by the Danish Energy Agency in the North Sea, internal waters and the Baltic Sea given the restrictions for offshore wind farm installation. However, if these commitments change, the scope of the build-out could be increased considerably, likely at a cheaper cost. If land-based energy sources cannot be sufficiently expanded, the offshore wind tenders may be scaled to ensure the necessary power generation by 2030. Whether offshore wind, onshore wind or solar power is expanded, the infrastructure must be strengthened in parallel with measures to ramp up flexibility and smart consumption. The necessary infrastructure build-out is described in more detail in chapter 4.2. The build-out of individual energy sources is described in the following sections.

4.1.1.1. Power generation from offshore wind must be increased at least fivefold

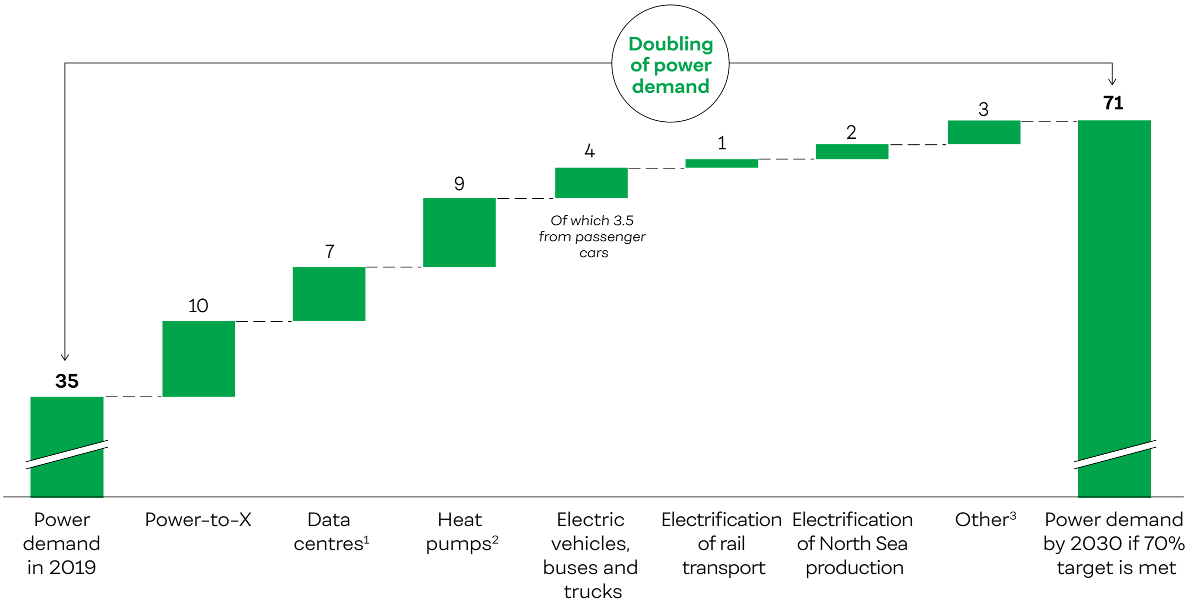
As a contribution to the 70% reduction target, offshore wind capacity must be increased by a minimum of 27-28 TWh out of the total of 45 TWh which must be added to meet Denmark's power demand by 2030. This means that by 2030 total power generation from offshore wind must be increased to 33-34 TWh, corresponding to more than a fivefold increase in the existing offshore wind production of approximately 6 TWh. With the proposed build-out, by 2030 approximately half of Denmark's power will come from offshore wind.

To deliver the amount of power required in 2030, the installed offshore wind capacity must be expanded by approximately 5.9 GW from the existing 1.7 GW in 2019 to at least 7.6 GW in 2030, see Figure 17. To enable the necessary build-out, government tenders corresponding to approximately 5 GW must be implemented towards 2030. In the Energy Agreement 2018, it has already been decided to put 2.4-3.0 GW to tender in 2021-2025.

4.1 Waste in power generation is expected to contribute a small increase of 0.1 TWh.

4.2 The Danish Energy Agency (2019): the Technology Catalogue. Assuming 3,411 full-load hours.

Figure 15. **Estimated increase in power demand towards 2030 (TWh)**



[1] Based on Denmark's Energy and Climate Outlook 2019.
[2] Household heat pumps (3 TWh), heat pumps in district heating (3 TWh) and industrial heat pumps (2 TWh).
[3] 'Other' covers an overall increase in the demand for power in industry, construction and public services (0.9 TWh), internal transport in agriculture (2.2 TWh) and electrification of maritime transport (0.01 TWh).
Source: Denmark's Energy and Climate Outlook 2019; Ea Energy Analyses; Danish Energy; QVARTZ analysis.

It is proposed that the 5 GW be split into four annual tenders in the period 2021-2024. If the wind turbines are to be operational by 2030, any offshore wind tenders must be held in 2024 at the latest. The four tenders are proposed to be the planned Thor tender for 0.8-1.0 GW in 2021, a tender for ~1 GW in Eastern Denmark in 2022, possibly in conjunction with interconnections to one or more of Denmark's neighbouring countries, a tender for ~1 GW in 2023 and a tender for ~2 GW in 2024[4.3] which may pave the way for the establishment of energy islands.

The proposed annual build-out rate and scope of the tenders will accelerate the current tender plan set out in the Energy Agreement 2018, which comprises 2.4-3.0 GW split into three tenders to be held in 2021 (Thor), 2023 and 2025, respectively[4.4]. Without the accelerated build-out, offshore wind will not be able to deliver the required amount of renewable power by 2030, which means that the 70% reduction target will not be met.

The government can ensure that the accelerated build-out can be implemented, including conducting strategic environmental assessments (SEAs) and bird counts across the areas considered to be most relevant to the future offshore wind build-out[4.5] to reduce preparations for each tender and ensure that a greater share of the feasibility studies are conducted by offshore wind turbine developers.

Continuous tenders from 2021 onwards create a transparent build-out pipeline in Denmark which provides transparency for market players and ensures a high level of competition. At the same time, it allows the wind turbine industry to plan ahead, with the ongoing offshore wind build-out consistently helping to create jobs across the country.

The tender scopes of 1-2 GW are based on a number of assumptions that could potentially change towards 2030 as described in chapter 3. If in 2030 the total power demand is greater than expected or the necessary build-out of onshore wind and solar capacity for power generation is not realised, Denmark may have to import fossil-based power in 2030. In order to minimise the risk of this happening, the proposed offshore wind supply may be scaled to 2-3 GW annually to ensure sufficient volumes of renewable energy in 2030, allowing Denmark to meet the 70% reduction target. A decision on the issue will have to be made within the next few years, as tenders for offshore wind which is to be operational by 2030 need to be prepared in 2023 at the latest.

In addition to scaling the tender scopes, the ongoing balancing of power demand and supply can also be ensured by boosting foreign trade. As detailed in chapter 5, it is recommended that an additional interconnection which is linked directly to an offshore wind farm in Eastern Denmark be constructed.

Four offshore wind government tenders in the period 2021-2024 can help Denmark reach its target

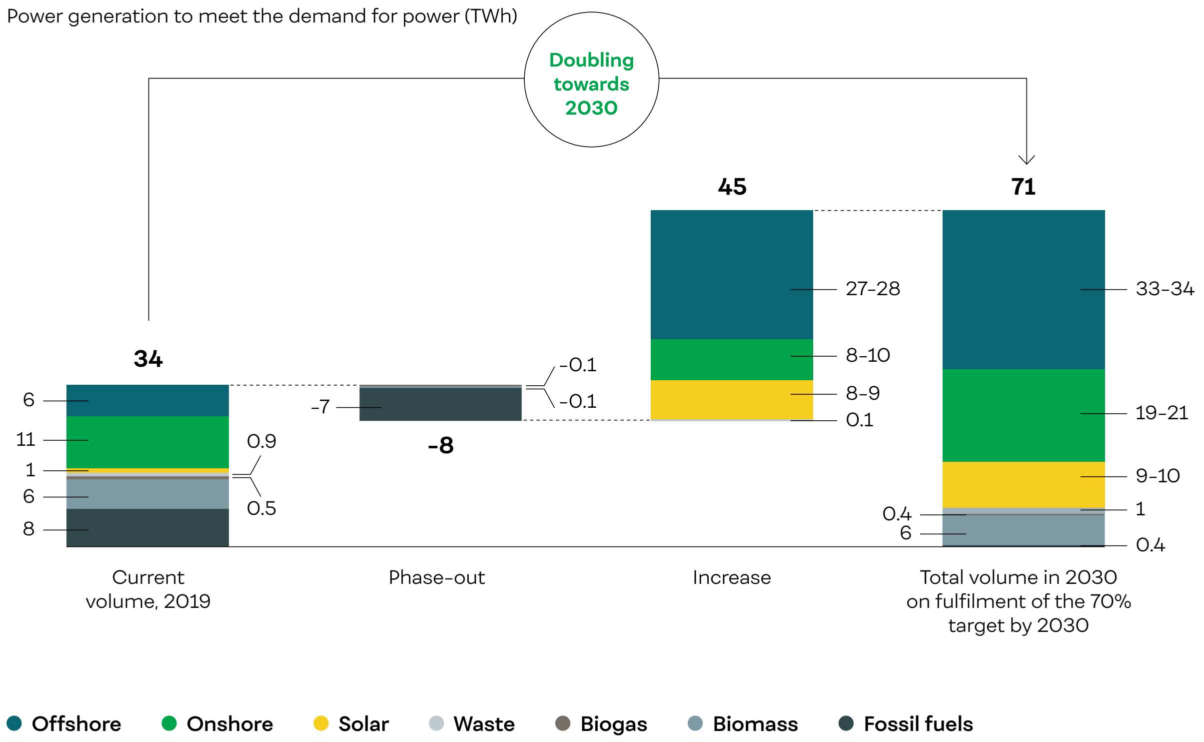
- The planned 0.8-1.0 GW Thor tender in 2021
- A tender for ~1 GW in Eastern Denmark in 2022
- A tender of ~1 GW in 2023
- A tender of ~2 GW in 2024

[4.3] The tenders in 2023 and 2024 are proposed to be tenders for multiple areas prepared by the government using a strategic environmental assessment across areas. Offshore wind turbine developers can then tender the desired capacity/production volume in areas, where developers believe power can be supplied at the lowest possible price.
The model is comparable to the technology-neutral onshore tenders.

[4.4] At the same time, it is estimated that a tender in 2025 is too late for offshore wind turbines to be operational and supply power by 2030.

[4.5] See the areas identified in 'Havvindspotentialet i Danmark' (Danish Energy Agency 2019).

Figure 16. **The total demand of 71 TWh by 2030 can be met through a significant increase in renewable energy sources**



Note: The build-out of biogas, waste, biomass and fossil fuels is calculated by Danish Energy on the basis of input from Ea Energy Analyses. The build-out of offshore wind, onshore wind and solar power follows the same relative distribution as the expected build-out of offshore wind, onshore wind and solar power from 2019 to 2030 in the Analysis Assumptions. The interval for offshore wind, onshore wind and solar power illustrates the difference between the projection of the build-out of the Analysis Assumptions as the net and gross build-out, respectively. The projected build-out of renewable energy sources is indicative and depends on technology prices.
Note: The volume estimates cover the gross energy consumption, incl. net losses.
Note: Phase-out and increase are calculated net, which means that the necessary gross build-out will be greater.
Note: In 2019, power generation amounted to about 34 TWh, while power consumption amounted to 35 TWh.
Note: Denmark's Energy and Climate Outlook 2019 has been used as a reference for the displacement model. However, the data has been revised with the newer and updated power consumption figures from the Danish Energy Agency's Analysis Assumptions 2019.
Source: The Danish Energy Agency (2019); Analysis Assumptions; Danish Energy; QVARTZ analysis.

The primary build-out of offshore wind towards 2030 must be driven by government tenders, but better conditions must also be provided to allow private players to build offshore wind farms independently of tenders, for example to supply large power consumers such as Power-to-X plants and data centres.

The total investment needed for the offshore wind build-out to achieve the 70% reduction target by 2030 is expected to be DKK 85-105 billion in the period 2019-2030 and is shouldered by the market players[4.6]. Given the very long investment horizons and the considerable uncertainty about the increase in demand for power which must partly be politically driven, it is imperative that settlement continues to be based on the sharing of risk between government and market players, where both parties assume some of the risk associated with the uncertainty of the long-term development in power prices.

In addition to the significant build-out through tenders to achieve the 70% reduction target towards 2024, offshore wind will already now have to be included as an important part of the ongoing carbon reductions towards full climate neutrality in Denmark and the EU by 2050. The total offshore wind potential in Denmark is 40 GW, of which only about 8 GW is realised in the proposed build-out towards the 70% reduction target by 2030. At the same time, provided that the existing restrictions for the installation of offshore wind farms are maintained. For example, much of the Danish sea shelf is currently reserved for the Danish armed forces and training terrain, designated as environmental zones or reserved for other purposes such as shipping. A comprehensive description of Denmark's potential for exporting green power from offshore wind and Denmark's ability to contribute to international reductions is provided in chapter 5.

4.1.1.2. Power generation from onshore wind must be doubled

To help achieve Denmark's 70% reduction target, onshore wind production must be increased by a minimum of 8-10 TWh by 2030. This will bring the total onshore wind production to 19-21 TWh in 2030, almost double the existing production of around 11 TWh.

To deliver the necessary power generation, the installed onshore wind capacity must be increased by 1.7 GW net from the existing 4.4 GW in 2019 to 6.1 GW in 2030. Because many of the existing installed onshore wind turbines are expected to be decommissioned by 2030, the total gross build-out, i.e. the actual build-out, of new onshore wind turbines towards 2030 must be up to 3.6 GW, see Figure 18.

The technical lifetime of the existing onshore wind turbine portfolio determines how big the onshore wind turbine build-out should be in order to realise the expected net build-out. Approximately 4,200 onshore wind turbines have already been installed across the country. Up to 3,400 of these wind turbines are expected to be decommissioned by 2030, either because they have reached the end of their technical lifetime or because they are replaced with newer turbine types *(repowering)*. If the technical lifetime of the existing onshore wind turbine portfolio is ten years longer than assumed in the Analysis Assumptions on which the sector roadmap is based, the majority of the wind turbines in operation today will remain in operation by 2030 and the total number of onshore wind turbines will be almost unchanged by 2030.

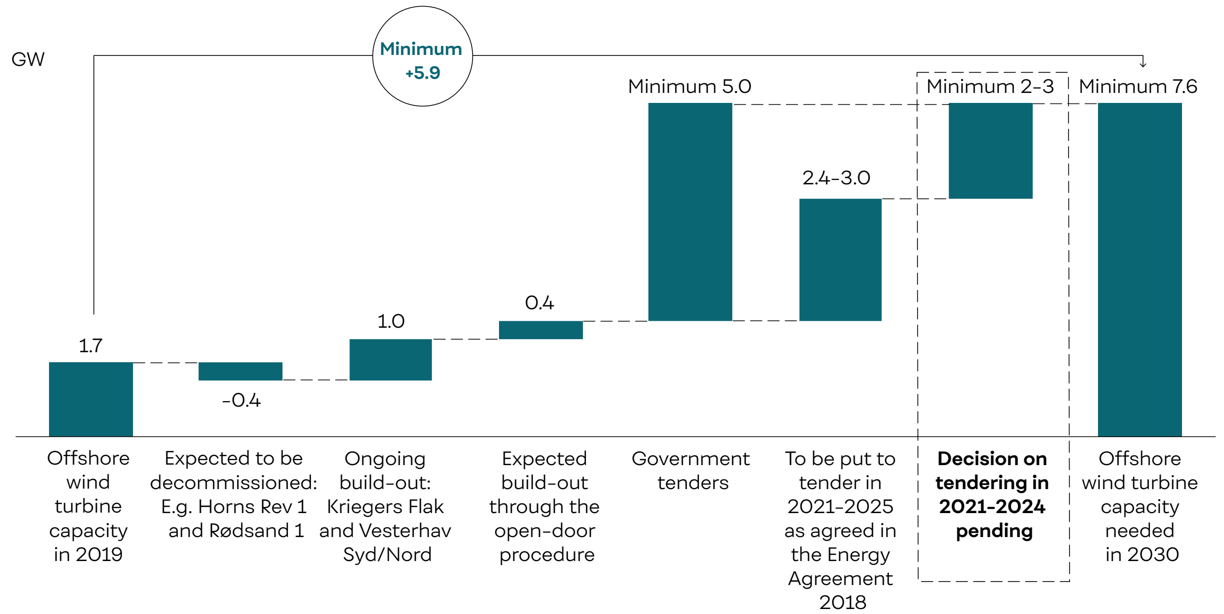
The sector roadmap assumes that the number of onshore wind turbines will be reduced by 2,300 (-54%)[4.7], while power generation from onshore wind will almost double. This means that 1,100 new wind turbines will be constructed, which in addition to the approximately 800 wind turbines constructed after 2002 results in an operational portfolio of some 1,900 units with a total capacity of 6.1 GW, of which up to 3.6 GW will be constructed towards 2030. However, despite the fact that only 1,100 onshore wind turbines need to be installed to secure the necessary power generation from onshore wind, it is a significant build-out compared to the past decade, when a total of some 630 onshore wind turbines were erected.

Most of the future build-out of 3.6 GW is expected to be realised in continuation of the subsidies granted from the technology-neutral tenders already agreed from 2020 to 2024. The funds allocated for the implementation of the tenders total DKK 4.2 billion and are primarily expected to be distributed among onshore wind and solar energy projects. It takes about 1-2 years from subsidies are granted to the individual project until the onshore wind turbines are operational.

[4.6] 6.3 GW is to be added, of which 0.95 GW is under construction as a result of the Energy Agreement 2012, approximately 0.4 GW is constructed outside government tenders and approximately 5 GW is constructed under government tenders.

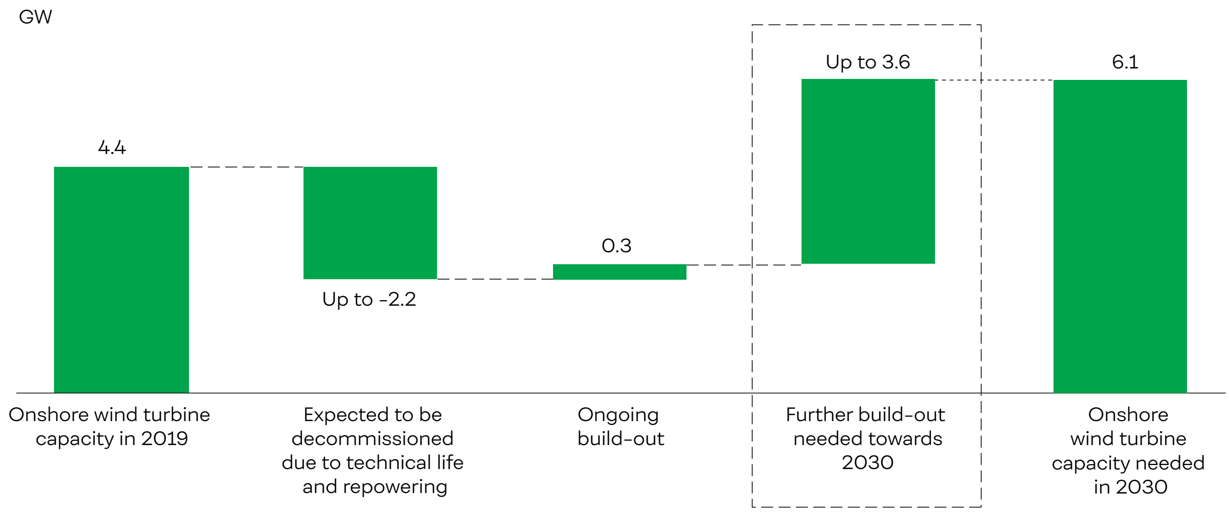
[4.7] Denmark's Energy and Climate Outlook 2019.

Figure 17. **Build-out of offshore wind to deliver the amount of power needed by 2030 (GW)**



Note: There must be a net build-out of 5.9 GW from 2019 to 2030. At the same time, it is assumed that approximately 0.4 GW will be decommissioned by 2030 (for example Horns Rev 1 and Rødsand 1), which is why the gross build-out should be 6.3 GW. Of this, 0.95 GW has already been agreed for construction under the Energy Agreement 2012 (600 MW at Kriegers Flak and 350 MW at Vesterhav Syd og Nord). As a result, a decision must be made to develop a further 5.4 GW to deliver the amount of power needed by 2030. Of this, 0.4 GW is expected to be constructed as near-shore wind turbines in special, favourable locations (the open-door procedure). The remaining 5.0 GW will be constructed under government tenders. The potential locations for the build-out of offshore wind are Fanø Bay, Jammerbugt, Jyske Banke, Nordsøen 1-3, Bornholm 1-3, Kriegers Flak, Frederikshavn, Hesselø and Kattegat 1-2.
Source: Denmark's Energy and Climate Outlook 2019; the Danish Energy Agency (2019): Analysis Assumptions; Danish Energy; QVARTZ analysis.

Figure 18. **Build-out of onshore wind to deliver the amount of power needed by 2030 (GW)**



Note: The gross build-out of 3.6 GW is inclusive of the 1.7 GW to be developed net towards 2030 as well as the replacement for the up to 2.2 GW expected to be decommissioned by 2030, but exclusive of the approximately 0.3 GW which is expected to already be under construction as a result of the technology-neutral tenders in 2018 and 2019. The decommissioning is calculated using a technical lifetime for an onshore wind turbine of 28 years (Danish Energy Agency), with all onshore wind turbines constructed in 2002 or earlier expected to be decommissioned before or in 2030. In practice, some onshore wind turbines may have longer lifetimes, so they may not necessarily be decommissioned after 28 years. Some onshore wind turbines are also decommissioned within their technical lifetime in connection with *repowering* projects, where existing, often operational, onshore wind turbines are replaced with new onshore wind turbines. This means that there is uncertainty about the scope of the decommissioning which must be evaluated on a regular basis to ensure the necessary level of build-out. At the end of 2019, enquiries had been made to Energinet and the distribution companies (Danish Energy) concerning the connection of approximately 1.5 GW onshore wind turbines. However, it should be emphasised that not all projects may necessarily be realised simply because an enquiry has been made.
Source: Denmark's Energy and Climate Outlook 2019; the Danish Energy Agency's Technology Catalogue; Danish Energy; QVARTZ analysis.

In connection with the build-out, areas which are not ideal in terms of wind resources will have to be used, existing wind turbines and properties will have to be purchased and payment under renewable energy schemes will be required[4.8]. The costs associated with the above mean that the necessary onshore wind build-out depends on the already planned technology-neutral tenders from 2020-2024 being maintained.

In addition to the build-out through technology-neutral tenders, a small share of capacity is expected to be realised without direct subsidies from the technology-neutral tenders. This is expected to be possible, as the production costs of onshore wind have fallen in recent years and are expected to continue to decline up until 2030, partly due to the ability to construct taller onshore wind turbines[4.9]. Subsidy-free installation will primarily be possible in the latter half of the 2020s in particularly favourable locations with low construction costs as well as costs of purchasing existing wind turbines and residential properties in combination with good wind resources.

The total investment needed for the build-out of onshore wind turbines to reach the 70% reduction target is expected to be in the range of DKK 25-35 billion, which is shouldered by onshore wind developers[4.10]. However, some of the production volume from operational wind turbines will be subsidised by the technology-neutral tenders.

In the Energy Agreement 2018, funds are earmarked for the implementation of annual technology-neutral tenders for the period 2020-2024 to support the build-out of land-based renewable energy sources. In the tenders completed so far, the demand for subsidies has been weaker than expected and we are likely to see continued cost reductions for land-based renewable energy sources which allow an increasing number of installations to be established on market terms. As with offshore wind, developers of land-based renewable energy installations must be offered a risk-sharing model. In addition, the deployment of bilateral power purchase agreements (PPAs)[4.11] should be supported to reduce the risk associated with uncertainty about the progress of electrification efforts, which will further reduce the need for subsidies.

4.1.1.3. Power generation from solar power must be increased tenfold

Historically, household solar panels have accounted for most of the build-out of solar capacity in Denmark, but towards 2030 predominantly commercial field installations with much higher capacity will be deployed.

To help achieve the 70% reduction target, power generation from solar power must be increased by a minimum of 8-9 TWh by 2030. This will bring the total power generation from solar power to 9-10 TWh in 2030, which is roughly a tenfold increase of the existing power generation from solar power of around 1 TWh.

To deliver the necessary power generation, the installed solar capacity must be increased by approximately 7.6 GW net from the existing 1.2 GW in 2019 to 8.8 GW in 2030. Of the necessary build-out, a small number of solar installations are already being constructed using the subsidies granted from the technology-neutral tenders in 2018 and 2019, which means that the total additional build-out needed towards 2030 will be approximately 7.4 GW, see Figure 19.

Of the 7.4 GW, 4-6 GW is expected to be realised in continuation of the subsidies granted from the technology-neutral tenders agreed from 2020 to 2024. The installation time from the tender is launched to the solar capacity is operational is approximately one year. The build-out of solar power is covered by the new renewable energy schemes, which will offer sales options to properties, cover loss of value and fund renewable energy bonuses as well as providing subsidies for the green climate pool resulting from the Energy Agreement 2018. The necessary solar build-out is therefore conditional upon the technology-neutral tenders already planned for 2020-2024 being maintained.

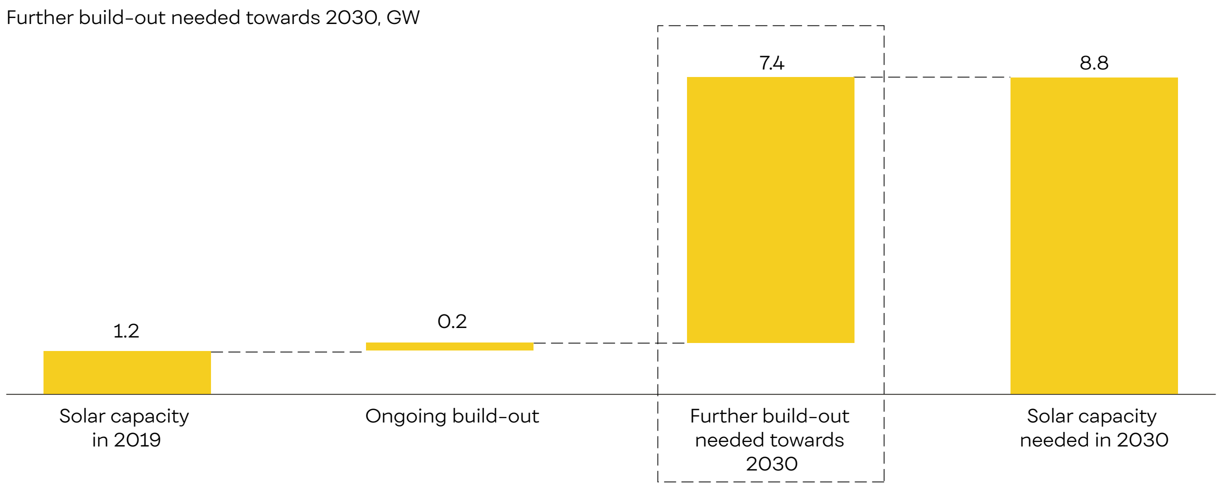
4.8 Schemes comprise renewable energy bonuses, sales options, loss of value and green pools.

4.9 The price of onshore wind is reduced by 30% from 2015 to 2020 and is expected to be reduced by a further 13% towards 2030 (the Danish Energy Agency (2019): the Technology Catalogue).

4.10 3.9 GW is to be added, of which approximately 0.3 GW is under construction as a result of the technology-neutral tenders in 2018 and 2019. The remaining 3.6 GW represents the proposed further build-out towards 2030.

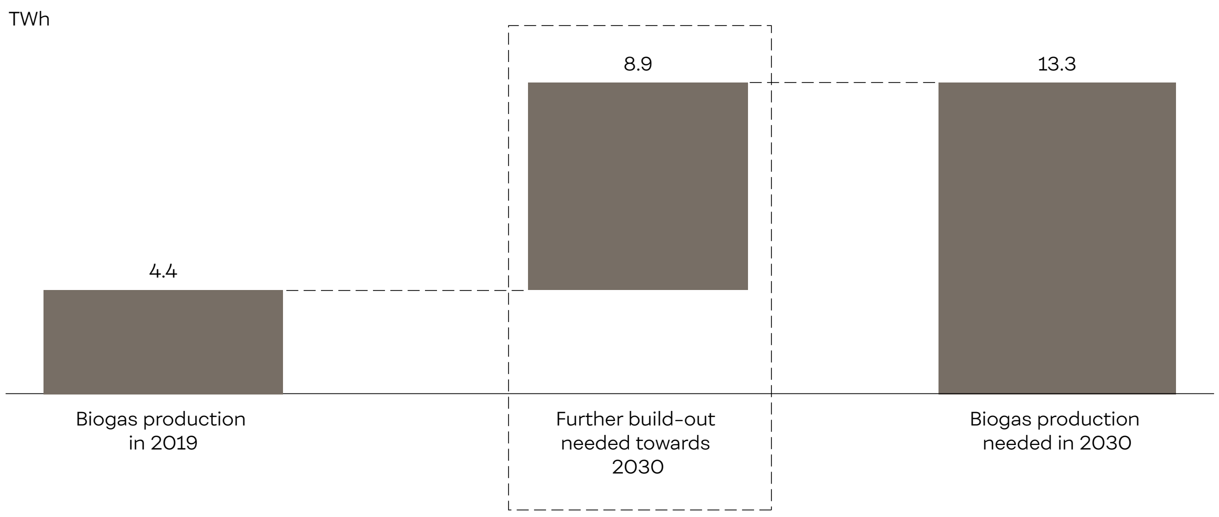
4.11 *Power purchase agreements* (PPAs)

Figure 19. **Build-out of solar power to deliver the amount of power needed by 2030 (GW)**



Note: Assuming that the approximately 0.2 GW of solar capacity approved in 2018 and 2019 in the technology-neutral tenders has not yet been constructed. Unlike offshore wind and onshore wind, decommissioning of solar energy towards 2030 is expected to be minimal, so there is no significant variation between the net and gross build-out. The 1.1 GW of solar capacity in 2019 is intended solely for power generation. At the end of 2019, enquiries had been made to Energinet and the distribution companies (Danish Energy) concerning the connection of approximately 10 GW of solar power. However, it should be emphasised that not all projects may necessarily be realised simply because an enquiry has been made.
Source: Denmark's Energy and Climate Outlook 2019; the Danish Energy Agency's Technology Catalogue; Danish Energy; QVARTZ analysis.

Figure 20. **Build-out of biogas production to deliver the biogas needed by 2030 (TWh)**



Source: Denmark's Energy and Climate Outlook 2019; the Danish Energy Agency (2019); Danish Energy; QVARTZ analysis.

In the latter half of the 2020s, it is expected to be possible to establish solar panels without direct financial support. This is because the price of key components for solar installations, which has been markedly reduced in recent years, is expected to be further reduced towards 2030[4.12], primarily in areas where conditions are particularly favourable for solar installations.

The total investment needed for the build-out of the 7.6 GW solar farms to reach the 70% reduction target is expected to be in the range of DKK 25-30 billion, which is shouldered by solar project developers[4.13]. However, some of the production volume from operational solar farms will be subsidised by the technology-neutral tenders.

For both onshore wind and solar power, falling production costs are a key element in the potential transition to market terms. Another key element is the ability to join bilateral power purchase agreements. For energy-intensive companies, being able to predict the costs of their future power consumption is beneficial, and knowing the long-term settlement price helps power producers to protect their investment. Confidence that sufficient capacity is available in the transmission grid to ensure the supply of power is important to the widespread use of power trading agreements.

The extensive build-out of power generation from offshore wind, onshore wind and solar power must deliver approximately 85% of the increase in renewable energy towards 2030 and is crucial to Denmark's ability to meet the 70% reduction target. In addition to a significant increase in renewable power generation, other renewable energy sources must also be developed as described in the following sections.

4.1.2. Biogas production must be almost tripled

To achieve the 70% reduction target, biogas production must be expanded by 8.9 TWh from 4.4 TWh in 2019 to 13.3 TWh in 2030, see Figure 20. The 13.3 TWh of biogas production corresponds to the total expected natural gas consumption in Denmark in 2030[4.14].

Towards 2030, biogas will be used primarily in industry and the transport sector and to a lesser extent in district heating production for peak and reserve loads as well as in individual heating systems as described in chapter 2. In industry, biogas can replace natural gas, while in the transport sector it can be used as fuel, for example as methane or be converted into liquid fuels. In addition to reducing carbon emissions through fossil fuel displacement, it can also reduce carbon emissions from liquid manure when the manure is degassed in biogas production. The used manure is returned to the fields after biogas production, where it can be used more effectively and with less negative impact on the environment in other agricultural processes.

Of the existing biogas production of 4.4 TWh, around half is raw biogas which can be used for incineration purposes in heat production and to a limited extent in industry, but which cannot be used in the natural gas grid. The other half is upgraded biogas, which can be used as a direct substitute for natural gas in the gas grid[4.15]. The total build-out of 8.9 TWh towards 2030 must be in the form of upgraded biogas.

For this build-out, applications to connect biogas plants with a total production of 3.0 TWh of biogas towards 2023 have already been submitted under the current subsidy scheme. The remaining 5.8 TWh are expected to be constructed and connected in parallel towards 2030. The biogas build-out follows a significant build-out over the past five years, when Danish biogas production has almost tripled[4.16].

4.12 The Danish Energy Agency (2019): the Technology Catalogue. The price of solar capacity is reduced by a further 34% towards 2030

4.13 7.6 GW is to be added, of which approximately 0.2 GW is under construction as a result of the technology-neutral tenders in 2018 and 2019. The remaining 7.4 GW represents the proposed further build-out towards 2030.

4.14 Natural gas consumption in Denmark is expected to fall from approximately 23.2 TWh in 2019 to 13.3 TWh in 2030, in part due to the electrification of a number of processes which were previously based on gas as well as replacement with biogas. The 13.3 TWh are exclusive of natural gas consumption in the North Sea production as well as refinery gas which is expected to make up approximately 6 TWh by 2030.

4.15 Raw biogas consists of approximately 60% methane and 40% carbon dioxide. Carbon dioxide has no fuel value. After separating the 40% carbon dioxide and an amount of water and sulphur, only pure methane remains – the upgraded biogas.

4.16 Denmark's Energy and Climate Outlook 2019.

Historically, biogas plants have mainly been small farm installations, but in future the build-out is expected to take the form of large shared industrial plants, which typically produce over 0.14 TWh of upgraded biogas per plant[4.17]. In addition to the expansion and build-out of new plants, some of the build-out is also expected to come from productivity improvements at existing plants[4.18]. The well-developed Danish gas grid ensures that the biogas can be marketed from both small and large production plants and that the biogas can be transported for consumption connected to the gas grid.

Failure to sufficiently scale production capacity or a lack of input for the production itself may potentially hamper the build-out. Such input includes liquid manure, industrial waste, organic household waste, agricultural waste, etc. The biogas industry itself estimates that the production capacity can be scaled sufficiently towards 2030. The Danish Agriculture & Food Council estimates that the total potential Danish input to biogas production in 2030 will be equivalent to approximately 15 TWh of upgraded biogas[4.19]. The potential can be further raised by 10 TWh if the carbon dioxide content of biogas is also used for the production of increased amounts of methane as described in section 4.1.4.

The total investment needed for the build-out of biogas production by 8.9 TWh in the period 2019-2030 is expected to be DKK 15-20 billion and is shouldered by biogas developers. Of this, production of up to 3 TWh is expected to be connected under the current rules up until 2023. In addition, the remaining build-out should be put to competition so that biogas market players can compete to supply biogas at the lowest possible subsidy costs. Some of the build-out will consist in expansions of existing plants, which are expected to need fewer subsidies. The biogas industry is committed to at least halving biogas production costs per TWh by 2030 through efficiency improvements and economies of scale. This can be further supported by a growth in demand, for example by imposing blending or displacement requirements on the transport sector.

4.1.3. There are only minor changes in energy production from other biofuels

Towards the 70% reduction target in 2030, only minor changes in the energy consumption of the other three biofuels – biomass, biowaste and biodiesel – are expected.

Biomass

Energy consumption from biomass is expected to fall by 6.4 TWh from 43.1 TWh in 2019 to 36.7 TWh in 2030. As a result, biomass's share of total energy consumption will fall from approximately 23% in 2019 to 21% in 2030. Biomass primarily comprises wood chips, wood pellets, firewood and straw and is used for the production of power and district heating in the energy sector as well as for heating homes with wood pellet boilers and wood burning stoves. The use of biomass has played a major role in replacing coal and natural gas in energy production, but will be reduced by 2030. This is due in part to the growing use of heat pumps in individual heating systems and the generally lower power generation from CHP plants, reducing the use of biomass.

Biowaste

Energy consumption from biowaste is expected to grow by 0.8 TWh from 6.3 TWh in 2019 to 7.0 TWh in 2030, in part because biowaste is expected to increasingly replace fossil waste in waste-to-energy plants.

Biodiesel and bioethanol

Energy consumption from biodiesel and bioethanol is expected to increase by 2.1 TWh from 2.6 TWh in 2019 to 4.7 TWh in 2030. Biodiesel and bioethanol are blended into diesel and petrol and have been an early instrument for the transformation of the transport sector, driven by blending requirements. Biofuels currently account for about 4% of total fuel consumption in the transport sector[4.20]. Biofuels are mainly based on rapeseed blended with other oily crops.

By 2030, biofuels are expected to play a greater role in the transformation of especially the heavy transport sector.

4.17 Compared to about 0.03 TWh for the small farm installations, which are typically shared between one or more farms.

4.18 The increased biogas production is in part due to the fact that the biogas industry steps up its capacity by, for example, adding straw and making general productivity improvements (such as economies of scale and more frequent evacuation of liquid manure, resulting in a higher gas content).

4.19 University of Southern Denmark and SEGES (2020): Energiafgrødeanalysen (preliminary report).

4.20 The Danish Energy Agency (2018): Energy statistics. Covers biodiesel and bioethanol.

4.1.4. Power-to-X must be expanded to enable large-scale deployment

There are a number of processes in which fossil fuels cannot be directly replaced with power, biogas or biomass, among others. These include heavy transport such as trucking, shipping and aviation as well as industrial processes where the necessary energy storage or density is currently only possible using fossil fuels. Power-to-X technologies can be used to produce fuels that can achieve a similar level of energy storage and intensity and thus replace fossil fuels.

Power-to-X means that *power* is used in electrolysis to produce hydrogen or a hydrogen-based product *(X)*. If the power used in electrolysis is green, the product itself will also be green. The immediate product of electrolysis is hydrogen, which can be used directly, for example in transport or as a substitute for fossil hydrogen in industrial processes or at refineries. It can also be used for energy storage, for example to smooth out fluctuating production patterns in offshore wind, onshore wind or solar power. In addition to using the hydrogen directly, it can also be processed with other chemical products such as carbon dioxide from a sustainable source or nitrogen to produce more advanced green fuels.

Carbon dioxide for green fuels comes from carbon capture from chimneys or from biogas. Raw biogas contains approximately 35-40% carbon dioxide which is currently separated to produce upgraded biogas that can be injected into the gas grid. Going forward, hydrogenation (hydrogen enrichment) of raw biogas will allow this carbon dioxide to be used in the production of renewable hydrogen-based fuels such as methane or methanol. The use of carbon dioxide from biogas will result in a significant increase in power consumption for hydrogen production at or near the biogas plants. Using hydrogenation of raw biogas, the total production from biogas plants can be increased from a biogas production of 13.3 TWh (see section 4.1.2) to a total green production of approximately 15-20 TWh.

If Denmark is to reach the 70% reduction target, the energy and utilities sector estimates that Power-to-X will have to deliver carbon reductions of 1.9 million tonnes. Some of the expected applications include hydrogen for heavy transport, diesel from renewable energy[4.21], dimethyl ether (DME) for heavy transport or methanol, for example for blending with fuel for heavy transport or for direct use in ships or vehicles, but may also include other applications such as hydrogen or methane for heavy industry. The total required electrolysis capacity is expected to be 2-3 GW in 2030, but this largely depends on the ultimate applications.

Other Power-to-X products are ammonia for shipping and kerosene for aviation, which will have a limited carbon reduction potential in an isolated Danish context, but which may have an enormous global potential for carbon reductions in international transport. At the same time, Denmark may potentially benefit from Danish logistics companies' good domestic opportunities for testing and phasing in green fuels in anticipation of future international regulation in this area. Ammonia and kerosene's potential contribution to the international transformation is described in chapter 5.

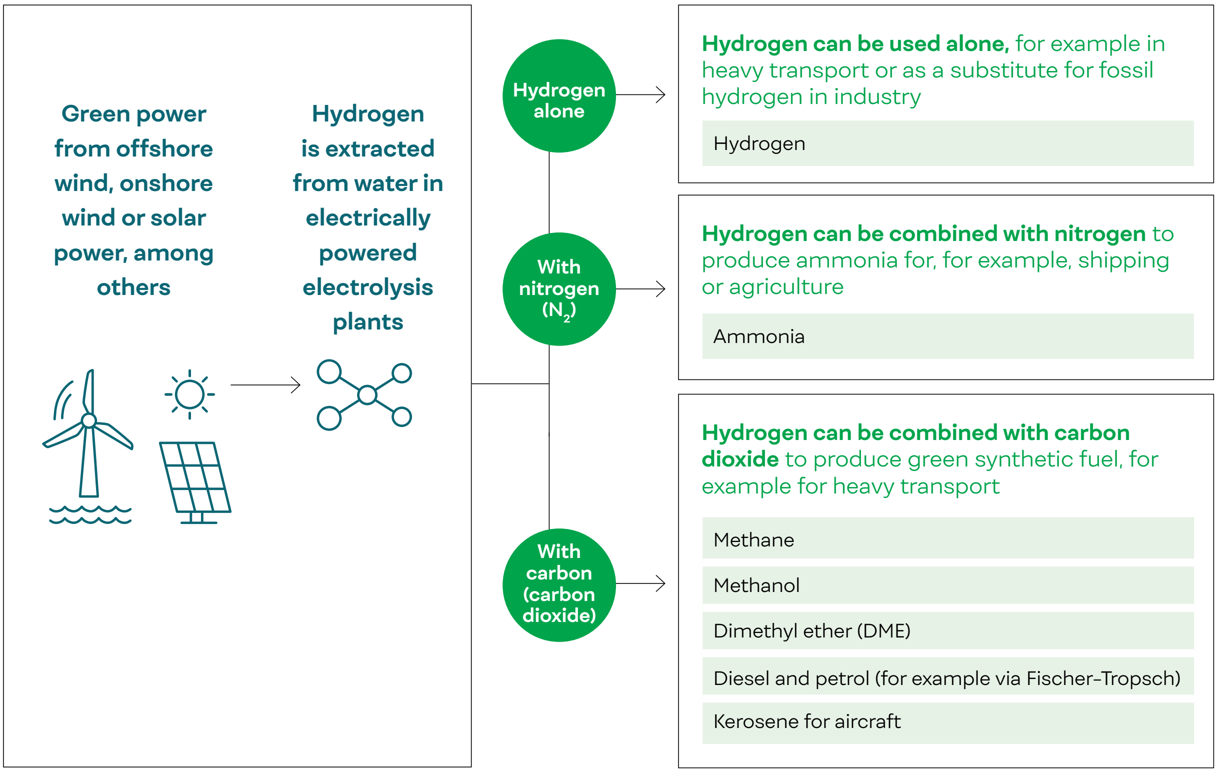
There is currently no large-scale production of Power-to-X in Denmark, but a number of demonstration projects are being established and developed in Skive, Fredericia and Copenhagen, among other cities. Achieving the 70% reduction target requires a substantial build-out of a number of full-scale plants in close cooperation between government, energy companies and other business partners as buyers of hydrogen-based fuels.

To ensure the necessary scaling, it is recommended that a national Power-to-X strategy be developed which must ensure the necessary level of investment and framework conditions as well as supporting demand. A Danish Power-to-X strategy may build on Energinet's Power-to-X action plan (2020), among other things.

The overall investment for the build-out of the Power-to-X production needed to support the 70% reduction target is expected to be in the range of DKK 10-20 billion. At the same time, DKK 2-5 billion will have to be invested to build the necessary associated infrastructure. As the ultimate Power-to-X applications in Denmark in 2030 are not yet known, the estimates are purely indicative.

[4.21] For example via a Fischer-Tropsch process.

Figure 21. **Power-to-X production process**



Source: Danish Energy; QVARTZ analysis.

Power-to-X is expected to play a crucial role on the road to full climate neutrality by 2050, and by working towards a build-out as early as 2030, Denmark will have a strong platform for expanding the build-out.

Section 4.1 described how the energy and utilities sector needs to significantly expand the production of renewable energy in order to supply energy for heat pumps, electric vehicles and heavy transport, among others. When the energy production is scaled, the associated energy infrastructure will also have to be scaled. This is described in the following section.

4.2. Infrastructure must be enhanced to accommodate future energy needs

The 70% reduction target places new demands on the Danish energy infrastructure. When fossil fuels are replaced with solar and wind, the power grid will have to transport significantly larger amounts of power, far larger of amounts of renewable energy will have to be connected to the grid and more power will have to be moved across national borders. At the same time, improved technologies such as batteries, data utilisation and demand-side response management enable better use of the grid and limit the need for grid upgrades. New infrastructure must be developed at sea in the form of a connected power grid in the North Sea and perhaps the Baltic Sea. In addition, the potential for energy islands should be identified.

In some places, the gas infrastructure will have to be shut down and elsewhere it will have to be converted to be able to transport green gases instead of natural gas. In some places, the district heating grid will have to be developed, while elsewhere district heating may be displaced by cheaper, individual green alternatives. With the development of Power-to-X technologies, a dedicated hydrogen infrastructure may also be needed beyond 2030. Finally, a closer sector coupling in the energy and utilities sector means that the power, gas and district heating grids will have to be used in new ways and with a higher degree of integration between the different supply forms.

Developing the energy infrastructure takes time and upgrading the infrastructure as part of ordinary replacement and maintenance work will be more effective. Investments in infrastructure are also capital-intensive and have long planning and investment horizons, which means that decisions on any upgrades must be made as soon as possible. In other words, the infrastructure needs to accommodate future energy needs to avoid having to dig up the same soil multiple times and remove otherwise well-functioning assets from service.

4.2.1. The power grid must be enhanced to support the growth in power consumption and production

The Danish power grid has a very high quality of supply and supplies power at competitive prices. This means that power is available to Danish homes and businesses virtually at all times. However, both the distribution and transmission grids will have to be significantly strengthened in order to maintain a high quality of supply in a green society in 2030, where twice as much power has to be supplied to end-users and where, for example, up to 1.5 times as much decentralised renewable production capacity is connected to the power distribution grid.

In 2019, the amount of power transported to Danish consumers equalled a power consumption of 35 TWh, split into 34 TWh at distribution level and 1 TWh at transmission level. In addition, 5.7 GW of renewable power generation capacity at distribution level and 1.5 GW at transmission level was connected. By 2030, total power consumption is expected to reach as much as 71 TWh, split into 58 TWh at distribution level and 13 TWh at transmission level. At the same time, an additional 15.2 GW of renewable power generation capacity is expected to be connected by 2030, resulting in an increase of up to 8.2 GW of decentrally connected renewable power generation capacity in the distribution grid. This places great demands on the power grid because, in addition to transporting more power, it also has to deal with a significantly changed energy flow due to the high level of decentralised production, among other things. On the Danish west coast, there are already examples of local grids, which were built at a time when power was produced using fossil fuels, and which are therefore dimensioned according to demand, at times have to handle up to ten times as much power production as consumption.

The distribution grid

Towards 2030, the distribution grid will have to be enhanced to handle up to 8.2 GW of additional connected onshore wind and solar power and to transport 24 TWh more power for consumption annually than it does today, i.e. an increase of 71%. On the consumer side, the enhancement is needed to supply power for the partial electrification of the transport and heat sectors, power for new hydrogen production and increased amounts of power for industry, agriculture and heavy industry. This includes power for 1.5 million electrical and plug-in hybrid vehicles, power for just under half of bus transport, power to replace oil boilers and natural gas boilers in private households and power for approximately 550 MW large collective heat pumps to replace natural gas cogeneration in decentralised district heating areas.

On the production side, it is expected that an additional 15.2 GW of renewable power generation capacity will be connected by 2030, including 9.3 GW of onshore wind and solar power, in order to achieve the Danish climate target. If the transmission grid is sufficiently enhanced and market players are provided with clear information and clear incentives to establish production in locations where production and grid connectivity can happen most efficiently, it is expected that around 5.4 GW of the additional onshore production capacity will be connected to the distribution grid and approximately 3.9 GW will be connected to the transmission grid[4.22]. Failing that, up to 8.2 GW is expected to be connected to the distribution grid and down to 1.1 GW is expected to be connected to the transmission grid.

The transmission grid

Similarly, the transmission grid will have to be enhanced to connect new production capacity and to supply far greater amounts of power to the distribution grid and 13 TWh more power than it does today to large new power consumers connected directly to the transmission grid. The new transmission consumption is expected to come from large collective heat pumps and electric boilers, data centres, hydrogen production, rail transport and partial electrification of the North Sea.

Investments in power infrastructure

To assess the costs of enhancing the power grid, two scenarios are used: a smart scenario and an expensive (inflexible) scenario. In the smart scenario, grid utilisation is optimised due to the activation of demand-side response, digitisation and geographical signals for the placement of new production, among other things. For example, it is assumed that consumers shift some of their power consumption to less-congested times of the day, smoothing out consumption more evenly over the course of the day. The expensive scenario offers no incentive to shift consumption or place new production in attractive locations. As a result, more investment is needed to deal with the added pressure on the grid that occurs when many people are charging their electric vehicles at the same time when they come home from work.

The total additional cost of enhancing the power grid to support the growth in power consumption and production is expected to amount to DKK 23 billion towards 2030 if the grid is used smartly, but if it is not, this figure may rise to DKK 54 billion, see Figure 22. If the grid is used smartly it may reduce the power distribution tariff by 5% compared to the present level, as the investments will result in a much higher power consumption. If the grid is not used smartly, the development will result in an increase of 10%. Overall, if the grid is used smartly, the power grid's ability to support the 2030 climate target is not expected to lead to higher distribution tariffs for Danish power consumers as also described in chapter 6.

A total of DKK 29 billion will already have to be reinvested in the distribution grid to maintain the current demand for power in 2030. An upgrade of the distribution grid to support the 70% reduction target is estimated to cost an additional DKK 13-33 billion depending on whether the grid is used smartly or expensively. The additional investment required to support the 70% reduction target in the smart scenario assumes that consumers are willing to shift some of their power consumption if they are rewarded for doing so. If many consumers instead opt to pay the higher cost of consuming power at times that particularly warrant a grid expansion, the power grid should be upgraded to support this. It is therefore important that grid tariffs send the right price signals, i.e. that they reflect the cost of using the grid at any given time.

For the transmission grid, investments totalling DKK 10 billion were already decided in early 2020, primarily for functionality upgrades and a new interconnection to the UK. In addition, DKK 15-20 billion must be invested to maintain the current demand for power in 2030[4.23]. An upgrade of the grid to support the 70% reduction target is estimated to cost an additional DKK 5-15 bil-

[4.22] The distribution is based on calculations from Danish Energy's experience with grid connection, including data from the compensation scheme.

[4.23] Energinet based on Energinet's Reinvestment, Expansion and Restoration Plan (RUS Plan) 2018.

lion and DKK 15-25 billion, respectively, depending on whether the grid is used smartly or expensively[4.24].

A number of conditions must be met in order for the grid companies and Energinet to make the necessary investments. Among other things, it should be ensured that the companies have the financial resources needed to support the 70% reduction target and that a strategy and tools are developed to ensure the backing of citizens for onshore transmission projects. It is also essential that there are clear policy objectives for the overall direction of the energy transformation, which will enable a timely and efficient build-out of the infrastructure.

The power grid must be ready for electrically powered transport

The upgrade of the power distribution grid to potentially handle 1.5 million electric and plug-in hybrid vehicles as well as partially electrified heavy road transport by 2030 is expected to require extra investments of DKK 6 billion in the period 2019-2030[4.25].

The extra investment needed in the power grid to handle DKK 1.5 million green vehicles by 2030 compared to a situation with just 1 million green vehicles will not have much impact on the individual power consumer's bill. However, the consequences and cost of underestimating the number of green vehicles are likely to be much more significant, as power grid companies risk having to dig up otherwise well-functioning cables to replace them.

Specifically, the extra investment needed towards 2030 to upgrade the power distribution grid to handle DKK 1.5 million vehicles rather than 1 million green vehicles totals approximately DKK 1.7 billion – or about DKK 45 per year per power consumer connected to the low-voltage grid[4.25]. If in 2035 there will be 1.5 million green vehicles on the roads anyway to also achieve the target of full climate neutrality by 2050, the total extra investment needed to prepare the power grid for 0.5 million green vehicles five years ahead of schedule is reduced to around DKK 1 billion in the period 2019-2035, as some later investments will not be necessary[4.25]. This equates to just under DKK 20 per year in the period 2019-2035 per power consumer connected to the low-voltage grid.

In other words, the extra investment is expected to be associated with a relatively small annual 'insurance premium' of approximately DKK 45 per power consumer in the period 2019-2030 or just under DKK 20 per power consumer in the period 2019-2035, see Figure 23.

The location of Power-to-X plants has a major impact on the power grid

The production of hydrogen in connection with Power-to-X requires large amounts of power for electrolysis (10 TWh in 2030). Towards 2030, a portion of Power-to-X is expected to happen near distributed carbon sources such as biogas plants and some of the electrolysis consumption can thus be expected to be connected to the power distribution grid. Electrolysis plants for the production of hydrogen for heavy transport are not dependent on carbon sources and are placed where it makes financial sense and where there is easy access to logistics infrastructure. These plants are expected to be connected to both the transmission and distribution grids, depending on their size.

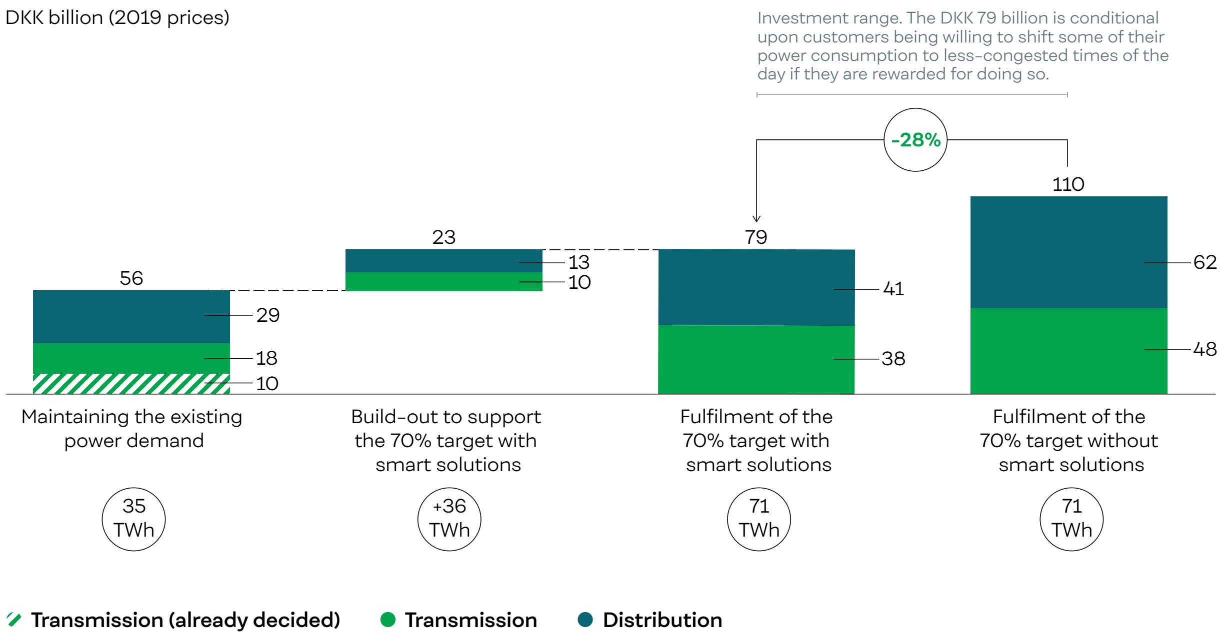
If large-scale hydrogen production is established, it will require correspondingly large amounts of power. To avoid having to design the distribution and transmission grids to transport the potentially large amounts of energy for hydrogen production over long distances, it may be advantageous to place large-scale Power-to-X plants in the vicinity of the energy sources. In the long term, there may be a need for transnational offshore infrastructure to harness the full offshore wind potential in the North Sea, in particular. This will require a new type of offshore infrastructure for both power and hydrogen as described in chapter 5.

4.2.1.1. Smart measures and demand-side response will reduce the need for investments in the power grid

A number of smart measures may reduce the need for expanding the distribution and transmission grids, see Figure 24.

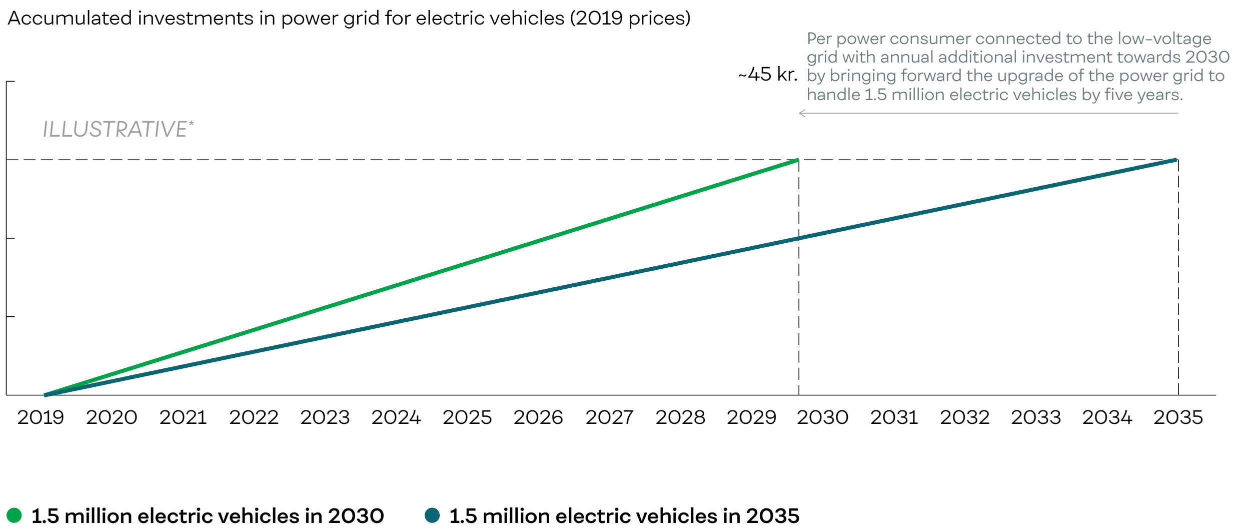
[4.24] The estimates are exclusive of investments in further interconnections, potential energy islands and cabling to shore.
[4.25] Calculations made by Danish Energy.

Figure 22. **Investments in power grid infrastructure towards 2030**



Note: Investments in transmission already decided are budget figures at the beginning of 2020 and mainly comprise functionality upgrades and costs for a new interconnection to the UK. Other investments in maintaining the existing demand for power are reinvestments in the period 2019-2030. Transmission figures for investments not yet decided represent the mean of large intervals and are exclusive of investments in additional interconnections, a potential energy island and cabling to shore. For the transmission grid, the illustrated effect of a non-smart transformation is an example. Calculations for the distribution grid are exclusive of investments to support the 3 TWh increase in consumption in 2019-2030 from agriculture and the private service sector (~5% of total consumption from the distribution grid in 2030).
Source: Calculations made by Danish Energy and Energinet based on the RUS Plan 2018.

Figure 23. **Additional cost towards 2030 of being ready for 1.5 million electric and hybrid vehicles five years ahead of schedule**



* The illustration is simplified, as a phase-in of electric and hybrid vehicles is likely to be S-shaped.
Note: The additional investment of DKK 45 per power consumer will be reduced in the long term, as bringing forward investments will reduce investments beyond 2030. In the period 2019-2035, the additional investment per power consumer is reduced to just under DKK 20.
Source: Danish Energy; QVARTZ analysis.

The distribution grid

Power consumption is currently relatively inflexible and peaks in the 'peak cooking hours' between 17.00 and 20.00, when many people come home from work, make dinner, do the laundry and turn on the TV. At this level of classic power consumption, there is currently sufficient capacity in the distribution grid to cope with demand. But by 2030, more electric vehicles and individual heat pumps will increase the demand for power during peak cooking hours. This new consumption will be absorbed in the low-voltage grid, but will also be transported through the higher voltage levels of the power grid, where increased consumption from collective heat pumps, industry, Power-to-X etc. is also absorbed.

More demand-side response may reduce the need for strengthening the power grid, see Figure 25. In an inflexible scenario, where electric vehicles are primarily being charged when consumers come home from work, there will be a significant peak in consumption during peak cooking hours. This requires relatively large capacity in the power grid, as cables and substations must be large enough to cope during these hours. In the flexible scenario, on the other hand, power consumption is distributed more evenly over the course of the day, reducing the maximum load on the power grid and thus also the need for strengthening the grid.

A number of levers, notably correct price signals (grid tariffs) can help to support demand-side response and reduce the need for a distribution grid upgrade. Power grid companies are in the process of modernising the tariff and are introducing tariffs that vary over the course of the day to reward power consumers for consuming power at less-congested times.

Demand-side response can be increased in the individual household using household batteries as well as flexible charging of electric vehicles and flexible use of heat pumps. The 2019 EcoGrid 2.0 demonstration project has shown that it is possible to achieve a sustained effect of demand-side response, when so-called 'aggregators' take control of power panels and heat pumps in an area and pool flexibility across households. Flexibility can be achieved without compromising on the power consumers' heat comfort. The development of local markets for flexibility can also support agreements with, for example, district heating companies and other players which can either shift much of their own consumption or small aggregated pools of consumption.

Sector coupling can be used to exploit the storage potential of other utilities sectors in order to boost flexibility, for example in existing and new heat storages in the district heating system. In a future with increased electrification of the district heating sector, the interaction between the power grid and power consumption in the district heating sector will become increasingly important. Heat storages can store energy from periods when power generation is relatively high and the power grid is less congested for periods when power generation is relatively small and grid congestion is higher.

In addition to adding value for customers, releasing supply data may pave the way for new business models by allowing commercial players to optimise the flexibility potential by developing products for smart power consumption management[4.26]. Finally, continued innovation in this area may lead to new solutions to the relationship between demand-side response and the power grid.

Smart use of the power grid requires digitisation, enabling power grid companies to operate the grid closer to the capacity limit without risking disruptions and better anticipate where there will be an increased need for flexibility. It also requires geographical signals for placing new production to make sure it is established in the right locations, including with regard to production, grid and system costs.

The implementation of smart measures for the distribution grid also assumes that regulation through benchmarking does not, as is the case today, provide an incentive to expand the grid rather than using smart solutions. Furthermore, the implementation requires faster approval processes for tariff changes, better conditions for the release of supply data and continued development of the political framework for cyber and information security in the utilities sector.

[4.26] Power grid companies can make user-relevant data available on neutral and easily accessible terms. By the end of 2020, all households in Denmark will have a digital, remotely read meter that records power consumption and other information about power and disruptions. The power grid companies have launched a process to develop a common tool for the release of consumption and production data in combination with other data sources of the power grid companies, which may be ready by the end of 2021.

Figure 24. **Examples of smart measures in the power grid**

Updated pricing	Flexibility in households	Flexibility via sector coupling
Release of supply data	Local flexibility markets	Innovation
Geographical signals	Peak-shaving	Market agreements on automatic disconnection of consumption

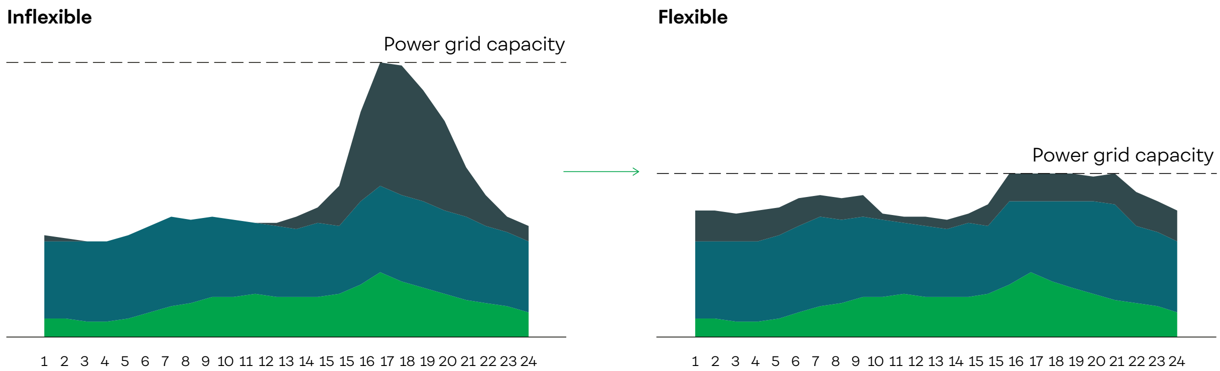
● **Distribution grid** ● **Transmission grid**

Source: Danish Energy and Energinet.

Figure 25. **Maximum 24-hour load on the power grid in inflexible and flexible consumption scenarios**

Power consumption (kW) in the low-voltage grid (0.4 kV), hours a day

ILLUSTRATIVE EXAMPLE



● **Ordinary consumption** ● **Individual heat pumps** ● **Electric vehicles**

Source: Danish Energy.

The transmission grid
The costs of strengthening the transmission grid can be reduced through suitable placement of new production and new consumption of renewable energy which reduces the maximum load on the grid and the distances over which power has to be transported. This can be encouraged by providing market players with clear information and clear incentives to establish production in locations where production and grid connectivity can happen most efficiently.

To avoid having to design the transmission grid to handle the few hours when solar and wind production is at its highest, measures such as markets for local downward regulation and geographical price signals may be introduced to either reduce production or increase consumption close to production at these times.

Alternatively, Energinet may enter into market agreements with production plants which are automatically disconnected in the event of a critical failure of a grid component. This automatically alleviates grid load and prevents damage to grid components, optimising the use of the existing power grid. However, there is little experience using automatic disconnection of renewable energy, even if the technology is known.

4.2.1.2. Maintaining a high level of security of supply towards 2030 requires further initiatives

Denmark boasts one of Europe's highest security of power supply levels with a more than 99.9% grid uptime. The high level of security of supply is due in part to high power adequacy, i.e. Danish power consumption is matched by either producing or importing a corresponding amount of power. The historical and current high power adequacy is due to the fact that a relatively large amount of power is generated using flexible production methods based on fossil fuels, biomass, waste and biogas. Together they account for 46% of power generation, while the remaining 54% are made up of energy sources (offshore wind, onshore wind and solar power) that cannot be switched on to meet demand. Denmark is part of an efficient regional power market with direct connections to Norway, Sweden, Germany and the Netherlands which means that power can be imported during periods, when power consumption exceeds power generation. As a result, the security of power supply cannot be viewed from a purely national perspective. Secure levels of foreign power generation are thus crucial to Denmark's security of supply and an important condition for the ability to integrate an increased amount of solar and wind in the Danish power system using existing technologies.

The flexible fuels will largely be phased out towards 2030 and replaced with mainly offshore wind, onshore wind and solar power. By 2030, the three energy sources are expected to account for up to 88% of total power generation[4.27]. In the rare but possible case that no power is produced from either offshore wind, onshore wind or solar power, Denmark will be dependent on the ever-decreasing number of CHP plants[4.28] and power imports from neighbouring countries, which are also phasing out flexible power generation capacity. The level of overall security of supply is determined by the Danish Minister for Climate, Energy and Utilities following an overall assessment by Energinet based on Denmark's Energy and Climate Outlook and an assessment of the development in Denmark's neighbouring countries[4.29].

It is important that the achievement of the 70% reduction target is not compromised by power customers and, by extension, society at large losing trust in energy being available when they need it. More instruments and initiatives will therefore be needed in the coming years to ensure that Denmark can maintain its high level of security of supply in 2030.

To this end, a combination of the following instruments may be used (the list is not exhaustive):

- **Development of interconnections:** Additional connections, especially in Eastern Denmark, to Sweden, Germany or Poland to increase trade capacity and allow increased cross-border trade in ancillary services (for example in connection with offshore wind farms).

[4.27] The remaining 12% primarily comprise biomass (9%), waste (2%) and biogas (1%).
[4.28] The increased share of renewable power generation is expected to result in more fluctuating power prices which increase the financial risk for CHP plants, thereby reducing the incentive to maintain and expand cogeneration capacity.
[4.29] The overall security of supply reflects power adequacy, the quality of supply of the distribution and transmission grids and cybersecurity.

- **Utilisation of battery or storage capacity:** Examples include decentral battery capacity in the grid (electric vehicles and homes) or industrial-scale plants and other forms of energy storage such as green gas storage, rock storage, etc.

- **Less peak load and more demand-side response:** Incentives to shift power consumption from periods when power consumption is traditionally high, for example by means of changed price formation, sector coupling, etc. or by means of directly interruptible consumption. Much of the power consumption will be from sources that have a higher degree of flexibility compared with what it is today, for example charging of electric vehicles, heat pumps, etc.

- **Correct price signals:** Energinet must continuously determine the need for services to maintain the desired level of security of supply and, as far as possible, provide the necessary services through market-based methods. These include tenders to obtain the correct price signals for investment in technologies for delivering ancillary services, which can often be delivered by the same technologies and installations that contribute to power adequacy.

The latest report on security of supply shows an increased risk of disruptions for customers on the island of Sealand[4.30]. Doubling power consumption and a corresponding phase-out of thermal power plants powered by coal and natural gas will put further pressure on the Danish power system, especially if consumption is not price flexible. In addition, phasing out, for example, nuclear power and coal in Germany will also exacerbate the situation in Denmark's neighbouring countries. It is therefore important that both the assessment of and steps to maintain security of supply are assessed in light of a consistent energy system scenario calculated on the basis of the 70% reduction target and up-to-date knowledge of the development in neighbouring countries. It has not been possible within the given time limit to assess whether and to what extent this will lead to higher costs, but there is much to suggest that costs will rise.

The assessment must also include the potential effects on the security of heat supply which is increasingly being challenged by the phase-out of adjustable power plant capacity and sensitivity to potential disruptions of the power system.

4.2.2. The district heating grid must be expanded, and operations must become flexible

The district heating grid must be expanded to replace approximately 140,000 individual natural gas boilers. The transition from natural gas to district heating is expected to take place in urban areas where district heating grids have already been established near homes with natural gas boilers. Consequently, it will only be necessary to expand existing district heating grids, meaning that no new independent grids will have to be established.

The total cost of expanding the district heating grids will largely depend on local conditions such as the capacity of existing district heating grids, population density and other geographical factors. Therefore, investment costs are also expected to vary considerably across regions. Using a rough estimate, the total investment costs of the district heating grid expansion will be DKK 7-11 billion in the period 2019-2030, which covers grid expansions as well as service pipes.

Historically, district heating grids have developed from a few central production units, where heat is supplied at high temperatures. In future, the grid should be able to receive more heat from smaller, decentralised production plants, which often supply heat at lower temperatures than power plants. This requires further optimisation of district heating grid operations and that the grids are generally operated at lower temperatures. Digitisation and remotely read district heating meters may contribute to more intelligent operation of district heating grids. Furthermore, consumer flexibility can help to limit investments in grids as well as production plants.

In future, heat storages must also help to make district heating system operations more flexible. To minimise the production costs of electrically powered district heating production, these plants need to produce heat and thereby consume power when the power price and the grid load are low. These times do not necessarily

[4.30] Energinet (2019): Security of Electricity Supply Report.

coincide with the times when there is a strong demand for district heating. At the same time, heat storages can also help to reduce the need for peak load power.

There will be a need for both small day storages and actual seasonal storage. Among other things, the small storages can be used to optimise power-consuming production units up towards the power market and the power grid. The large seasonal heat storages can capture solar and waste heat during the summer period and store the heat for the winter. The ultimate storage need varies from one region to the next and depends to a large extent on the associated production system. The expansion of the district heating grid and flexible operations require forward-looking financial regulation.

4.2.3. The role of the gas grid will change

Denmark has a well-developed gas infrastructure, which is designed to handle larger amounts of gas than is currently being consumed and transported. In the green transformation, gas infrastructure will play a different role than in the past.

Natural gas consumption must be substantially reduced towards 2030 in order for Denmark to reach the 70% reduction target by 2030. The reduction is expected to be achieved by phasing out natural gas consumption for household heating, phasing out natural gas for power and heat production as well as reducing industry consumption of natural gas.

At present, upgraded biogas is produced and fed into the gas grid, while raw biogas is not fed into the gas grid. The amount of upgraded biogas is expected to increase substantially in future. The build-out of biogas is expected to be in the form of upgraded biogas connected to the gas grid. In future, the gas grid must be capable of receiving the amount of biogas which is upgraded and fed into the gas grid. Overall, the transformation will mean that by 2030 significantly less natural gas will have to be transported in the distribution grid than is the case today, and that in future the gas grid will have to be converted to be able to transport new green gases.

The distribution of gas consumption segments such as households and industry in Denmark varies considerably locally. At the same time, most of the total Danish biogas production is produced and fed in in North and West Jutland. Biogas plants are connected to the low-pressure distribution grid (6 bar), but the pressure of the gas is subsequently raised after which the gas is fed into the high-pressure grid (40 bar). Although the general trend is for large shared plants, a number of small farm installations are also expected to be established in future.

The total demand for natural gas is expected to decline in 2030 due to the replacement of large numbers of natural gas boilers and the phase-out of natural gas for process heat in industry. However, the gas distribution grid will still have to supply natural gas to industry, the transport sector and for the portion of heating that continues to be generated by natural gas boilers. In energy-intensive industry, which due to its high-temperature processes currently uses large amounts of coal in production, some of the natural gas could be used as a substitute for coal and as a stepping stone for biogas towards 2030, as carbon emissions from natural gas are lower than those of coal. In some places, this will require a build-out of the gas grid, but will at the same time facilitate the transition to biogas in the long term.

The overall role of gas infrastructure will change significantly in the years to come and must be used to promote the green transformation where it makes economic sense. This calls for a gas infrastructure plan. Some parts of the gas distribution will have to close due to declining consumption as natural gas for heating homes is phased out, the industry welcomes new customers and the increased biogas production is captured and distributed. In addition, the gas transmission grid and gas storages will be able to support the development of Power-to-X technologies and act as storages/buffers in relation to the more fluctuating power generation from wind and solar.

4.2.4. Power-to-X is likely to use existing infrastructure combined with new hydrogen infrastructure

For Power-to-X products that directly replace or are blended with fossil fuels, the existing service station infrastructure can be used, while new filling options have to be developed for the direct use of hydrogen for transport. There are currently seven hydrogen filling stations in Denmark, which are mainly located in large cities[4.31]. A build-out to reduce the required amount of carbon dioxide by 2030 is expected to require 100-200 hydrogen filling stations, which means that it must be possible to fill up with hydrogen at 50-100 existing or new filling stations. These are estimated to cost approximately DKK 2-5 billion[4.32].

Power-to-X products such as hydrogen, diesel, dimethyl ether (DME) and methanol can be produced at electrolysis plants close to power or carbon sources and transported by road to the filling stations. There is therefore thought to be no technical need for new infrastructure for these types of products. However, a hydrogen grid for transport and storage by 2030 may be an economical way to connect Power-to-X production with storage facilities and hydrogen customers. A concrete example would be the regional integration of, for example, electrolysis production, a carbon source such as biogas, storage and large hydrogen customers (such as an airport or a refinery). These regional hydrogen grids must be integrated into the overall energy infrastructure.

The gas grid can support Power-to-X production through the transport of biogas and pure hydrogen. Hydrogen in the existing gas grid depends on the price of conversion and available capacity, among other things. Furthermore, the infrastructure can be expanded with new dedicated hydrogen grids.

The necessary Power-to-X infrastructure depends on the Power-to-X products, and as it remains uncertain which fuels will be preferred by 2030, it is also uncertain which build-out and utilisation of existing infrastructure will be necessary. As part of a national Power-to-X strategy, it is therefore recommended to identify the need for Power-to-X infrastructure and the possibility of using existing infrastructure.

4.2.5. Tomorrow's infrastructure must enable tighter sector coupling

Sector coupling is a key component of climate action. Sector coupling occurs, when, for example, the transport sector is electrified, the use of electric heat pumps in industry increases and waste heat from industrial processes is utilised in the district heating system. Renewable energy use can be effectively increased by ensuring tighter coupling of the individual elements of the energy sector and tighter coupling between other sectors and the energy sector. In other words, a stronger focus on sector coupling could drive the green transformation across energy types and sectors and ensure a faster and more cost-effective green transformation. Green electrification, particularly of the transport sector and industry, is one of the most important areas of cooperation across climate partnerships.

The accelerated green transformation will also significantly alter the interaction between green gas, power and heat. Tighter sector coupling requires closer integration of the energy infrastructure. The existing energy grids are currently being used relatively one-dimensionally, but in a green energy system it will be possible to support multi-dimensional use, where, for example, power is used for district heating, hydrogen is used for gas and waste heat is extracted from industrial processes and waste water, see Figure 26.

An accelerated transformation of the entire Danish energy and utilities sector can be optimised and made more efficient through a significant change in the interaction between the individual sectors – gas, power and heat. Consequently, the regulation of these sectors has a major impact on the ability to harness the potential. Among other things, investments in storage capacity may bring gains across sectors, for example between the power grid and the heating system, while closer interaction between sectors can also make the use of systems for monitoring and retrieval of data more efficient. Regulation of monopolised sections of the energy and utilities sector should support the ability to exploit synergies between sectors.

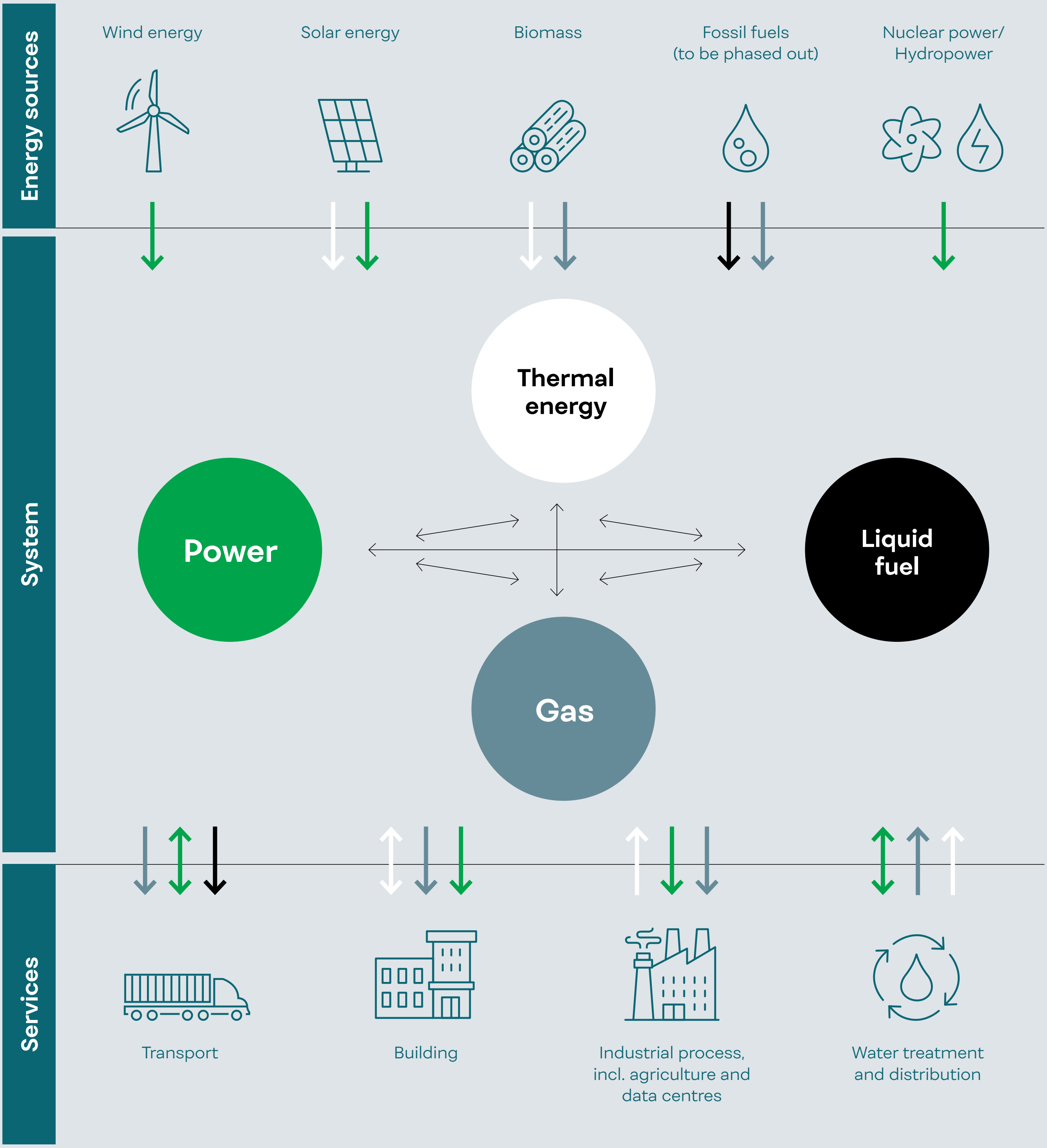
The previous three chapters have described how Denmark can reduce its emissions and expand its renewable energy production and infrastructure to reach the 70% reduction target by 2030. Substantial reductions must also be achieved in the rest of Europe and globally, however, and as described in the next chapter Denmark can make a valuable contribution to achieving this goal.

[4.31] www.brintbiler.dk (2019).

[4.32] Ea Energy Analyses.

Figure 26.

Tighter sector coupling will be needed in a green energy system in 2030



Source: DTU (2020): Smarte Energisystemer er vejen frem. Sector development report on smart energy systems (in Danish). (The report will be published in April or May 2020). The figure has been tentatively presented in the Danish Energy Industries Federation/DareDisrupt (2020): Sektorkobling – nøglen til fremtidens bæredygtige energisystem (in Danish).

5.0 Green energy exports from Denmark can support the international transformation

Denmark is in a unique position to support the international transformation by exporting large quantities of green offshore wind power and Power-to-X products to replace fossil fuels in international transport and industry. An increase in exports will build on Denmark's long-standing position as a green pioneer nation and could contribute significantly to the EU target of climate neutrality by 2050. At the same time, Denmark can increase its already significant global exports of technologies and consultancy services within energy efficiency improvements and renewable energy production. Increased exports will not only contribute to reducing carbon emissions, they will also create export revenues and create jobs across Denmark. Export of energy commodities will require a build-out of the power export infrastructure and the establishment of a Danish Power-to-X production framework during the 2020s. An increased export infrastructure to neighbouring countries will also play a significant role in reducing risks, both economic as well as in relation to security of supply, if the build-out of renewable energy does not match the Danish energy demand all the way to 2030.

Denmark has a long tradition of exporting energy commodities, primarily based on oil and natural gas, and since the late 1990s, exports have increased significantly, peaking in 2008 at around DKK 76 billion in export revenues, see Figure 27[5.1]. Since then, oil and natural gas production has decreased as have exports. With green power and Power-to-X as new export energy commodities, Denmark is in a great position to continue exporting energy to the outside world for many years to come.

The previous three chapters have described the reduction initiatives and the build-out of renewable energy and infrastructure required for Denmark to achieve its 70% reduction target. In addition to its ambitious national reductions of carbon emissions, Denmark can also make a significant contribution towards European and international reductions, especially towards 2050. Such contribution comprises exports of green energy, Power-to-X products and energy efficiency improvement technology and consultancy.

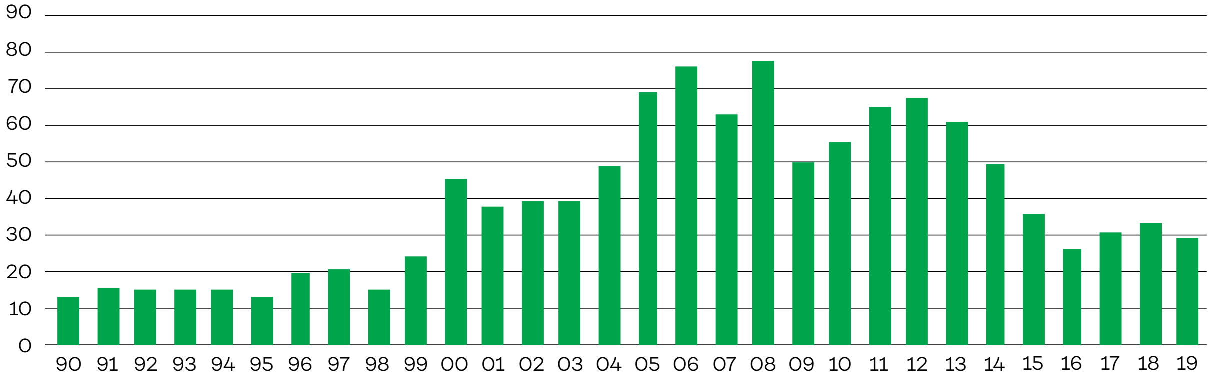
5.1. Large volumes of green Danish power can replace fossil fuels in Denmark's neighbouring countries

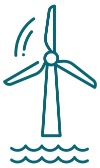
Denmark is well positioned to realise extensive build-out and operation of offshore wind capacity due to its large sea areas with great wind conditions, shallow waters and optimal seabed conditions. Moreover, Europe aims for climate neutrality in 2050, which, like the green transformation in Denmark, is expected to be largely based on extensive electrification. If Denmark scales its power generation from offshore wind for export, it can replace fossil fuels in Denmark's neighbouring countries, thereby contributing to the green transformation in Europe and to export revenues and the creation of jobs across Denmark.

5.1 Adjusted for inflation to 2019 prices. Actual exports in 2008 amounted to DKK 68 billion.

Figure 27. **Energy exports potential**

Energy exports[1], 1990-2019
DKK billion constant prices[2]





Offshore wind

Green power exports

Denmark could potentially install 25 GW of offshore wind for export purposes the designated maritime spaces for offshore wind farms

Export potential: DKK 30-40 billion annually[3]

Power-to-X

Great potential as a new energy solution

Power-to-X is predicted to become a key climate solution towards reaching European climate neutrality by 2050, and Denmark is in a great position to contribute

Export potential: Not yet estimated, but the technology is assessed to add value to the export potential

[1] Energy exports comprise fuels, lubricants and electric currents (KONJ classification).
[2] Converted from current prices using Statistics Denmark's consumer price index (PRIS112).
[3] For build-out to 40 GW of which 25 GW can be used for export purposes and 15 GW is assumed to be used to reach climate neutrality by 2050. The export potential is calculated at 4,749 full load hours and a settlement price of DKK 322.

Source: The Danish Energy Agency's technology data catalogue; Statistics Denmark; Danish Energy; QVARTZ analysis.

The Danish Energy Agency assesses Denmark's total build-out potential of offshore wind to be approximately 40 GW[5.2], which means that in addition to the approximately 7.6 GW of offshore wind, which Denmark needs for its own power generation in order to achieve its 70% reduction target, there is an additional build-out potential of approximately 32 GW. If the build-out is realised, the power can either be used for the transformation to full climate neutrality in Denmark by 2050 or it can be exported. Estimates of the offshore wind capacity build-out required to go from the 70% reduction target in 2030 to full climate neutrality in 2050 have yet to be developed. Assuming that full climate neutrality requires a further build-out of approximately 7 GW, approximately 25 GW of offshore wind capacity will remain for export[5.3]. Power exports of 25 GW are expected to displace approximately 11-25 million tonnes of carbon emissions in Denmark's neighbouring countries to the south, depending on whether the power is exported to Poland, Germany or the Netherlands, see Figure 28.

A carbon reduction of 11-25 million tonnes corresponds to 50-100% of Denmark's expected carbon reduction towards 2030, representing a significant contribution to the green transformation in Europe. At the same time, exports of green power from offshore wind of 25 GW could generate export revenues of approximately DKK 30-40 billion a year[5.4] and Danish jobs in production, installation and service of offshore wind turbines. The Danish Ministry of Climate, Energy and Utilities, for example, estimates the overall job creation resulting from the construction of 950 MW of offshore wind farms to be 7,000 jobs over three years[5.5].

If the existing restrictions that are currently limiting the maritime space dedicated for offshore wind farms are altered maintaining only the distance to the coast of approximately 20 km, and if the separation distance between turbines is reduced, the total technical potential for Danish offshore wind could be up to ~180 GW[5.6]. Realising a major proportion of this potential could allow for a considerable Danish contribution to the 230-450 GW of offshore wind that, according to the European Commission, is to be installed by 2050[5.7] in order to achieve the target of full climate neutrality by 2050.

5.2. Power-to-X can help replace fossil fuels in European industry and transport

Power-to-X is expected to be a necessary replacement for large quantities of fossil fuels in European heavy transport and industry, thus contributing to carbon reductions in Denmark's neighbouring countries. The European Commission estimates European Power-to-X consumption to total ~1,600 TWh by 2050, equivalent to about 3/4 of the total European power consumption today[5.8].

There is still no large-scale production of Power-to-X in Europe, but a number of projects are under construction in Denmark's neighbouring countries, particularly in Northern Europe. Examples include *HYBRIT* in Sweden, where a major renewable hydrogen production plant for steel production is under construction, *Westküste 100* in Germany with public annual investments of EUR 100 million in the development of hydrogen technologies and *Gigawatt Electrolysis Factory* in the Netherlands with a national ambition to install 3-4 GW of electrolysis capacity by 2030[5.9]. Projects are also being developed in Norway and the UK.

5.2 The total potential area for the location of offshore wind in Danish marine territory, taking into account existing restrictions and distance to the shore, is 34,914 km^2. Applying the assumptions of the Danish Energy Agency, this corresponds to approximately 40 GW. The Danish Energy Agency (2019): Offshore wind potential in Denmark.

5.3 The offshore wind build-out of approximately 6 GW from 2019 to 2030 should contribute to a 35% reduction in carbon emissions, and the 7 GW would have to contribute to an additional 30% reduction towards 2050. The 7 GW is a very rough estimate and must be further qualified before a final export recommendation can be made. The 25 GW serves solely to illustrate the displacement and export potential.

5.4 2019 prices. The price per MWh is based on an average of the technology catalogue's LCOE for offshore wind between 2030 and 2050. LCOE is used as an indicator of the power price.

5.5 Ministry of Climate, Energy and Utilities (2016).

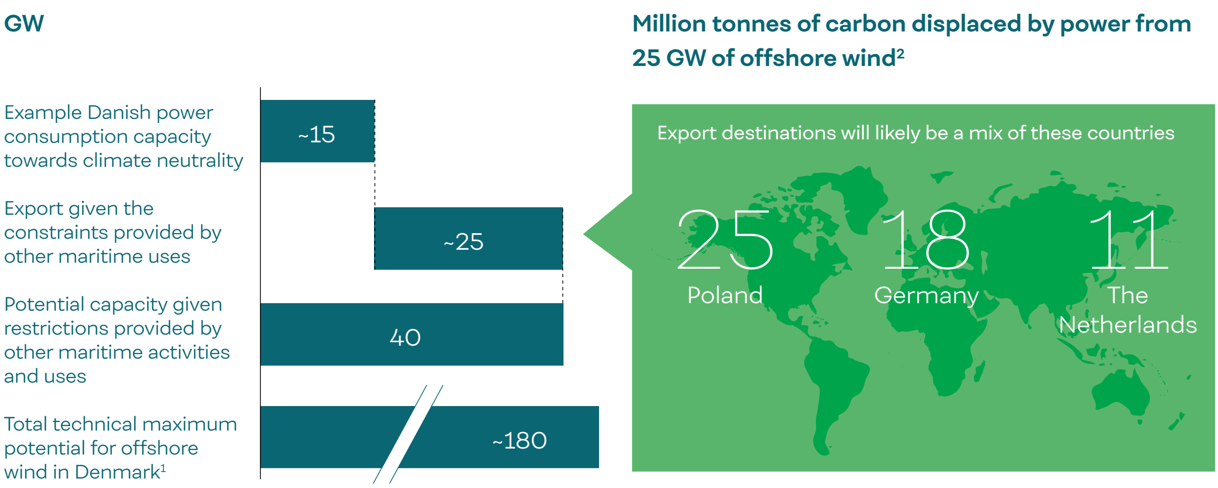
5.6 BVG Associates (2017): Unleashing Europe's offshore wind potential – A new resource assessment. The technical maximum potential of approximately 180 GW is the total potential production volume from offshore wind turbines provided that existing restrictions are changed, build-out is realised 22 km from shore and the separation between wind turbines is reduced, which will result in an annual power generation of approximately 800 TWh.

5.7 The European Commission (2018): A clean planet for all.

5.8 Power-to-X consumption covers both hydrogen consumption and other Power-to-X products and is calculated by using an average of the European Commission's '1.5 Tech.' and '1.5 Life' scenarios.

5.9 www.hybritdevelopment.com (2020); www.westkueste100.de (2020); www.iphe.net (2020).

Figure 28. **Installed offshore wind capacity and reduction of carbon emissions in a scenario where Denmark exports offshore wind power**



[1] Assuming existing restrictions are changed, a build-out 22 km from shore and reduced separation between turbines (BVG Associates 2017).

[2] European Commission: Electricity and Steam production (t of CO_2/MWh 2030), technical note, results of the EUCO3232.5 scenario on Member States. Calculated by using the average of carbon emissions per MWh in Germany, the Netherlands and Poland in 2030 and zero emissions in 2050, assuming energy neutrality in 2050 and exports between 2030 and 2050.

Note: Norway, Sweden and the UK are expected to achieve low carbon emissions as early as 2030 and, consequently, power exports do not significantly displace fossil sources.

Source: The European Commission (2019); the Danish Energy Agency (2019); BVG Associates (2017); Danish Energy; QVARTZ analysis.

With the right policy initiatives, including a national Power-to-X strategy, Denmark may join the cluster of countries in Northern Europe which are working particularly actively on the development and build-out of Power-to-X. With the right efforts, Denmark is uniquely positioned to establish a considerable Danish Power-to-X industry.

Denmark's unique position builds on:

- **Large quantities of green power.** With its large sea areas and its relatively low cost of energy compared to other European countries, Denmark is capable of producing large quantities of green power from offshore wind for the highly power-intensive electrolysis process. Large quantities of the power otherwise produced for export, can be refined into Power-to-X products for export.

- **Carbon capture.** Renewable hydrogen must be combined with carbon dioxide to produce, among other things, methanol, methane and diesel. This process requires large amounts of carbon dioxide which can be captured at point sources such as Danish biogas, industrial and CHP plants.

- **Ambitious business partners.** A number of large Danish road, rail, shipping and air transport businesses with ambitious climate targets can cooperate with the government and Power-to-X manufacturers on testing and procurement of new fuels.

- **Sector coupling.** Sector coupling of power, gas and district heating systems can ensure cost-efficient production of Power-to-X – probably more so than in countries with less sector coupling. An example of this is that the electrolysis and refinement processes create substantial amounts of waste heat that can be sold in the well-developed Danish district heating system, thereby contributing to climate neutral heating while supporting the profitability of the Power-to-X production.

The potential for Power-to-X is great, and as with offshore wind, early demand-side incentives combined with a strong cooperation among relevant operators can make Denmark a leading nation in this field.

Danish Power-to-X perspectives go beyond the 70% reduction target

In addition to the direct reduction of carbon emissions produced by the Power-to-X technology, early build-out and demonstration of the technology in Denmark may also accelerate the build-out of Power-to-X in other countries. Denmark may thus become a role model for integrating Power-to-X in an energy system that is highly reliant on renewable energy sources, which is expected to be the future of many other countries.

In terms of replacing fossil fuels in heavy transport on Danish soil, there lies great potential in displacement of emissions from international shipping and aviation. These emissions do not count towards the national climate accounts, but they account for substantial carbon emissions in the global climate accounts. Establishing a Danish commercial-scale production of green fuels such as ammonia and kerosene for these modes of transport will have a significant impact on global emissions.

Today, the choice of fossil fuels for refuelling of vessels and aircraft is largely determined by the price and location of existing infrastructure such as ports and airports. Imposing new regional or global climate reduction requirements on shipping and aviation may increase the demand for green fuels, thus increasing refuelling in countries and regions with cost-effective and green production of Power-to-X fuels. Denmark could thus become a green 'refuelling hub' for international shipping and aviation.

Furthermore, if new industries demanding hydrogen or hydrogen-based products choose to place their business in Denmark, thereby displacing or rendering superfluous industry in countries with less green energy and utilities sectors, this would contribute positively to the global climate accounts. For example, increased production of agricultural fertilisers based on green ammonia produced from renewable hydrogen. Developing and attracting new Power-to-X industries to Denmark can be compared to the development seen within data centres where the three first large centres in Denmark will be operational in 2020, and it looks as though there are more to come in the future[5.10].

[5.10] Denmark's Energy and Climate Outlook 2019.

The existing hydrogen consumption in industry and refineries is approximately 400 TWh in Europe. Today, hydrogen is largely produced from fossil fuels, i.e. natural gas and coal, which could potentially be replaced by electrolysis-based hydrogen. Part of the green replacement products could potentially be produced in Denmark from renewable energy and exported to existing industries. Some of the most obvious applications of Power-to-X would be as replacement for hydrogen, ammonia and methane produced from fossil fuels.

The most likely export destinations would be Germany and the Netherlands. Both countries have large hydrogen-dependent industries and both have ambitious climate targets and define themselves as future hydrogen importers due to their limited renewable energy build-out potential[5.11].

This sector roadmap does not include an estimation of the Power-to-X export potential as it is still very uncertain which Power-to-X products Denmark will be able to export and what the extent of the global demand and supply will be. The Danish Power-to-X production will most likely comprise refining part of the offshore wind power that would otherwise have been exported. This export scenario is thus expected to result in increased value.

5.3. An increased Danish contribution to the European transformation requires a strengthened export infrastructure

If power exports and Power-to-X increase significantly, the existing export infrastructure will have to be expanded.

Power

Today's power exports go through interconnectors with a total capacity of 7.1 GW to Norway, Sweden, Germany and the Netherlands. The current projection of the expansion until 2023, when, among others, Viking Link to England and interconnections to Germany will be extended to a total capacity of 10.7 GW.

If further 25 GW of offshore wind power is to be exported, more interconnections must be established. Four different models for interconnection exist, see Figure 29. The first model is the one used today where transmission cables from offshore wind farms are landed in Denmark and power is exported via the onshore transmission grid. This puts significant load on the transmission grid.

Another model is a simple hybrid where a single offshore wind farm is connected to transmission cables in Denmark and a recipient country. An example of this could be an offshore wind farm in Eastern Denmark with connections to the rest of Denmark, Poland and possibly Sweden. This reduces the infrastructure need and new extensions can relieve the pressure on the existing interconnectors.

A third model is a cluster where several offshore wind farms are connected at sea and the power transported to a single country.

Finally, a fourth model consists of a network of clusters where several offshore wind farms are interconnected and power transported to several countries. An example of this could be a large offshore wind farm area in the North Sea with connections to the UK, the Netherlands and Denmark. The more advanced models are expected to provide major advantages in terms of the most cost-effective extension of interconnectors.

The Kriegers Flak development with connections to both Denmark and Germany is an example of the simple hybrid model. However, realising the full potential of hybrid and cluster models requires significantly increased regional coordination[5.12].

In case the demand for power does not increase as anticipated towards 2030, an early expansion of the power export infrastructure will enable Denmark to export its surplus green power, thereby contributing to reducing carbon emissions in neighbouring countries. At the same time, expansion of the infrastructure also has a positive knock-on effect on the Danish security of supply.

5.11 Energinet (2020): Nye vinde til brint.
5.12 For example, in connection with the North Sea Energy Hub.

Power-to-X
Expanding the Power-to-X infrastructure will depend on the Power-to-X products that Denmark will produce for export. Export of hydrogen for direct use is likely to require a hydrogen pipeline directly connected to large consumers in neighbouring countries, for example, Germany and the Netherlands. There is no pan-European hydrogen pipeline today, but the UK, Germany and the Netherlands have specific plans for a hydrogen infrastructure[5.13].

If high energy density Power-to-X products such as methanol, diesel or ammonia are produced, they could be exported to other countries by tanker vessels (long distances) or by lorries (short distances). Liquid Power-to-X products have the advantage that they are relatively cheap to transport[5.13].

When producing Power-to-X products on a scale that allows for export, the Power-to-X production should be strategically placed. Being a highly power-intensive process, it may potentially be more cost-effective to establish the Power-to-X production close to or directly at the energy source than to transport the power. An example of this would be to establish Power-to-X production on platforms in the North Sea, close to offshore wind farms and with direct export connections to surrounding countries.

5.4. Increased exports of energy technology and consultancy could also contribute to reducing carbon emissions internationally

In addition to the direct export of energy commodities, the extensive transformation and build-out of the Danish energy system is also likely to lead to increased exports of energy-related technology products and services. Denmark's exports already contribute to reducing carbon emissions internationally. This occurs both in products that ensure high energy efficiency, for example, thermostats, pumps, building insulation, remote heating systems and advice on optimising energy consumption, and for products that are directly related to the production of renewable energy, for example, wind turbines, biogas plants and related consultancy.

In addition to its positive impact on carbon emissions, energy technology and consultancy also generate Danish export revenues. In 2017, Denmark's exports of energy technology and consultancy amounted to DKK 85 billion of which 50% were related to green energy technology[5.14]. Energy technology accounted for 11.1% of total Danish goods exports in 2017. In addition to export revenues, businesses in the field of energy technology and consultancy create more than 55,000 jobs across Denmark[5.15].

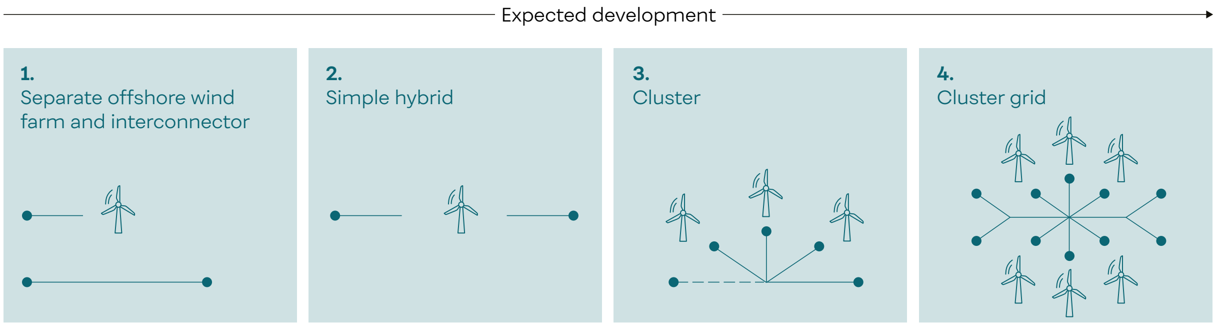
Denmark's strong position has been built through years of active Danish energy and climate policy, which has ensured a good commercial basis for the development of green technology in Denmark[5.16]. Furthermore, the 70% reduction target by 2030 could increase the incentive for Danish consumers and businesses to use energy-efficient solutions, thus increasing the demand for energy technology. This supports energy technology innovation in Denmark, which gives Danish businesses an excellent platform for continued development and export of competitive energy technology solutions.

Sector coupling, intelligent design of energy systems, digitisation, district heating technology, energy-saving building technology and bioenergy technologies are other areas where Denmark is in a strong position to strengthen its exports[5.17].

[5.13] Energinet (2020): Danish publication: Nye vinde til brint (new winds for hydrogen)
[5.14] The Danish Energy Agency (2018): Export of Energy Technology and Service 2017.
[5.15] Danish Energy (2017).
[5.16] The Danish Energy Agency (2020).
[5.17] Danish Energy, Confederation of Danish Industry (DI), IDA (2017): Danish publication: Danmark som energiteknologisk pionerland (Denmark as a pioneering country in energy technology)

Figure 29. **Transmission infrastructure models for offshore wind farms**

The offshore transmission infrastructure model is developed on a regular basis



Source: Ørsted; Danish Energy; QVARTZ analysis.

6.0 The transformation requires significant investments, but the cost for the individual is manageable

When Denmark reaches its 70% reduction target in 2030, the energy sector and its energy customers will have made significant investments in renewable energy, energy infrastructure and new energy-efficient technologies. The energy and utilities sector estimates that these additional and extra investments will total approximately DKK 32 billion annually towards and including 2030. These investments can be made if the political framework supports the right investment decisions. Investments must be made in our shared energy infrastructure, and, not least, the power grid must be prepared to handle twice the power consumption and the many additional wind turbines and solar panels that will be connected to the grid. The gas and heating systems will also undergo major changes.

The total additional costs to society are estimated at around DKK 15 billion in 2030. This corresponds to approximately DKK 5,000 per year per household. Even though this is a significant amount for the individual household, the average gross income of a Danish household is expected to have increased by DKK 90,000 by 2030. All in all by 2030, the Danish energy consumption will be more climate-friendly, and Danes will be spending less of their total household budget on energy compared to today.

If left unchanged, the current energy tax regime, which imposes heavy taxation on fossil fuels, will lead to lost government revenues of approximately DKK 23 billion in 2030. In addition, the Danish government will have to allocate support funds in the form of subsidies and targeted tax remissions to ensure that immature technology can be developed and scaled and potentially negative effects on Danish competitiveness mitigated. Subject to the recommendations of other partnerships, the need for funding is estimated to be in the range of DKK 5-7 billion annually towards 2030.

This chapter describes the economic consequences for Denmark of achieving the 70% reduction target by 2030. The chapter is divided into three sub-chapters on investments in the form of a need for additional investments in green technology for energy consumers and the need for extra investments made by the energy and utilities sector (6.1), distribution tariffs (6.2) and costs to society in the form of additional costs and the effect on government revenues (6.3).

The calculated investments and costs assume a cost-effective transformation, making optimum use of each year until 2030. All players in society, including the public sector, must contribute actively to the transformation by making continuous green investment decisions as existing technology reaches the end of its life. All estimates are subject to uncertainty, as they are based on assumptions about the development in the price of technology.

The costs will rise if Danes continue to buy many vehicles powered by fossil fuels and reinvest in oil and natural gas boilers well into this decade. The reason is that investments that have not yet reached the end of their life will have to be scrapped towards the end of the decade in line with the 70% reduction target.

What is an additional investment?

Additional investments in technology at energy customers relate to the replacement of fossil energy with technology powered by green energy. This includes the switch from gas boilers to heat pumps in households and industry or the switch from fossil-fuelled vehicles to green passenger cars.

An additional investment is calculated by subtracting from an investment in green technology the corresponding investment in fossil-based technology which is not made.
The additional investment thus refers to the additional resources that must be invested to ensure a successful green transformation.

Example: If an electric vehicle costs DKK 300,000 and a similar petrol-powered vehicle in the same class costs DKK 200,000, the additional investment is DKK 300,000 - DKK 200,000 = DKK 100,000.

What is an extra investment?

An extra investment is an extra investment made by the energy and utilities sector in renewable energy (onshore and offshore wind turbines, solar power and biogas) and energy infrastructure (power, heat and gas) in order to meet the expected demand for green energy.

The amount of the extra investment is not assessed against the alternative, as the investment cannot be made by prolonging the lifetime of existing coal power plants.

What is an additional cost?

An additional cost is the added cost associated with the switch to green technology as opposed to maintaining fossil technology. The additional cost includes depreciation on an investment in green technology (for example an electric vehicle) + running costs (power), less similar investments in fossil technology (petrol-powered vehicle) and running costs (petrol) which are saved.

Example: The annual additional cost of an electric vehicle depreciated over ten years is:
a. Vehicle: Additional investment of DKK 100,000/ten years = DKK 10,000
b. Running costs: Power costs of DKK 1,000 - petrol costs of DKK 5,000 = DKK -4,000.
Total, a + b: DKK 10,000 - DKK 4,000 = DKK 6,000

What is the effect on government revenues?

The green transformation will directly affect government revenues in two ways:

1. The government loses revenue when Danes buy fewer highly taxed vehicles with internal combustion engines and use fewer taxed fossil fuels in industry, households, agriculture, the transport sector and the energy sector.

2. Government expenditure is expected to rise, as some of the transformation can only be realised if subsidies are granted to selected energy customers.

An example is the scrapping of a new oil boiler which is still a long way from having reached the end of its life. If Danes are not willing to make the necessary switch to electric vehicles and alternative heat sources, other sectors – agriculture and industry – will be forced to make up for the lack of carbon reductions. As a result, the level of investment and cost will be considerably higher if from now on Denmark's actions are not aligned with the 70% reduction target and all sectors do not play their part.

The calculations in the sector roadmap are based on the assumption that the Danish economy will develop as expected in Denmark's Energy and Climate Outlook towards 2030, and that the further reduction measures in the displacement model do not reduce economic growth and the demand for activities that rely on energy[6.1]. Given that the 70% reduction target will result in slightly lower economic growth, it is necessary to either introduce compensatory measures to counteract the economic loss as described in, for example, the Confederation of Danish Industry's 2030 plan or factor in the loss in economic projections and the Danish Energy Agency's baseline projection of the expected energy demand.

The calculations only estimate energy-related costs linked to the achievement of the 70% reduction target. There will be additional costs associated with the reduction in non-energy-related emissions from agriculture and industry emissions of greenhouse gases, in particular, which are not related to their energy consumption.

6.1. An additional annual investment in green technology, renewable energy production and infrastructure of approximately DKK 32 billion is required towards 2030

Additional and extra investments illustrate the additional economic resources that must be mobilised by society over the next ten years to reach the 70% reduction target.

The investments are due to additional investments in green technology to replace technology powered by black energy. But they also include additional investments that do not directly replace black technologies such as investments in carbon capture and investments in the production of green fuels which are blended with black fuels in, for example, the transport sector. The additional investments require extra investments in more renewable energy production and new energy infrastructure (see the previous page for definitions of additional investment and extra investment).

An investment is not the same as an additional cost. And it does not mean that Denmark must pay or 'repay' the full investment in the year in which the investment is made. It is similar to buying a car, where the car is paid for the day we pick it up from the seller, but the loan is repaid over several years.

The total need for additional and extra investments in the period 2019-2030 is expected to be around DKK 350 billion. Of this, additional investments in new green technology amount to approximately DKK 125 billion, while extra investments in the build-out of renewable energy production and infrastructure amount to approximately DKK 225 billion. This equates to around DKK 32 billion annually, with the energy and utilities sector accounting for DKK 23 billion annually.

Annual additional and extra investments of DKK 32 billion are significant both for society and for the individual citizen. By comparison, total annual investments in housing development and renovation amount to approximately DKK 100 billion, total annual investments in the transport sector amount to around DKK 50 billion, while investments in energy supply amount to approximately DKK 18 billion annually.

No separate calculations have been made as to how the growing investments will affect the wider economy. The assumption is that the supply side in the Danish economy is sufficiently flexible to accommodate the calculated additional and extra investments towards 2030 without overheating the economy and without leading to bottlenecks in some parts of the labour market, etc. In addition, it is assumed that the financial markets are able to secure funding for the transformation without pushing out other activities and that, like the energy and utilities sector, energy users – households and businesses – are able to secure the necessary capital.

6.1 See the methodology chapter for a more detailed description of assumptions and conditions of the calculations of economic effects.

Figure 30.

Energy consumers' need for additional investments – inclusive of non-fossil energy-consuming technology in the utilities sector towards 2030

Reduction initiatives	Need for additional investments, 2019-2030 DKK billion (fixed prices 2019)	Resp. for investment
Energy and utilities		
Replacement of coal, oil and natural gas in district heating	8-10	CHP plants
Replacement of oil and natural gas in individual boilers	8-10	Households[1]
Carbon capture and storage	7-11	Waste-to-energy plants, CHP plants
Plastics recycling in waste-to-energy	0.5-1.5	Waste-to-energy plants
Electrification of North Sea production[2]		Production platforms
Transport		
1.5 million electric and hybrid vehicles	45-55	Vehicle owners
Electric and hybrid commercial vehicles	3-5	Commercial vehicle owners
Electric buses and electric trucks	1-3	Bus and truck owners
Biofuels such as biogas and biodiesel	8-9	Transport vehicle owners
Industry		
Heat pumps in industrial processes	4-6	Companies
Biogas in gas grids, industry and buildings[3]		Companies
Energy efficiency improvements	6-8	Companies
Other (for example internal transport)	9-11	Companies
Buildings		
Optimisation of building installations	0.5-1.5	Building owners
Renovation of building envelope	(1-2)	Building owners
Power-to-X		
Phase-in of hydrogen vehicles[4] *ROUGH ESTIMATE*	2-5	Hydrogen vehicle owners
Total	**Σ approximately DKK 125 billion (100-135)**	

[1] Includes investments in heat pumps only. Investments in roll-outs of the district heating grid, incl. service pipes, are shown in Figure 29.
[2] Electrification of North Sea production requires investments, but these could not be calculated within the given time limit.
[3] Biogas for all purposes (incl. heating) is included in Figure 31.
[4] Investments needed in electrolysis plants and end-systems for all Power-to-X fuels are shown in Figure 29.
Source: Ea Energy Analyses; Danish Energy; QVARTZ analysis.

6.1.1. Additional investment in new technology for energy consumers (households and businesses), including the energy and utilities sector

The additional investment needed to secure the transformation for energy consumers is expected to be in the range of DKK 125 billion (DKK 100-135 billion), see Figure 30. This equates to an additional investment of around DKK 11 billion annually.

All investments require framework conditions that encourage investment in economically attractive green technologies compared to fossil alternatives. This means that investors should not lose money on the switch compared to a scenario, where investments are made in fossil technology or where the current fossil solutions are not replaced.

The specification of who will make the investment decision illustrates the number of players who have to make concrete investment decisions in order for society to meet the 70% reduction target. On the other hand, there will be many players who will have to make relatively few, but important, decisions between now and 2030. For example, many consumers will only make one decision to invest in a new heating technology between now and 2030, and most consumers will only buy one car once or twice. It is therefore important that the framework for all investment decisions is clarified within a very short period of time, so that households, businesses and the energy sector make the right investment choices between now and 2030. Known and predictable framework conditions such as taxes that encourage consumers to make green choices will play a key role, as the impact of choices made today will be felt for years to come.

6.1.2. The energy and utilities sector will have to invest an additional DKK 20 billion annually in the renewable energy and energy infrastructure build-out

The total extra investment needed for the build-out of solar power, wind turbines, biogas production and Power-to-X production as well as infrastructure is expected to be approximately DKK 225 billion in the period 2019-2030 as shown in Figure 31, which equates to around DKK 20 billion per year.

The total future investment need of the energy and utilities sector with the existing capital stock is not estimated in this analysis. For example, investments in maintenance and reinvestments in assets are not included. Many of these will not be needed, while some will remain. Historically, the energy and utilities sector has invested a total of approximately DKK 18 billion annually in new capital stock, maintenance and reinvestments. If it is assumed that some of these investments are to be made simultaneously, the total investment need of the sector will exceed DKK 20 billion due to the new increased demand for energy from renewable energy sources.

The renewable energy build-out represents the bulk of the extra investments with an estimated need for extra investments of DKK 160-215 billion between 2019 and 2030. Of this, at DKK 85-105 billion offshore wind represents the single largest investment.

The extra investments in the renewable energy build-out and infrastructure are being made to accommodate an expected increase in energy customer demand for green energy, mainly green power and biogas. Ultimately, the increased demand for green energy will pay for the investment. Energy customers pay via the end-price of energy.

Although the price of green power is expected to fall further in the coming years, future power prices will be markedly affected by future demand, which will depend on whether Denmark and the EU choose to phase out fossil energy consumption to comply with the Paris Agreement. The future price risk will be difficult to manage for private investors alone, as the uncertainty is partially driven by political actions. Despite the falling prices of green energy, it remains important for investors and government to share the risk, so that investors are guaranteed a minimum return in the absence of demand.

The decision to invest is made by the energy companies and they must therefore be able to raise the necessary capital. This requires that the capital market is confident that the sector can pay interest on and repay the investment. With its robust energy and utilities sector and a financial sector capable of supporting the transformation, Denmark is well placed to do so. As a result, focus needs to be on regulatory challenges. Investors must invest in markets where policy decisions have a major impact. Specifically, this means that it must be possible to have confidence that the goals set by policymakers ensure that the subsequent framework promotes future demand for one's product. In addition, investors should be able to trust that the frameworks and goals will not be changed later and lead to losses on green investments already made.

Figure 31.

The energy sector's extra investments in renewable energy and infrastructure (smart scenario) towards 2030

Investments	Investment need, 2019-2030 DKK billion (fixed prices 2019)	Investment manager
Renewable energy[1]		
Offshore wind is increased by ~6.3 GW	85-105	Energy companies
Onshore wind is increased by ~3.9 GW	25-35	Energy companies
Solar power is increased by ~7.6 GW	25-35	Energy companies
Power-to-X is increased by ~2-3 GW[2] *ROUGH ESTIMATE*	10-20	Energy companies
Biogas is increased by ~1 GW[3]	15-20	**Energy companies and agriculture**
Transport		
Increase in public **charging stations** for electric vehicles	2-4	**Private players**
Increase in **hydrogen filling stations** for hydrogen vehicles[4] *ROUGH ESTIMATE*	2-5	**Energy companies**
Infrastructure		
Power distribution grid[5]: Phase-in of heat pumps	2	Distribution companies (distribution) and Energinet (transmission)
Power distribution grid[5]: Electrification of ~1.5 million vehicles and ~50% of bus transport[6]	6	Distribution companies (distribution) and Energinet (transmission)
Power distribution grid[5]: Grid connection of renewable energy[7]	3	Distribution companies (distribution) and Energinet (transmission)
Power distribution grid[5]: Power-to-X and heavy industry	2	Distribution companies (distribution) and Energinet (transmission)
Power transmission grid[8]	10	Distribution companies (distribution) and Energinet (transmission)
District heating grid	7-11	**District heating distribution companies**
Gas grid[9]	~0	**Gas distribution companies**
Total need for additional investments	**Approximately DKK 225 billion (194-258)**	
Reinvestment in power grid to maintain existing power demand and already decided transmission investments	56	*Distrib. companies and Energinet*
Total, incl. reinvestments in the power grid	246-327	

[1] Gross increase, i.e. the total additional increase from 2019 to 2030. In theory, a small part of the growth in the demand for power towards 2030 which cannot be attributed to the introduction of technologies facilitating the green transformation (such as data centres) can be achieved using power produced from fossil fuels. In this context, the reference investments in, for example, new construction of fossil power generation sources have not been calculated and deducted, but are expected to represent marginal savings.

[2] Investments in electrolysis and compression plants and end-systems. Investments in hydrogen vehicles are shown in Figure 28. Capacity and investment require 8,147 full-load hours for electrolysis for Fischer-Tropsch diesel and 3,000 full-load hours for electrolysis for other purposes. Assuming technology prices in 2030 of DKK 2.2 million per MW of electrolysis, DKK 22.4 million per MW of methanol and DKK 11.7 million per MW of Fischer-Tropsch based on Ea Energy Analyses calculations.

[3] Calculated with a capacity factor of 90%.

[4] Some of the calculated investments may also be used for other new tank infrastructure, including for biogas for transport purposes.

[5] Build-out of distribution, incl. smart measures.

[6] In relation to Danish Energy's electric vehicle analysis from May 2019, the conditions for the number and distribution of electric and hybrid vehicles have changed.

[7] Expected as per the political PSO agreement 2016 in the Danish national budget. The investment is in the range of DKK 2-3 billion. The high end of the range is shown in the figure.

[8] Build-out of transmission, incl. smart measures. However, it does not include projects already initiated and decided, new interconnections, a potential energy island and cabling to shore.

[9] Biogas is expected to replace natural gas consumption in the gas grid and the phase-in is therefore not associated with additional investment costs for the build-out of the gas grid.

Note: The investment figures comprise the overall need for investments in renewable energy and transport as well as additional investments in the power grid, i.e. reinvestments in the power grid to support the existing (2019) level of power consumption are not included.

Source: Danish Energy based on Ea Energy Analyses assumptions of power consumption in 2030 and Energinet based on an accelerated reinvestment, expansion and restoration plan 2018.

District heating distribution companies will make extra investments in the roll-out of the district heating grid to new consumers, which are expected to be financed by heating customers. The build-out of the gas grid is not expected to entail extra investments, as the increased amount of upgraded biogas is expected to be transported in the existing gas grid[6.2].

The power distribution companies (distribution)[6.3] and Energinet (transmission) will make extra investments in the power grid, which are financed by consumption tariffs. Distribution tariffs are not expected to rise due to economies of scale and smart solutions as described in section 6.2.

Power distribution, power transmission, district heating and gas systems are natural monopolies which are subject to strict regulation. Companies will only be able to make the necessary investments if political regulation supports the necessary transformation.

The extra investments in the build-out of renewable energy production and infrastructure will decrease if energy consumption can be reduced. It is therefore imperative that the energy efficiency improvements which are expected to occur as new technologies are implemented are in fact realised and that regulatory obstacles are removed. The government and the Green Business Forum should therefore carefully scrutinise the roadmaps of the other climate partnerships for initiatives that can ensure an optimum energy demand.

Predictable and clear framework conditions are therefore crucial to ensuring that the required investments are made, as investments in renewable energy production and energy infrastructure require careful planning and the implementation takes years. Investment decisions of this kind must be made several years before the need is felt by energy customers. Investments in the energy sector are typically made in technology which is expected to last for 30-50 years and is thus depreciated over a very long period of time. Therefore, investments and the national political strategy should also look beyond 2030.

6.2. Distribution grid tariffs are not expected to increase

The development in the overall power price has a significant impact both on the budget of the individual energy customer and on the competitiveness of power-consuming companies. The energy and utilities sector has therefore calculated in detail how expected investments in power infrastructure will affect the price of transporting power. The analysis shows that power consumption is expected to increase more than investments and that the price of power distribution is expected to decrease for most customers.

The power price paid by end-customers is made up of four elements as shown in Figure 32.

The total end-price paid by the power customer will be affected by opposing price trends towards 2030, when the 70% reduction target is realised. A greater need for reinvestments, higher system costs and an increased risk premium caused by market and regulatory risks pushing up the price, while greater scale and flexibility in power consumption, increased digitisation, the switch from fossil fuels and closer integration with Denmark's neighbouring countries will push down the price.

The power market price

The power market price is expected to become more volatile, as it will be based to a greater extent on fluctuating power generation from wind and solar. The price is also expected to remain low on average, as renewable power generation has low marginal costs. On the consumption side, the increased electrification will lead to a significant increase in consumption. All other things being equal, increased consumption will lead to higher prices in the market, while supply in the form of higher power generation from wind and solar will reduce prices. As a result, there will be a pressure on prices in one direction or another if the two build-out rates do not follow a consistent pace[6.4].

6.2 The investment in connections to the existing main gas grid from the new biogas plants is factored into the actual build-out of the biogas plants.

6.3 The build-out of the power distribution grid to connect renewable power generation is expected as per the political PSO agreement from 2016 in the Danish national budget.

6.4 Adjusted for import and export opportunities.

Figure 32. **Elements of the end price of power, excl. taxes**

Share of power price in 2019[1]

1. Power market price	Wholesale market price of power	**~42%**
+		
2. System tariff	Costs of security of supply and power supply quality[2]	**~5%**
+		
3. Transmission tariff	Costs of operating and maintaining the entire power grid[3] and interconnections	**~6%**
+		
4. Distribution tariff	Costs of operating and maintaining the distribution grids	**~46%**

The development in distribution tariffs is calculated as an example

1 Relative share of power price in 2019. The average wholesale market price for power in Eastern and Western Denmark traded in the European *day ahead market* is used in the calculation of the power market price. The distribution tariff shown is calculated for an ordinary household with a consumption of 4,000 kWh, and the fixed annual subscription payment is included in the calculation and distributed across the consumption of 4,000 kWh.

2 Including back-up capacity, system operation, etc.

3 The highest voltage levels – 132/150 kV and 400 kV grids – are included.

Note: Taxes and VAT are also included in the end price of power, but are not included in the table to show the relative share of price elements excl. regulation.

Source: Danish Energy; QVARTZ analysis.

The system tariff
The system tariff is expected to increase due to more complex power system operations owing to increasingly fluctuating production from wind and solar as well as new types of consumption. First, there will be an additional need for balancing and a need for creating incentives for market players to provide the necessary flexibility. Second, day-to-day operations will become more complex as more production and consumption is injected into the grid[6.5]. On the other hand, the increased consumption will also result in more kWh on which to distribute costs.

The transmission tariff
Like the system tariff, the transmission tariff is expected to be affected by opposing effects. On the one hand, rising investments to enhance the grid, closer integration with neighbouring countries and increased connection of renewable energy will push up the price, while larger-scale consumption will push down the price.

The distribution tariff
The distribution tariff is expected to fall due to increased demand-side response and economies of scale. The grid costs are thus rising more slowly than power consumption, which means that the price per kWh may potentially fall. The price of transporting the increased amount of power in the distribution grid is estimated to fall by approximately 5% in real terms by 2030 compared to the present level, see Figure 33.

The first increase in the distribution tariff of 5% in Figure 31 covers reinvestments needed to maintain the existing demand for power. These reinvestments are necessary to maintain a high level of security of supply. This is because much of the power grid was established in the 1960-80s, which saw a sharp rise in power consumption, and a number of cables and substations will reach the end of their life in the coming decades and will have to be replaced. The next 5% increase in the tariff compared to the present level covers upgrades of the distribution grid which are needed to support the 70% reduction target without smart measures. Smart measures are expected to reduce the tariff to a level that is up to 5% below the present level[6.6].

The positive effect on the tariff is expected to be felt across all customer types, see Figure 34.

Figure 34 shows that the power distribution tariff for residential, business and small industrial customers is expected to decrease by approximately 5% by 2030 compared to the present level[6.7], while the power distribution tariff for large industrial customers is expected to remain unchanged. The latter is partly due to the fact that these customers use only the high-voltage grid and that much of the high-voltage grid is due to be replaced in the coming decades. This has a relatively greater impact on the distribution tariff for these customers, as they only use the high-voltage grid and therefore do not pay for the low- and medium-voltage grids.

6.3. The cost of the transformation will be approximately DKK 15 billion in 2030

There will be costs associated with the transformation to a society that meets the 70% reduction target. This sub-chapter presents two different perspectives on the level of costs:

- The total annual additional costs of the green transformation in 2030 associated with the acquisition and operation of new green solutions to replace fossil solutions for all players in society, i.e. both citizens and businesses.

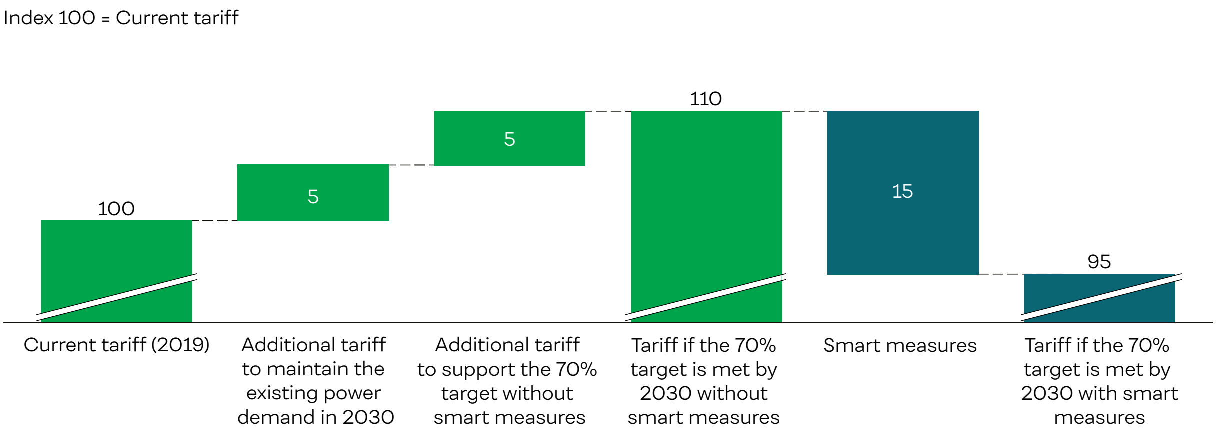
- Impact on the government budget in 2030, including the impact on government revenues when fossil energy is phased out.

6.5 There will also be a trade-off between system tariffs and grid tariffs. For example, in some situations it may make economic sense to compensate wind turbine owners in a peak production situation instead of increasing capacity to deal with these peaks. This shifts costs from grid tariffs to system tariffs.

6.6 See section 4.2.1.1. for more details.

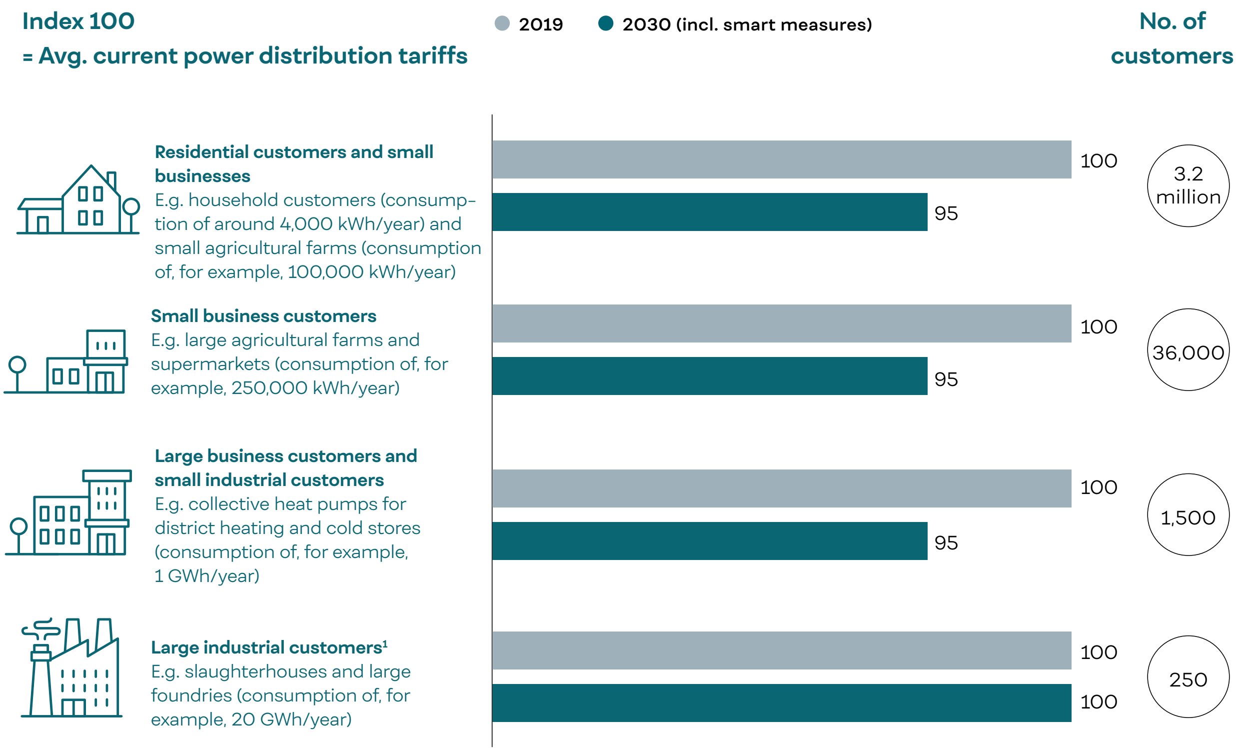
6.7 The fall in tariffs requires that customers are willing to shift their consumption. If instead customers opt to pay a higher tariff for consuming power when the grid is congested, power grid companies will have to invest in a grid build-out to deal with this. It is imperative that when introducing differential tariffs power grid companies ensure that those customers who necessitate the biggest upgrade of the grid also pay for it.

Figure 33. **Expected development in average power distribution tariff towards 2030**



Source: Danish Energy; QVARTZ analysis.

Figure 34. **Expected development in average power distribution tariffs by customer type in a smart scenario**



[1] The tariff for large industrial customers is not expected to fall, as much of the high-voltage grid has reached the end of its life. Significant reinvestments are therefore required towards 2030. The tariff has thus been extraordinarily low in recent years due to the high-voltage grid being relatively depreciated.
Source: Danish Energy; QVARTZ analysis.

6.3.1. Additional cost of the transformation to meet the 70% reduction target

The transformation to a society with 70% less carbon emissions than in 1990 will give rise to costs across sectors. These are additional costs resulting from the acquisition of new green technology which is more expensive than similar fossil-based technology (for example an electric vehicle instead of a petrol-powered vehicle) and for operating green technology which for some parts of the transformation will be more expensive than operating fossil technology (for example biogas in the gas grid instead of natural gas). These additional costs of the green transformation are what it takes for Denmark to become a climate leader and prepare for the future that will come in the expectation that most countries will take the Paris Agreement seriously.

For many shifts in technology, the green transformation will bring economic gains or be economically neutral. For example, a switch to urban electric buses and heat pumps in much of the individual heating system is not expected to involve additional costs, as additional investments will be recouped through greater operating cost savings. Conversely, in other areas there will be additional costs associated with the technological shift from fossil to green technology.

When calculating the additional cost, no explicit or implicit assumption has been made as to who bears the additional cost. Whether it is the individual citizen, businesses or the government depends on the technology in question and on the regulatory framework in the area towards and in 2030.

It is assumed that green technologies will gradually become cheaper compared to the fossil technology they are replacing. However, it is not assumed that there will be substantial price falls as a result of leaps in technology. The future will develop differently and the prices of green technologies may be lower than assumed in these calculations as a result of marketisation as well as national and global scaling. For example, projections of technology prices ten years ago assumed that the costs of wind power, battery technology and solar power would be much higher than they actually are today. The same thing is likely to happen with several of the new technologies that will be commissioned in the next ten years, but to what extent is obviously uncertain. In this context, additional costs do not include what can be described as the total economic costs. This means that external factors beyond the financial factors are not included in the calculations. For example, these may be less noise from electrically powered transport, less air pollution, better indoor climate, better control over industrial production processes, etc. Finally, nor is the global benefit of reducing greenhouse gas emissions included in the calculation of the additional cost of the transformation[6.8].

There are also a number of factors which may increase the additional costs. It is possible that the expected fall in the price of green technologies will not materialise. The individual players may incur extraordinary or unknown additional costs which have not been taken into account here. Some consumers have, for example, a petrol-powered vehicle or an oil boiler that still has a useful value, although according to the technical models they are about to be replaced. This could explain why a shift in technology may not necessarily be implemented, even if the green alternative in the models is economically attractive. Studies of consumer behaviour also show that homeowners, for example, are reluctant to switch to new and thus unfamiliar technology such as a heat pump.

Consequently, in the real world it may be necessary to send an even stronger financial signal to citizens and businesses than the one described in this analysis. This means that the cost of measures will increase. There is also a risk that the final choice of initiatives and measures will not be the most economical one, as other considerations will be given greater weight by policymakers (distribution between income groups, rural vs urban areas, safeguarding the competitiveness of selected sectors, etc.).

6.8 Depending on the energy source, a reduction of 26 million tonnes of carbon could translate into a global gain of DKK 10-40 billion.

Figure 35.

Additional cost of a 70% reduction in carbon emissions by 2030

Reduction initiatives	Additional cost 2030[1] DKK billion (fixed prices 2019)
Energy and utilities	
Replacement of coal, oil and natural gas in district heating	0.3–0.5
Replacement of oil and natural gas in individual boilers	0.6–0.8
Carbon capture and storage	1.4–1.8
Plastics recycling in waste-to-energy	0.5–0.9
Electrification of North Sea production	0.8–1.0
Transport	
1.5 million electric and hybrid vehicles	1.3–1.7
Electric and hybrid commercial vehicles	(0.3–0.5)
Electric buses and electric trucks	(0.2–0.4)
Biofuels such as biogas and biodiesel	1.2–1.6
Industry	
Heat pumps in industrial processes	(0.0–0.2)
Biogas in gas grids, industry and buildings[2]	2.3–2.7
Energy efficiency improvements	(0.0–0.2)
Other (for example internal transport)	0.2–0.4
Buildings	
Optimisation of building installations	0.0–0.1
Renovation of building envelope	(0.0–0.1)
Power-to-X	
Phase-in of Power-to-X technology *ROUGH ESTIMATE*	5–7
Total	**Σ Approximately DKK 15 billion (12–17)**

[1] For additional cost, only the financial difference without taxes between technologies is calculated. This means the difference in price between the replacing technology (for example a heat pump) and the technology being replaced (an oil boiler). The calculation includes depreciation and operating costs. No external factors are included, i.e. potential benefits from less pollution, noise, etc. Nor is a potential loss included if funding is to be provided for the replacement of technology.

[2] The cost shown for biogas also includes heating for homes and businesses.

Note: Additional costs in Denmark's Energy and Climate Outlook 2019 are not calculated. A range of green technologies are expected to be phased in without further action. These are associated with costs, but due to favourable tax conditions the technologies are expected to be phased in by 2030.

Source: Ea Energy Analyses; Danish Energy; QVARTZ analysis.

The total additional cost of realising this sector roadmap[6.9] is expected to be around DKK 15 billion, see Figure 30. In other words, by 2030 switching to and using green technologies will be approximately DKK 15 billion more expensive than maintaining or reinvesting in fossil fuels. The assessment of the additional cost of DKK 15 billion in 2030 should be seen in light of the fact that the Danish economy is expected to grow by DKK 350 billion in the period 2019-2030.

The DKK 15 billion is a snapshot of the calculated additional cost in 2030. It does not mean that Denmark will have to pay the additional cost permanently. The transformation involves swiftly deploying a host of new technologies. As these technologies mature, the price difference compared to fossil technologies will be eliminated – in the same way that green power generation is currently able to compete with fossil power generation.

The phase-in of Power-to-X technology represents the biggest additional cost of approximately DKK 5-7 billion annually which is needed to reach the 70% reduction target by 2030 and full climate neutrality by 2050. The calculated additional costs of Power-to-X are subject to considerable uncertainty and, as with all immature technologies, a dedicated effort to promote Power-to-X will increase the likelihood of a major price fall towards 2030.

The same is true for the development in the price of electric vehicles which may also turn out to happen much faster or much slower than anticipated. In the calculations, it is expected that the marginal costs of phasing in the last 0.5 million electric vehicles are higher than for the first 0.5 million vehicles, as the phase-in will have to be stepped up early on in the process when the technology is more expensive in order to reach 1.5 million electric vehicles in 2030. It is assumed that the vehicles will be phased out as they reach the end of their life. As a result, in order to reach a higher number of electric vehicles in 2030 electric vehicles will need to quickly dominate new auto sales.

Looking at the additional cost per vehicle in the individual year, the additional cost will be much lower in 2030 than in 2021. If instead the ambition was to only reach 1 million electric vehicles in 2030, it would be possible to begin the phase-in later when the technology is more mature and presumably cheaper. As the vehicle fleet in Denmark is replaced over time, the difference between 1 or 1.5 million vehicles means that electric vehicles will make up more than 90% of new auto sales in 2027 rather than 2029.

For the other costs of the green transformation of approximately DKK 7-10 billion, the biggest additional cost relates to the replacement of natural gas with biogas in the gas grid, carbon capture and storage, the replacement of fossil vehicles with electric vehicles and the blending of biofuels. Overall, the four initiatives account for about 70% of the total additional cost, exclusive of Power-to-X.

The road to 2030 involves a rapid phase-in of a number of technologies that cannot yet compete with the fossil technologies they replace. That is why, by 2030, Denmark will face an additional cost of DKK 15 billion, which, however, will only have to be paid once. Switching from fossil to green technologies will also lead to a drop in the price of green technologies. In other words, when the first electric vehicle or heat pump is to be replaced after 2030, it is likely to be at a price that is more competitive than that of the fossil-based alternative. After 2030, the additional cost is therefore expected to fall for this particular area of the transformation.

The road from the 70% reduction target in 2030 to full climate neutrality by 2050 may involve new additional costs, but these are beyond the scope of this analysis. The calculated additional costs comprise only energy-related emissions. Additional costs of reductions not related to energy use are not included in these calculations.

6.9 Additional costs in 2030 include depreciation in 2030 on green technology acquired in the period 2019-2030 as well as current operating expenses.

Electric vehicles must dominate new auto sales to a higher degree to increase the total number of electric vehicles by 2030

Economic impact of measures in the green transformation

The green transformation requires that appropriate measures are in place to bring about the shift in technology. Even when the additional cost is negative and thus a gain, the transformation will not necessarily happen by itself. Public transport, for example, is governed by public tenders, and both citizens and businesses have historically been slow to make fundamental shifts in technology. In addition to financial losses, there will be economic losses when the government has to seek funding for new expenditure or when consumers are required to comply with prohibitions and requirements they would not otherwise have followed.

The additional cost can be borne by both consumers and businesses or by the government, depending on the measures chosen. If the transformation is secured through prohibitions, the measures will not impose costs on the government, but will instead be borne by consumers and businesses. If, on the other hand, the transformation is secured through financial or economic assistance, the cost is borne by the government.

Assuming that all additional costs are paid by consumers, this means that each household will have to pay an extra DKK 5,000 in 2030 for their total energy consumption, including to cover the additional cost incurred by businesses. The additional cost should be seen in the context of the fact that, over the same period, Denmark's wealth is expected to grow by approximately DKK 350 billion. This means that by 2030 Danes on average can expect to see an increase in wealth equivalent to around DKK 90,000 per household per year[6.10].

The impact of the green transformation on consumers can also be assessed by considering the development in the share of households' disposable income which is spent on their total average energy consumption. In 2019, these expenses made up approximately 19% of consumers' household budgets (this includes vehicle purchases as well as running costs of energy for lighting, heating and transport, etc.). Assuming that all additional costs are covered by households, the share will be 17% in 2030. Consumers can thus look forward to green energy, technology and a total energy bill which will make up a reduced share of an average family's disposable income.

6.3.2. The 70% reduction target is a challenge to government, but it can be done

The green transformation will directly affect government revenues in two ways:

- The government loses revenue when consumers buy fewer highly taxed vehicles with internal combustion engines and use fewer, taxed fossil fuels in industry, households, agriculture, the transport sector and the energy sector.
- Government expenditure is expected to rise, as part of the transformation can only be realised if subsidies are granted to selected energy customers.

6.3.2.1. With the current tax regime, the direct loss of government revenue is expected to be approximately DKK 23 billion in 2030

A comprehensive calculation of lost government revenues requires insight into a comprehensive selection of measures which is not yet known. Instead, the overall economic impact on government revenues can be illustrated, assuming that the necessary transformation is implemented without changing the existing system of taxes and duties. As a result, the calculation merely illustrates the scale of the challenge, as it is reasonable to assume that it will be partially offset by an increase in other taxes. Towards 2030, it is expected that some of the green technologies will have experienced price falls allowing them to be taxed more heavily than in 2020.

6.10 Expectations for increases in household wealth are calculated on the basis of the Danish Ministry of Finance: Denmark's Convergence Programme (2019).

Figure 36.

Annual loss of government revenues in 2030 with the current tax regime

Reduction initiatives **Denmark's Energy and Climate Outlook 2019**	**Lost government revenues, 2030[1]** DKK billion	**Primary cost drivers**
Development in the baseline projection 2019-2030	1.0-1.5	Fewer taxes from coal, oil and natural gas
Energy and utilities		
Replacement of coal, oil and natural gas in district heating	0.9-1.1	Fewer taxes from coal, oil and natural gas
Replacement of oil and natural gas in individual boilers	0.5-0.7	Fewer taxes from oil and gas
Carbon capture and storage	0.0-0.1	Fewer carbon taxes from fossil waste emissions
Plastics recycling in waste-to-energy	0.4-0.6	Fewer carbon taxes from fossil waste emissions
Streamlining and electrification of North Sea prod.[2]		Additional sales of natural gas
Transport		
1.5 million electric and hybrid vehicles[3]	16.0-19.0	Lower registration taxes, fewer petrol and diesel taxes
Electric and hybrid commercial vehicles	0.8-1.0	Lower registration taxes, fewer petrol and diesel taxes
Electric buses and electric trucks	0.2-0.4	Fewer diesel taxes
Biofuels such as biogas and biodiesel	0.4-0.6	Fewer petrol and diesel taxes
Industry		
Heat pumps in industrial processes	~0	Minimal change in tax rate when switching from fossil energy
Biogas in gas grids, industry and buildings[4]	~0	Minimal change in tax rate when switching from fossil energy
Energy efficiency improvements	~0	Minimal change in tax rate when switching from fossil energy
Other (for example internal transport)	~0	Minimal change in tax rate when switching from fossil energy
Buildings		
Optimisation of building installations	0.0-0.2	Fewer taxes on fuels
Renovation of building envelope	0.0-0.2	Fewer taxes on fuels
Total	**Σ Approximately DKK 23 billion (21-25)**	
Subsidies needed	**DKK 5-7 billion**	*Subsidies to enable green transformation*

[1] Annual effect based on a frozen policy scenario, i.e. with the current tax regime in which fossil fuel sources are heavily taxed.
[2] Could not be calculated within the given time limit.
[3] Registration taxes for electric vehicles have been calculated assuming that the 2020 tax rate of 40% is maintained until 2030. A higher registration tax towards 2030 is being discussed by policymakers, but as a mid-range electric vehicle (dealer price of DKK 250,000 excl. tax) is eligible for a full registration tax reduction due to its high energy efficiency, there will continue to be a significant impact on government revenues even with a full phase-in of registration tax for electric vehicles.
[4] Includes biogas for all purposes. Assuming that regulation remains unchanged, biogas production is expected to be subsidised until 1 January 2021.
Note: Lost government revenue is calculated with a revenue change from behavioural response.
Source: Ea Energy Analyses 2019; calculations by Danish Energy; QVARTZ analysis.

The greatest direct impact of the green transformation on government revenues comes from the replacement of fossil fuels and fossil-fuelled technologies. The government currently collects around DKK 30 billion in taxes on fossil fuels and a little over DKK 30 billion in taxes on fossil-fuelled transport of people and goods. As the transformation continues, a significant proportion of the revenue from fossil fuel taxes and fossil-fuelled vehicles in use today will be eliminated.

Specifically, the lost government revenues are expected to amount to approximately DKK 23 billion in 2030, assuming that the taxes remain unchanged, see Figure 36.

There are many different ways to make up for the loss of government revenue. The single biggest contribution to the loss of government revenue is expected to be the switch to electric and hybrid vehicles which will involve losses stemming from lower registration tax on electric and hybrid vehicles and falling revenues from taxes on petrol and diesel. It is expected that some of the loss can be gradually recovered through an incremental increase in taxes on electric and hybrid vehicles as their prices approach those of fossil-fuelled vehicles. The analysis thus shows that, in addition to the 70% reduction target, government and parliament must adapt to a decade in which the taxation of private vehicles will contribute less to government revenues than has historically been the case.

Over time, green energy may also be taxed if green energy sources maintain their competitiveness towards fossil fuels. It will also be possible to raise taxes on fossil fuels, with due regard being given to the competitiveness of businesses, in particular. Finally, it is possible to reprioritise public consumption or redistribute taxes so that lower tax payments on vehicle purchases or via the energy bill are offset by higher taxes in other areas.

6.3.2.2. The government must contribute actively to the green transformation

Meeting the 70% reduction target requires new technologies and widespread use of existing and new technologies. The energy and utilities sector and energy customers need support to make this development happen. Although, for example, the infrastructure and some of the green fuels have to be paid for by energy customers via their energy bill, this will not in itself be sufficient to maintain a strong business community, a strong energy sector and a fair social balance in Danish society which, as described in the Climate Act, are essential to reaching the 2030 target. Society as a whole will therefore have to shoulder some of the costs through redistribution via government revenues.

First, investments in the accelerated build-out of renewable energy will require subsidies in some areas. These are primarily continued subsidies for biogas production and new subsidies for scaling carbon capture and for Power-to-X fuels.

Second, risk sharing is required in the build-out of wind and solar power. For this level of power generation, the main challenge is that the price of power depends on whether or not the electrification of Denmark and the EU progresses according to plan. If production is increased without a corresponding increase in power consumption, the price of power will fall and put the profitability of the build-out at risk. As the electrification of Denmark and the EU over the next 10-20 years is largely driven by policy decisions, such risk is difficult to manage for private investors alone. Consequently, there is a need for regulatory models in which society assumes part of the risk, for example through tendering schemes where investors are compensated when power prices are low.

Third, there will be a need for public action to 'develop' suitable sites for electric vehicle charging stations in public spaces, in sparsely populated areas, along motorways, etc.

Fourth, the additional cost incurred by some energy customers must be covered by way of financial support. The need for support to cover the additional costs incurred by energy customers will be included in the roadmaps of the 12 other climate partnerships. In this sector roadmap, this need has not been assessed by the energy and utilities sector. However, the energy and utilities sector recognises the severity of the situation facing any business without sufficient revenue to absorb additional costs. The energy and utilities sector faces the same challenge. The government, parliament and the Green Business Forum must therefore assess the overall need for financial support.

Specifically, support for the transformation may take the form of government subsidies or dedicated tax remissions (for example for waste heat and power) to cover some of the additional cost to citizens and businesses and accelerate the transformation, financial support for the development, scaling and implementation of technologies as well as investment in the research required to mature the technologies needed. The need for collective financing of the transformation can be justified for distribution-related and competitive reasons. The former should make it possible for all citizens to be part of the switch to green technology. The latter should help sectors exposed to international competition, such as transport, industry and agriculture, to successfully make the transition without it curbing their competitiveness.

The level of government expenditure this requires can only be estimated if a fully calculated plan based on the recommendations of all climate partnerships specifying all measures is in place. At the same time, the combination of measures is a policy decision.

Overall, the analyses of the economic impact of the 70% reduction target show that, alongside the choice of strategic direction, action and measures, the government and parliament must also consider an overall financing plan for the journey towards 2030.

7.0 A new green social contract on the path to climate neutrality

A new partnership between business, the Danish government and the Danish parliament will secure the investments and policies necessary to take Denmark all the way to a 70% reduction by 2030 and to full climate neutrality by 2050. Investments in competitive and novel and immature technologies must be made ahead of an increase in demand under the assumption that policy will drive demand. Attracting new capital is only possible when people are willing to share the risks that come with it, for example, by entering power purchase agreements. The energy and utilities sector is requesting a mutual, green social contract in line with the 70% reduction target.

The starting point for the work of this sector roadmap is Denmark's Energy and Climate Outlook, which annually estimates the future energy demand in order to predict how the sector is expected to develop under current regulation. This means that we have an official estimate of what measures the energy sector may implement without new framework conditions. Denmark's Energy and Climate Outlook clearly shows that further action such as new regulation, new strategic decisions by Danish businesses and households, including the energy and utilities sector, is needed to reach the 70% reduction target.

The 70% reduction target can be achieved if everyone contributes capital, insight and strategic decisions. For years, Denmark has benefited from a broad political consensus on energy and utilities sector regulation, which has spawned green investments and green industrial leadership. The energy and utilities sector looks forward to continuing its contribution to Denmark's green transformation and to the government's and parliament's 70% reduction target.

A green social contract is based on policy in line with the 70% reduction target

The strategic direction towards 2030 is crystal clear: all energy must be used efficiently and fossil fuels must be replaced with green energy in the form of power from solar and wind, supplemented by biogas. Denmark's renewable energy production must therefore be increased substantially. The power infrastructure must be expanded, the role of the gas system must be changed, district heating must undergo major changes and energy customers must embrace new technology. Much of the development will be driven by direct electrification in the form of electric vehicles and heat pumps or by biogas, which will replace coal and natural gas. However, Denmark will not reach its 70% reduction target by 2030 or full climate neutrality by 2050 through direct electrification alone.

New, advanced hydrogen-based fuels produced using carbon capture or biogas will not only have to be developed as soon as possible, but will also have to be deployed in industry and transport. Steps must be taken to make carbon storage a strategic option for cutting Denmark's emissions, and better sorting and recycling methods must be introduced to significantly reduce the carbon dioxide content of waste incinerated to produce heat.

Naturally, there will be different opinions of what role each measure will have to play towards 2030 and how quickly the different technologies can develop, what technologies will be preferred and in what quantities. However, if Denmark is to reach the 70% reduction target and achieve full climate neutrality by 2050, it is imperative that all measures are considered. It is equally important that strategic choices are made now so that the many changes facing the energy and utilities sector and energy customers are supported by regulatory framework conditions. This will also allow us as a sector, and our customers, to contribute through our consumer behaviour and investment decisions.

The energy and utilities sector is calling for a mutual, green social contract in line with the 70% reduction target. As a sector, we are willing to raise further capital for the necessary green investments which can 1) ensure a near fossil-free energy and utilities sector by 2030, 2) deliver green energy and infrastructure for the full transformation of Denmark and 3) contribute large amounts of renewable energy for exports and the green transformation of our neighbouring countries, while also creating growth, value and prosperity in Denmark.

The energy and utilities sector encompasses activities which are subject to highly regulated monopolies – district heating, gas infrastructure and power infrastructure – and activities carried out in an ordinary free market. A national climate strategy must therefore address not only how regulated sections of the sector can be equipped to deal with their changed role resulting from the 70% reduction target, but also how commercial investments to achieve the 70% reduction target can be made profitable.

Changes in customers' energy consumption must be guided by regulation, which, in turn, calls for difficult choices to be made when it comes to concrete policy. Some aspects must be driven by an increase in fossil fuel costs, while elsewhere incentives such as subsidies must be introduced, and in exceptional cases requirements or prohibitions. The sub-sectors and businesses in our climate partnership naturally have quite different views on the action required and the same is likely to be true among consumers.

Difficult choices lie ahead, and not all technological opportunities and market opportunities are known at this point. Despite this, we call on the government and the parties behind the Climate Act to present a comprehensive climate action plan in line with the 70% reduction target. The plan should take into account the fact that some technological solutions remain uncertain and in such cases show how future uncertainty can be reduced and addressed today, for example through support for technological development and the accelerated implementation of technology.

Across all parts of the energy and utilities sector, there are two issues that need to be dealt with politically. One is how the risk associated with large investments can be shared between sector and society. The other is access to land.

Such risk sharing is necessary, as much infrastructure and renewable energy must be planned so well in advance and investment decisions have so long horizons that the investments will have to be made long before demand arises. At the same time, energy technology tends to have a very long lifespan (20-50 years). That is why it is imperative that there is political will in a green social contract to push demand and share the risk of the energy and utilities sector having to make investments before we know the full scope of demand. It is only possible to attract new capital if society is willing to share the risks that come with it. For the monopoly infrastructure that characterises our sector, in particular, regulators must also accept that major investments will have to be made to achieve the 70% reduction target and full climate neutrality by 2050. For technologies exposed to competition such as renewable energy production, political will in the form of various types of power purchase agreements is required. In addition, we need to build trust that green investments based on existing knowledge and regulation will not be compromised by future changes in legislation.

Access to land is another important issue for the energy and utilities sector towards 2030. Renewable energy plants that supply Danish households with green power and biogas take up space on land and at sea. Even in cities, land for, for example, electric vehicle charging stations is in short supply. It is therefore vital that the government and the parties behind the Climate Act acknowledge that the climate action plan will not only take up considerable economic resources, but will also be visible and felt around the country. Furthermore, the designation of land requires difficult trade-offs, for example in relation to environmental impact and long-term climate change. Closer dialogue with municipalities should therefore be part of the equation. From offshore wind farms to urban parking areas and charging stations – all require that clear policy choices are identified, prioritised and made.

Policy decisions must pave the way for major reductions in fossil fuel use throughout Danish society. If we invest only in the supply of green energy and infrastructure, but not in green and fossil-free consumption, Denmark will not reach the 70% reduction target. A clear and proactive policy must be pursued to guide energy customer choices in the coming years, ensuring that customers always choose green options when investing in a vehicle, home or business. These efforts must be coupled with a strategic goal to not only to supply the whole of Denmark with green energy, but also to reap the benefits of supplying the rest of Europe with green energy.

Financing

As shown in chapter 6, the transformation will require substantial investments. A green social contract must therefore be accompanied by a clear strategy for financing Denmark's progress towards the 70% reduction target in a way that does not increase social inequality or undermine the competitiveness of business. Denmark may be able to reduce the cost to energy customers by lowering taxes on green solutions in the same period and subsidising the switch to new technology in hard-to-decarbonise areas. An accelerated build-out of green energy will continue to require subsidies during a transitional period. Initially, the energy and utilities sector estimates that total subsidies of DKK 5-7 billion will be needed annually to transform the energy sector and deliver enough green energy to meet the 70% reduction target by 2030 and put Denmark on track to reach climate neutrality by 2050.

The funding of the welfare state is essential to the energy and utilities sector, business and, of course, the Danish public. But it is more than that. In fact, tax adjustments and the predictability of knowing how taxes are going to develop over the next ten years are important tools to guide the many people who need to make green investment decisions in the coming years.

A comprehensive green tax reform should therefore be implemented, in which the funding of the welfare state is less dependent on energy and vehicle taxes. In addition, a balance must be struck between carbon taxes, subsidies and incremental increases in taxes on green passenger cars as they become cheaper. Taxes must be carefully adjusted to avoid the risk of business operations being moved abroad without any benefit to the climate. Similarly, taxes on green vehicles must be introduced in a way that does not conflict with the need for carbon reductions. The need for major changes to the overall tax system will be reduced if in future there is political will to set aside public funds for the climate action plan supplemented by a growth-oriented economic policy. This will make it possible to reach the 70% reduction target without undermining the competitiveness of business or increasing social inequality.

Strategic direction, partnership and action

We call on the government and the parties behind the Climate Act to define an overall strategy in the coming months to put Denmark on track to reach the 70% reduction target. With five key actions, the strategy must set the direction for the energy and utilities sector which must be in place by 2030.

Once the government has defined its strategic direction and crucial strategic decisions have been made, these must be translated into action and detailed official regulations. In some areas, swift action can and must be taken. For example, new offshore wind tenders must be decided as soon as possible to allow officials to begin the process of identifying suitable sites and preparing the infrastructure. The distance from decision-making to action must be short.

In light of the obvious policy choices that lie ahead in the coming months, the energy and utilities sector is ready and willing to continue the work in partnership with the government and fulfil the role we have been given. We fully recognise the scale and complexity of the task ahead and the need for adapting policy and action in step with the implementation of technologies, technological development and consumer behaviour. The social contract needed for Denmark to achieve its 70% reduction target rests on three pillars: clear strategic direction, partnership and decisiveness.

Methodology

The energy and utilities sector's roadmap comprises: (A) calculated initiatives for reducing greenhouse gas emissions in the energy and utilities sector, (B) an estimate of the total energy demand in 2030 if reduction initiatives are implemented in the energy and utilities sector and other sectors to achieve the 70% reduction target, (C) an estimate of the build-out of renewable energy production and associated energy infrastructure needed to meet the energy demand and (D) a calculation of the economic costs associated with the initiatives and the expected build-out of renewable energy production and infrastructure to reach the 70% reduction target. The calculations in the roadmap have been made by Danish Energy and QVARTZ with significant contributions from Ea Energy Analyses.

The entire analysis is based on Denmark's Energy and Climate Outlook (2019), notably the calculation of initiatives to reduce greenhouse gas emissions and the build-out of renewable energy sources towards 2030. Denmark's Energy and Climate Outlook is a so-called frozen policy scenario for how greenhouse gas emissions and energy production will be in 2030 in the absence of new climate and energy initiatives, but with a projected development in other parts of the economy. All anticipated initiatives in Denmark's Energy and Climate Outlook are included in the calculation model of this analysis. Basing the analysis on Denmark's Energy and Climate Outlook means that greenhouse gas emissions are calculated according to the same principles applied by Denmark when reporting its emissions to the UN. Emissions are calculated exclusive of LULUCF and as actual emissions, which means that they have not been climate-adjusted or adjusted for power trading. Biomass is treated as being carbon neutral on the basis of the industry agreement on sustainable biomass, which was fully phased in in 2019.

A) Calculated initiatives for reducing greenhouse gas emissions in the energy and utilities sector

In addition to the reduction initiatives calculated in Denmark's Energy and Climate Outlook for the energy and utilities sector, the sector has identified further initiatives in this analysis which can be implemented to contribute to the 70% reduction target. In this context, emissions from the energy and utilities sector are defined in the same way as in the climate partnerships, i.e. as emissions from gas and oil extraction, conversion to power and heat as well as end-user heating systems (both district heating and individual heating). For each initiative identified, the annual carbon reduction potential from the displacement of fossil fuel sources and the expected economic cost in DKK per tonne of carbon have been calculated.

B) Estimate of the total energy demand in 2030 if reduction initiatives are implemented in the energy and utilities sector and other sectors to achieve the 70% reduction target

In addition to the reductions in its own sector, the energy and utilities sector can make a sizeable contribution to reductions in other sectors by ensuring that the heightened demand for renewable energy resulting from the transformation of other sectors is matched by a corresponding increase in renewable energy production. To provide a qualified and concrete estimate of how much renewable energy is needed in 2030, Ea Energy Analyses has further developed the displacement model it has previously prepared for the Confederation of Danish Industry. The displacement model lists potential initiatives to reduce greenhouse gas emissions towards 2030 and the related costs calculated for each initiative. By ranking initiatives according to the related costs per tonne of greenhouse gas reduction, the model can be used to identify which reduction initiatives constitute the overall most cost-effective way to achieve the 70% reduction target. These initiatives are used in combination with the expected energy demand in Denmark's Energy and Climate Outlook to predict the total energy demand in 2030.

In this context, it is important to emphasise that it is not up to the climate partnership for the energy and utilities sector to decide which reduction measures should be implemented in the other sectors to meet the 70% reduction target. The displacement model is thus used solely to provide a concrete and qualified estimate of the expected energy demand in 2030 which is to be met by the energy and utilities sector. The energy demand in 2030 is estimated across energy sources such as power, biogas, biofuel, etc. The displacement model also contains substantial energy efficiency improvements. If the 70% reduction target is met, the total energy demand in 2030 is expected to be 13% more energy efficient than estimated in Denmark's Energy and Climate Outlook due to the transition to more efficient technologies (such as electric vehicles and heat pumps) and energy efficiency improvements (such as process efficiency improvements in industry and building envelopes).

C) Estimate of the build-out of renewable energy production and associated energy infrastructure needed to meet the energy demand

The increased energy demand in 2030 must be met by the energy and utilities sector. In 2030, energy demand will consist of fossil fuels, green fuels (such as biomass, biogas, biowaste, etc.) and power from renewable energy sources (solar and wind). All energy sources are based on the 2030 scenario in Denmark's Energy and Climate Outlook, supplemented by the energy demand resulting from the expected further initiatives to achieve the 70% reduction target. Power demand, in particular, will increase significantly as a result of the large-scale electrification of processes that currently use fossil fuels (for example transport, heating and industrial processes).

The estimate of the growth in green power (offshore wind, onshore wind and solar power) needed to meet the increased demand for power is based on the expected build-out towards 2030 in the Danish Energy Agency's Analysis Assumptions (2019). The difference between the expected installed power volume in the Analysis Assumptions in 2030 and the power volume required if the 70% reduction target is met is split between offshore wind, onshore wind and solar power in the same relative build-out share as projected by the Analysis Assumptions between 2019 and 2030. Consequently, the build-out of power generation volume follows the same build-out pattern as the build-out already projected by the Analysis Assumptions between now and 2030. The concrete build-out proposal for offshore wind, onshore wind and solar power is included only to illustrate how a build-out of the necessary power volume can be realised, but this may differ from the proposal. Using the same relative build-out pattern as the Analysis Assumptions, no correction has been made for technology prices, tender size, technical lifetime, infrastructure constraints, etc. beyond what is implicit in the Analysis Assumptions. The required build-out of the distribution grid and the heat grid has been calculated by Danish Energy on the basis of the expected initiatives in the displacement model and the total power and heat demand. Energinet has calculated the required build-out of the transmission grid.

Further initiatives are expected to be introduced to avoid security of supply challenges in a situation where flexible fuels have been phased out of power generation to some extent. A precise estimate of the extent of the challenges and the action proposed to avoid them (such as interconnections, power plant capacity, etc.) are outside the scope of this sector roadmap. It is therefore recommended that, in addition to the sector roadmap of the energy and utilities sector, a comprehensive analysis of security of supply in 2030 be conducted using scenarios which are consistent with the fulfilment of the 70% reduction target and with the expected phase-out of flexible power generation capacity in Denmark's neighbouring countries.

(D) Economic costs associated with reduction initiatives and the build-out of renewable energy production and infrastructure

Based on the measures in the displacement model and the estimated demand for renewable energy, the economic effects of the green transformation have been calculated. The sector roadmap calculates both the total additional economic cost in 2030 and the required investments in the replacement of technology, the build-out of renewable energy production and the establishment of new infrastructure towards 2030. The calculations are made in real terms without discounting.

The calculations of economic effects are based on the assumption that towards 2030 the Danish economy will develop as expected in Denmark's Energy and Climate Outlook 2019. It is thus assumed that the further reduction efforts will not hamper economic growth and that any negative growth impact of the necessary reduction initiatives will be offset by corresponding policy initiatives. Moreover, it is assumed that the supply side of the Danish economy is sufficiently flexible to accommodate the calculated investments towards 2030 without overheating the economy.

All calculations are based on the assumption that the transformation will be as cost-effective as possible, regardless of the measures chosen to ensure a successful transformation. Additionally, it is assumed that the technological development will be unaffected by the choice of measures in the reduction efforts. If the transformation is not cost-effective, the reduction costs may be higher than estimated in the sector roadmap.

The initiatives described are generally designed to eliminate the need for an accelerated phase-out of fossil technologies. An accelerated phase-out of technology which has not yet reached the end of its life will lead to increasing marginal costs in the individual initiatives. However, there may be adjustment costs for the individual players that have not been taken into account. The measures will likely also have to offer a stronger economic incentive than required in the technical calculations to ensure a shift in technology. For some, making the switch to a heat pump or an electric vehicle involves costs that have not been taken into account. This is some of the inherent uncertainty in the calculations.

The measures chosen to bring the initiatives to fruition may have indirect effects. For example, some consumers will opt to travel by train or bike instead of by car if petrol and diesel prices go up. All other things being equal, these effects will lower the reduction costs, but they cannot be calculated until it has been decided which measures to adopt.

Based on the required build-out of the power grid, it is also calculated how power distribution grid tariffs are expected to develop towards 2030. Finally, the expected impact on government revenues and households in 2030 is calculated assuming a frozen policy scenario. The calculated impact on government revenues does not take into account any measures needed to ensure a successful green transformation. All economic calculations are subject to considerable uncertainty and assume that all measures in the displacement model are implemented.

Contributors to the climate partnership for the energy and utilities sector

Many organisations and companies have contributed to the development of the sector roadmap for the climate partnership for the energy and utilities sector.

We would like to thank everyone for their valuable contributions and great work on the project.

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Wind Denmark
The Danish Forest Association
Hydrogen Denmark
The Danish Metalworkers' Union

THE CLIMATE PARTNERSHIP SECRETARIAT
Danish Energy

EXTERNAL SUPPORT
Ea Energy Analyses
QVARTZ (now part of Bain & Company)

Photo: Jeppe Carlsen.
Ørsted, Clever, Nature Energy,
Eon, HOFOR, Radius
Design: Essensen®

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