System Value Analysis

DENMARK

November 2022

Accenture Strategy & Consulting

AGENDA

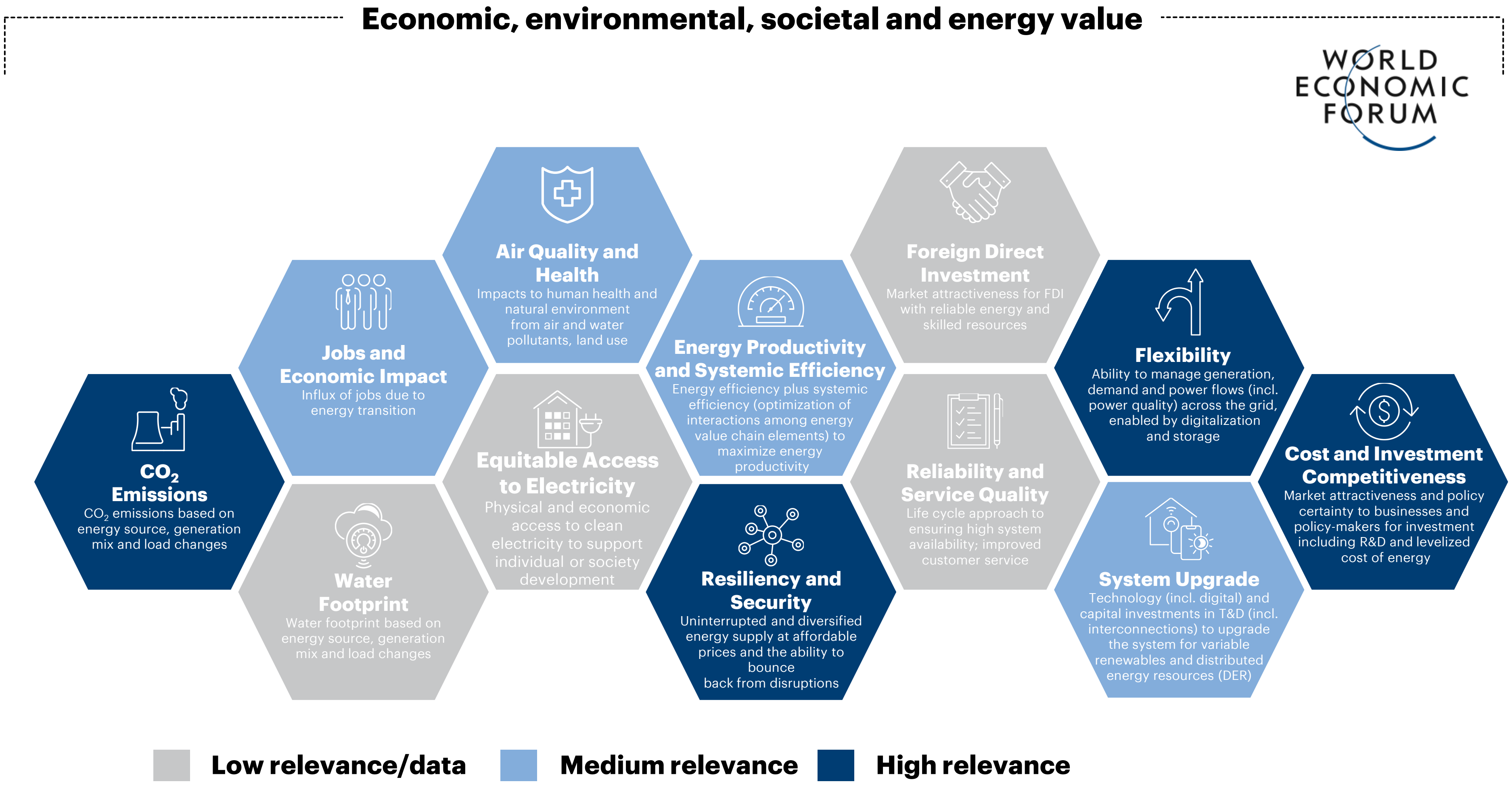
1. Executive Summary
2. Market Analysis
3. Solutions

System value of the clean energy transition in Denmark

The System Value framework more holistically evaluates economic, environmental, social and technical outcomes of potential energy solutions across markets. The framework aims to **shift political and commercial focus beyond cost to include value**.

Using the System Value framework, the World Economic Forum, supported by Accenture and a group of global electricity companies, conducted analysis across several geographies as part of market evaluations that examined recovery opportunities to accelerate economic growth and the clean energy transition.

The flexible nature of the framework allows inclusion of both quantitative and qualitative analysis. The relevance of System Value dimensions may vary by geography and over time horizons.



MARKET ANALYSIS | EXECUTIVE SUMMARY

70% — CO_2 emission reduction target by 2030 (relative to 1990), meaning a reduction of 23.2 Mio tCO_2e (1)

10.1 Mt — CO_2e gap for target set by the Danish government in 2030 based on frozen-policy scenario (1)

100% — Target for CO_2 emission reduction by 2050 to reach net-zero emissions (1)

80% — Of the total historic GHG emissions come from transport, agriculture and industry (1)

Integration of 90% VRE in the grid of 2030 leads to generation uncertainty and availability (1)

5-6 % — Of global GHG emissions are represented by shipping and aviation industries which are mostly excluded in NDC's

Privately owned vehicles are the preferred mode of transportation in Denmark from which only 1% are electric vehicles (1)

Most of the GHG reductions historically have come from electricity and heating (1)

>50% — Of total GHG emissions in Denmark is due to land cultivation of carbon-rich peatlands (3)

3.7 Mt — CO_2e is emitted yearly by the release of methane due to enteric fermentation when livestock digest food (1)

1.3 Mt — CO_2e is caused by energy intensive industries as cement, glass & tile in 2030 (1)

Sources: (1) Klimafremskrivning 2022 (2) Mitigation - UN Climate Change Conference (COP26) at the SEC – Glasgow 2021 (ukcop26.org) (3) Klimarådet - Carbon rich peat soils

Path to maximize System Value

Markets are moving from addressing core elements of the electricity sector transition…

…through "pivot points" where generation mix hits 20%-30% annual variable renewables (>50% instantaneous) and transformational elements enable…

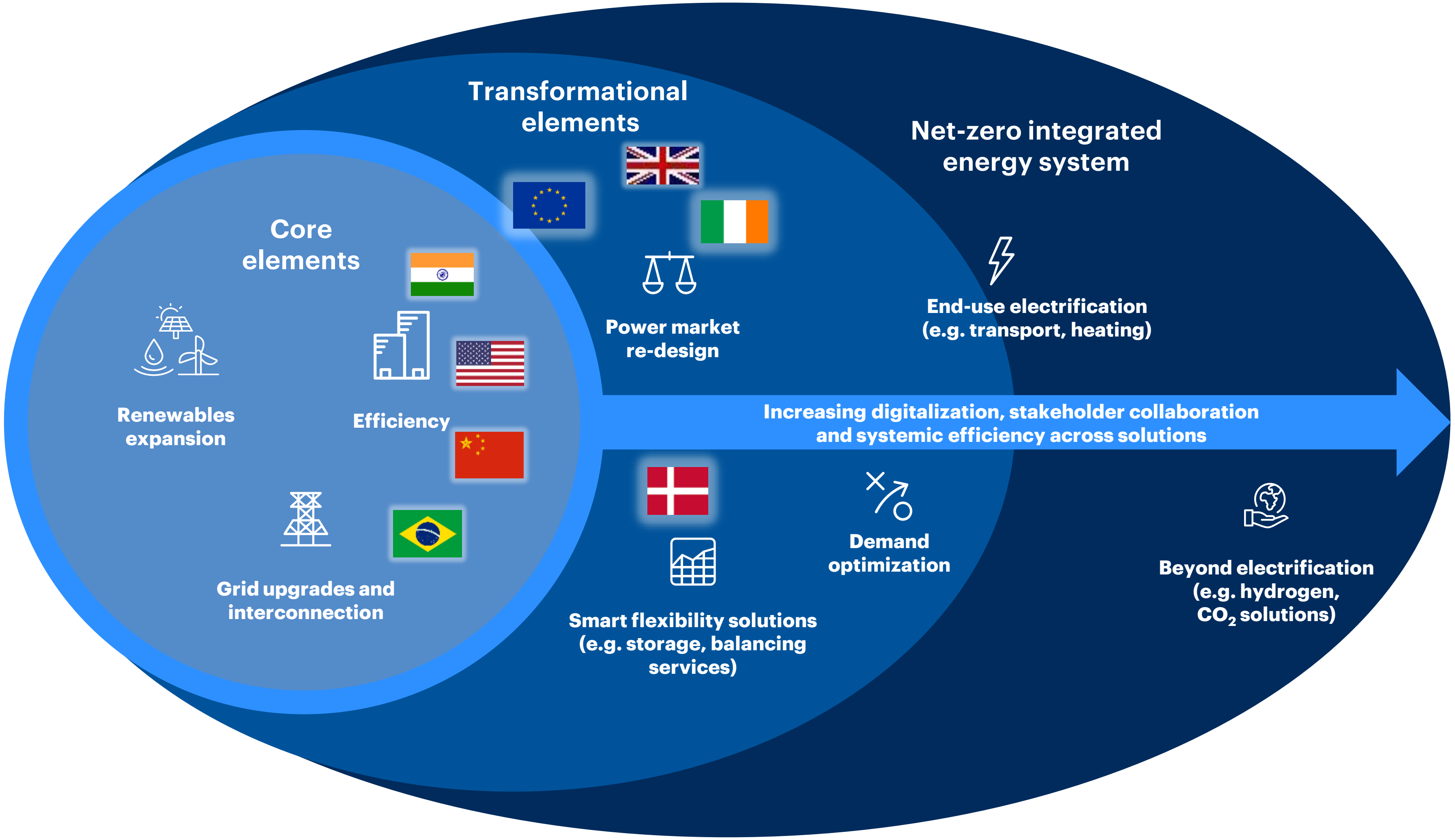
… acceleration to a net-zero integrated energy system with a strong focus on systemic efficiency

WHY

Denmark has committed to reduce its **CO2 emissions by 70% by 2030** compared to GHG emissions in 1990 (1)

Denmark to achieve **net-zero emissions** across the economy **by 2050**

There is an urgent need for Denmark to take concrete actions.



Sources: (1) Energistyrelsen- https://ens.dk/service/fremskrivninger-analyser-modeller/klimastatus-og-fremskrivning

Note: Icons represent solution types which deliver System Value outcomes. Flag indicates market progression along the path.

Solutions for speeding up the green transition in Denmark

1. Mature electricity backbone

The construction of two energy islands speeds up the decarbonization in Denmark and Europe. Using intelligent digital technologies to monitor the grid, enable flexibility, balance generation and consumption, while utilizing rapid and seasonal storage to balance supply with demand and allow for growing share of renewables.

~9.5 Mt CO_2 reduction in 2030 across involved countries

77.3K Jobs created due to hydrogen and the energy islands

€ 60 bn Export potential of Denmark

704-1409MW Potential flexibility due to demand response

2. Rapid transport electrification

Accelerate EV deployment in passenger cars through incentives, improved charging infrastructure and deterrents.

~2 Mt CO_2 reduction in 2030

2.7K Economy-wide jobs by 2030

~ €0.2 bn Human health benefits per year from 2030

3. Industry decarbonization

Electrification of low energy intensive processes and utilize P2X technology to fuel high temperature manufacturing. Setting up industrial clusters for exchange of resources and further exploration of new technologies, such as carbon capture, to cut process-related emissions.

~3.8 Mt CO_2 reduction in 2030

63K Economy-wide jobs by 2030

€ 3.5 bn Export potential green hydrogen

1.4 % Increase of GDP in 2035 due to industrial symbioses

4. Sustainable agriculture

Reduce agricultural emissions by moderation of animal product consumption and adopt sustainable farming approaches to reduce fertilizer application. Installing biogas plants while getting rid of animal waste and utilizing biogas in industrial processes.

Up to 5.5 Mt CO_{2e} reduction in 2030

10K Economy-wide jobs by 2030

~ € 0.2 bn Health benefits 2022-2030 due to a healthier diet

Green fuels for shipping and aviation

The construction of electrolyser plants for providing green fuels for shipping and aviation. The rise of new technologies in green fuels requires global support such as global pricing or a levy scheme.*

*Emissions are on a global level and do not count for Denmark's NDCs.

Market Analysis

Call for action

Projections made by the Climate Council of Denmark's CO_2 emissions in 2030 show a gap of **10.1 Mt Co2e** with respect to the 70% emission reduction target set by the Danish government. (1) Reductions in transport, agriculture and industry sector are needed to meet emission targets.

What has been promised

By 2030

70%

23.4 Mio tCO2e

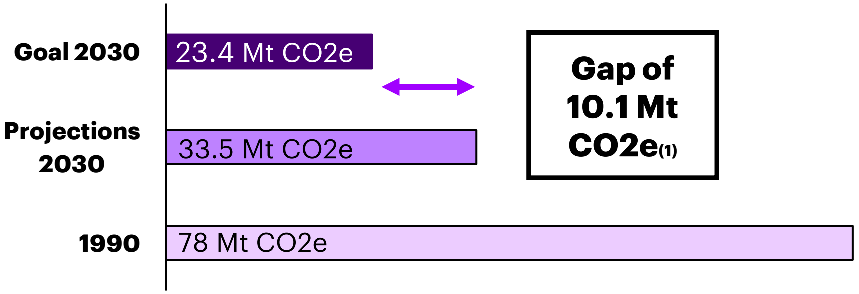
Compared to GHG emissions in 1990 (1)

By 2050

100%

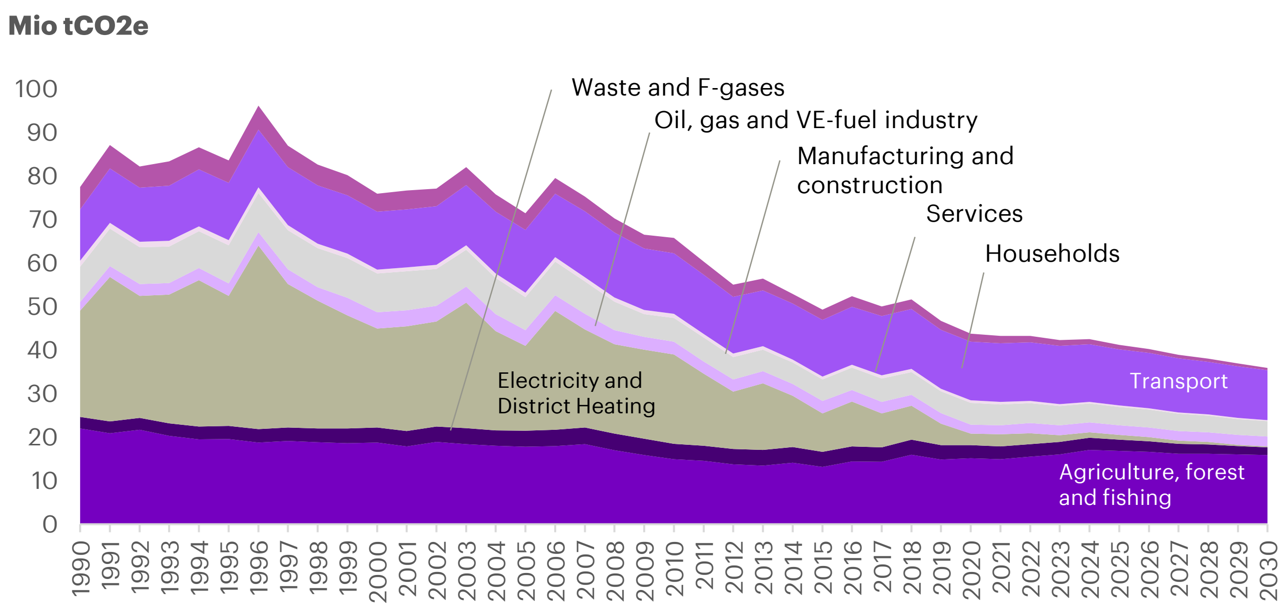
Denmark to achieve net-zero emissions across the economy

Emissions in 1990 vs projected emissions in 2030 (1)



Gap of 10.1 Mt CO2e(1)

Emission reductions since 1990 and projections until 2030 by sector (1)



1990 — Global commitments — 2030

The EU 'fit for 55' package forces Denmark to cut CO2 emissions **by 55% in 2030**. Multiple agreements have been made regarding agriculture, energy efficiency, renewable energy sources and CO2 emissions from transport. At COP26 a global methane pledge has been made, as well as the statement to phasedown coal in the coming years. It has been concluded that all measures taken so far are insufficient to fulfill the goals of the Paris Agreement. (2) In May 2022 the REPowerEU Plan has been issued where new targets are set to rapidly reduce EU's dependence on Russian fossil fuels and builds on the Fit for 55 package. **The renewables target is increased from 40% to 45%**, where the aim is to have nearly 600 GW of solar photovoltaics (3). Additionally, around 30% of EU primary steel production is expected to be decarbonized utilizing renewable hydrogen by 2030 (3).

Sources: (1) Klimafremskrivning 2022 (2) Mitigation - UN Climate Change Conference (COP26) at the SEC – Glasgow 2021 (ukcop26.org) (3) European Commision

Denmark has a strategy towards a green transition but is missing concrete measures

In order to reach the 2030 and eventually 2050 goal the Danish government has adopted certain policies and set out a strategy for the coming years, but this strategy is insufficient to meet the target of 2030 if no other concrete actions are taken.

Current measures taken by the government

November 2019	June 2020	2021	2022
• 13 Climate Partnerships representing all branches of Danish economy	Climate agreement for energy and industry: • Construction of two energy islands • Investment in CCUS and P2X • Energy efficiency, electrification improvements and more green gas • Investments for green transport • Green Tax reform	• Agreement on Finance Act 2021: economic recovery while working towards green transition • Agreement for roadmap on CCUS	• New strategy for Danish shipping to accelerate green transition in next three years • Agreement on corporate carbon tax of 151€/ton by 2030 • Agreement on the implementation of a pool for green continuing education and upskilling in 2022

Roadmap towards the goal of 2030

2022	2023	2024	2025
• Agreement on the development and promotion of hydrogen and green fuels • Agreements on green regulation of industry and energy • Aim for fossil-fuel free domestic flights by 2030 • Speeding up phase-out of natural gas	• Development of sustainable fuels for transportation and in shipping • Climate neutral waste sector and circular economy	• Development of basic agricultural technologies and revisit of agricultural area • Focus on green academic research and innovation	• Green cars revisited • Climate action plan • Evaluation of 2025 targets • Introduction of a corporate carbon tax from 2025

Sources: Ministry of finance; Danish ministry of climate, energy and utilities

The main sources of remaining emissions originate in the agriculture and transport sectors

While a lot of progress has been made within the electricity and heating sector, emissions from transport, agriculture and industry have proven hard to abate and remain largely unchanged.

FOCUS AREAS

1

Electricity generation and consumption
The green electricity system drives the energy transition. The majority of historic GHG emission reductions is related to energy generation.

2

Transport
Transport activity makes up 29% of CO2 emissions and will even continue to increase in the coming years.

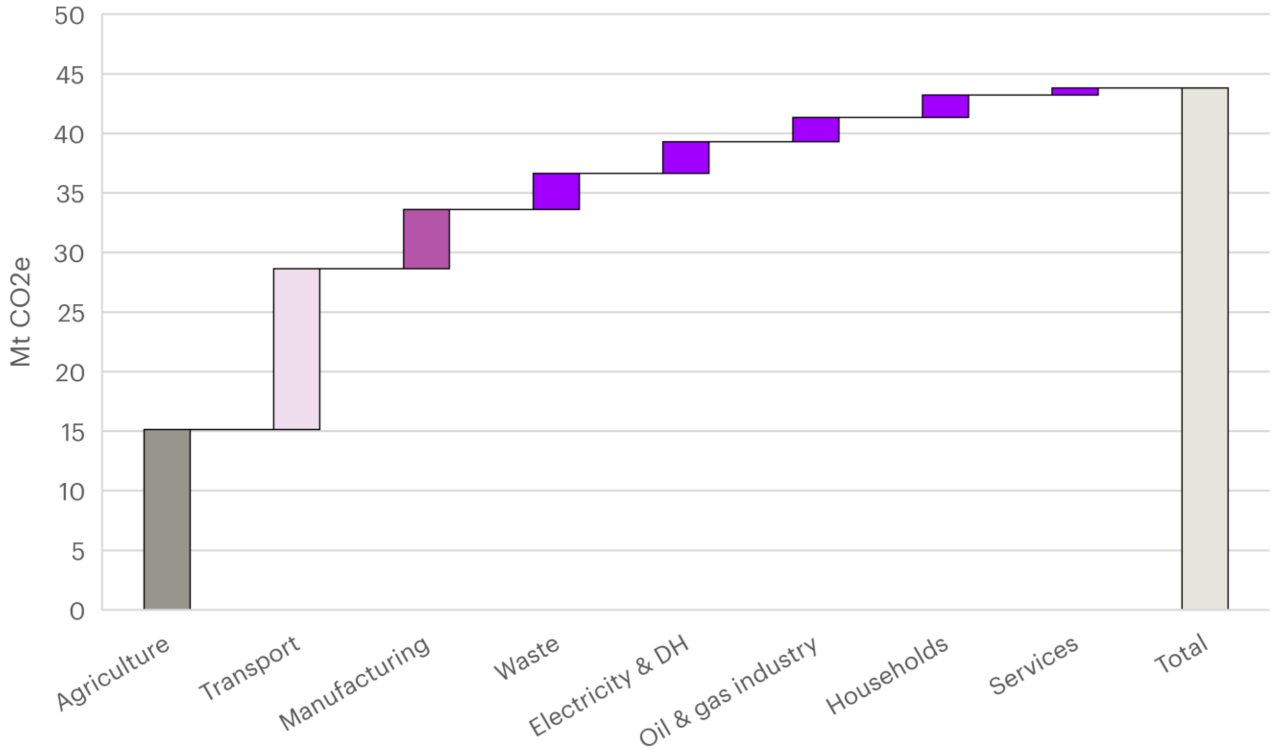
3

Manufacturing & construction
Emissions from manufacturing and construction are hard to abate due to energy intensive processes.

4

Agriculture
The agricultural sector is responsible for more than 30 % of the total emissions in Denmark, related mainly to livestock and fertilizers.

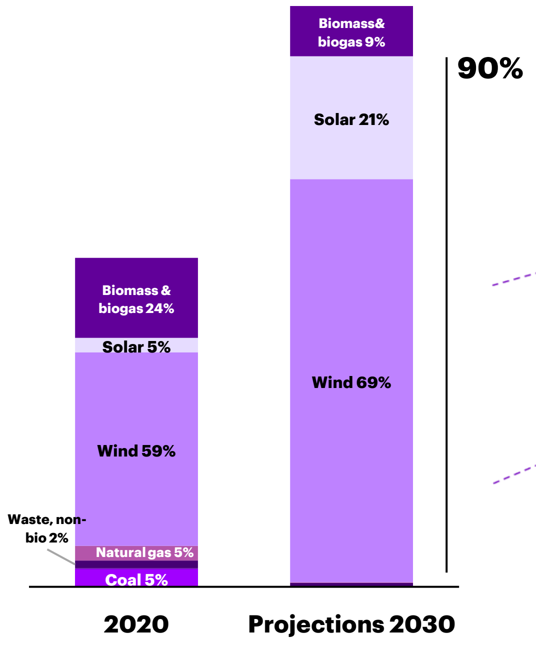
Emissions by sector in Denmark in 2020

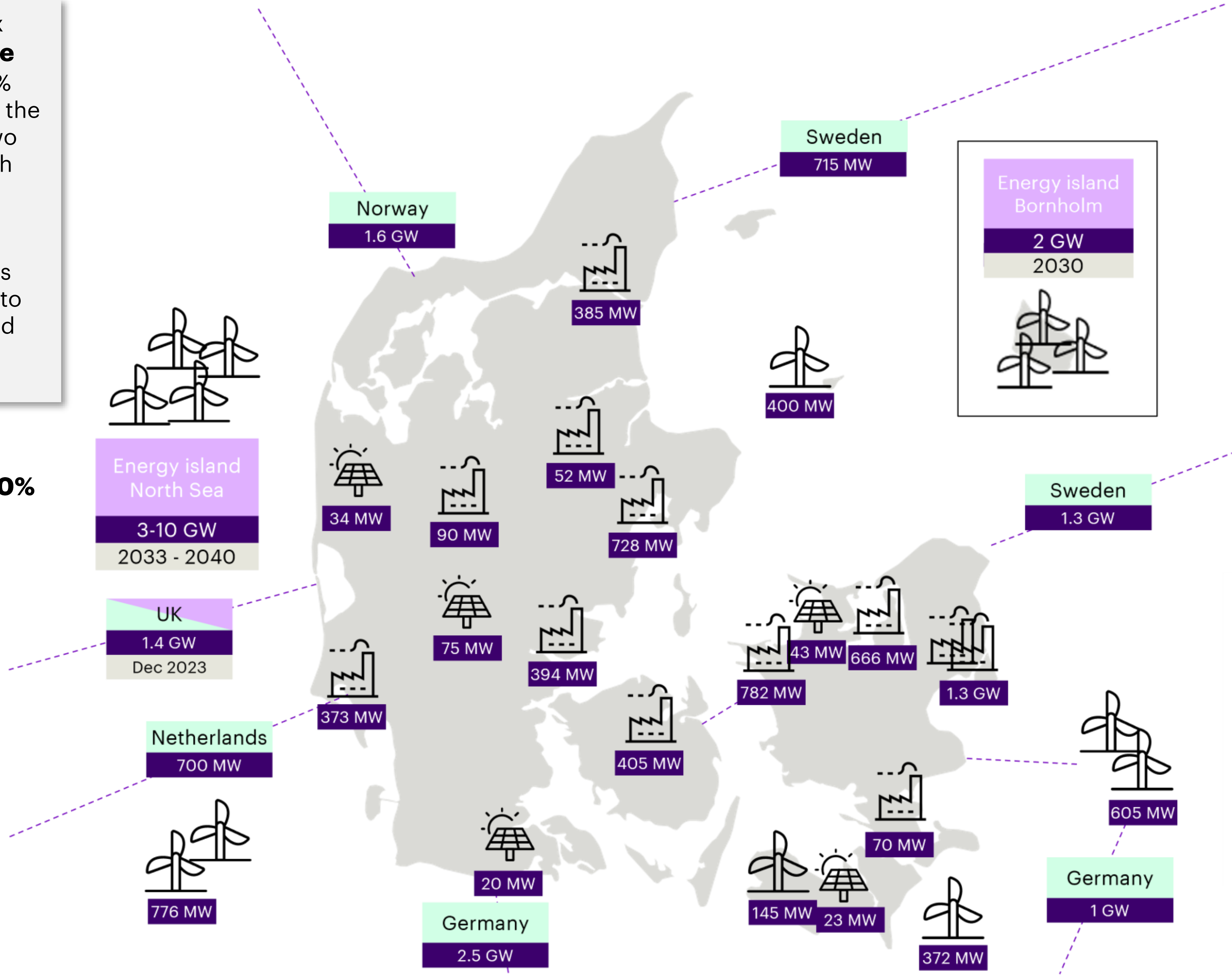


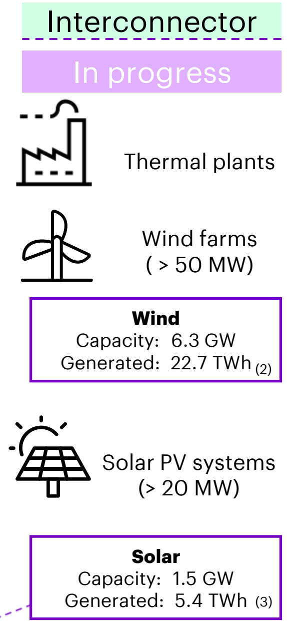
International Shipping and Aviation is not included in the emission breakdown on a national level despite high contribution to each Dane's carbon footprint.

1a. The electricity system in Denmark

In 2030 the electricity generation mix will be expected to have **90% variable renewable energy**, consisting of 69% wind energy (1). This is partly based on the government's proposal to construct two offshore wind energy hubs, in the North Sea and on Bornholm. Households, industry and services consume the majority of the generated electricity. Towards 2030 the electricity demand is expected to increase significantly due to new data centers, P2X, electric cars and more electric heating in houses and industry.







Interconnectors to neighboring countries are essential to Denmark's security of supply

Neighboring countries such as Norway and Sweden, with large hydroelectric power capacities, support balancing Denmarks variable energy supply from wind and solar.

Sources: (1) Klimafremskrivning 2022 (2) Denmark | IEA Wind TCP (iea-wind.org) (3) • Denmark: solar PV capacity additions 2021 | Statista

1a. Danish Power Market Structure

Generation

Plant Owners
sell the electricity produced at the plant to the electricity suppliers

Transmission

Energinet
Danish TSO, responsible for operating the grid and electricity system in Denmark

Owns and operates

DataHub
IT system that stores all data about the Danes' electricity consumption and handles all communication data between the players in the electricity market.

Distribution

Grid companies
have a monopoly on transporting power in separate geographically defined network areas. It is the network companies' responsibility to measure the consumption and production of electricity in their grid area and submit it to DataHub

There are multiple DSO's in Denmark of which the biggest ones are owned by Andel, Norlys and Ewii.

Suppliers
Electricity suppliers buy power through a balance responsible player on electricity exchanges or from other balance responsible players and sell it on to customers

Consumption

Costumer
buys electricity from the electricity supplier and, in addition to consumption, also pays all taxes, subscriptions, tariffs, etc. to the electricity supplier. To ensure that there is power in the switch, the customer must actively select an electricity supplier

Balance responsible actors buy and sell power on electricity exchanges on behalf of electricity suppliers and plant owners. They send daily plans to Energinet on how much electricity they expect to be produced and used in the coming day by the producers and customers they are responsible for in the coming day.

One of the characteristics of the Danish power market is the integration of renewables. 7 GW of wind & solar energy has been integrated in past 40 years, but in 2030 around 28 GW of VRE needs to be integrated in the power system. Distributing the electricity produced on the energy islands will require the flow of large amounts of power, potentially necessitating the development of the worlds first multi-country meshed off-shore grids. Energinet, the Danish TSO, is investing DKK 25 billion in expansion of electricity transmission networks over the next 5 years. (1)

The price of electricity is fixed by the hour on the basis of supply and demand. This market model ensures that while taking congestion in the transmission grid into consideration, electricity is generated from the cheapest production unit in order to match the buyers' bid.(1)

Nordic power grids are coupled and the Nordics have a long history of cooperation for balancing the power. The Nordic power system is transforming with more unregulated production like wind and solar and increased cross-border exchange. (2)

In September 2022, energy ministers from the nine members of the North Seas Energy Cooperation (NSEC) agreed to reach at least **260 GW of offshore wind capacity by 2050**. This will represent more than 85 per cent of the EU-wide ambition of reaching 300 GW of offshore wind capacity by 2050. The members of NSEC are Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden, and the European Commission. The members have also agreed on expansion targets for the North Sea region of 76 GW of offshore wind by 2030, and 193 GW by 2040. NSEC has also agreed on developing more hybrid offshore renewable projects that combine wind farms and interconnectors and connect to several member states.

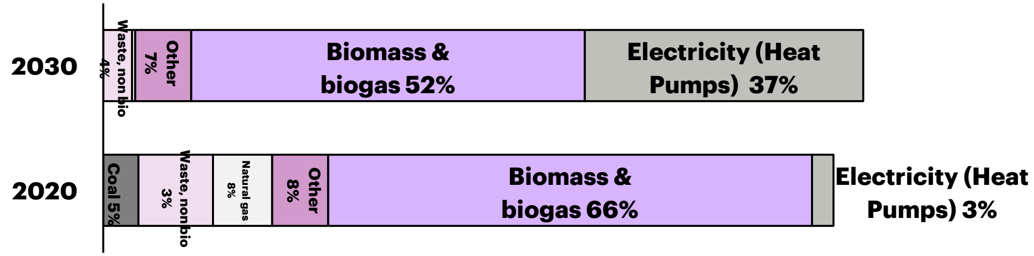
Sources: (1) Energinet (2) Nordic Balancing Model

1b. Energy industry characterized by high penetration of renewables and sector coupling

The energy use in Denmark in 2020 by source

Source	Energy use (PJ)	As % of total energy use	
Coal & Coke	19.95	2.9	Fossil fuels 58.6%
Oil	277.29	40	
Waste	19.56	2.8	
Gas	89.52	12.9	
Biogas	25.42	3.7	Renewable energy 41.4%
Biofuels	11.54	1.7	
Wind & Solar	70.17	10.1	
Biomass and other VE	179.42	25.9	

Generation of district heating



3 phases of sector coupling in Denmark (1)

1. The establishment of **district heating and decentralized CHP plants**. The surplus heat from electricity generation is used for this purpose. Here there is sector coupling between electricity, heating and gas.
2. Direct electrification by using **heat pumps** to replace oil-fired boilers outside district heating areas. Denmark is currently in this phase.
3. Power to X and the use of **indirect electrification**

District Heating development

Denmark has a well-developed network for the supply of district heating. Around 64% of all Danish private households are connected to district heating utilized for space heating and hot water (1). Denmark is aiming to **end dependency on Russian gas by 2028** – around 50 percent of Danish households that are currently heated by natural gas will be converted to district heating (2). Today there are approximately 400,000 homes that are heated by natural gas. By 2028 all of these will be converted, either they will be supplied by a district heating network or a heat pump. (2)

The District Heating network in Denmark is still dependent on fossil fuels, specifically coal and natural gas, while most of the energy is generated by burning biomass. In the past years a large amount of coal-fired district heating plants have been converted to biomass-fired plants. This is expected to be a transition phase before switching to district heating plants consisting of large heat pumps. (3) **In 2030, 37% of the heat demand is expected to be covered by heat pumps** powered by electricity from renewable sources. It is expected that the remaining coal-fired power stations will be converted to heat pumps followed by natural gas and biomass. Bioenergy will still play a large role in 2030 but this share is expected to decrease after 2030. Emissions due to heating are therefore expected to be very limited in 2030.

Sources: (1) Energinet (2) Energiwatch (3) Foresight

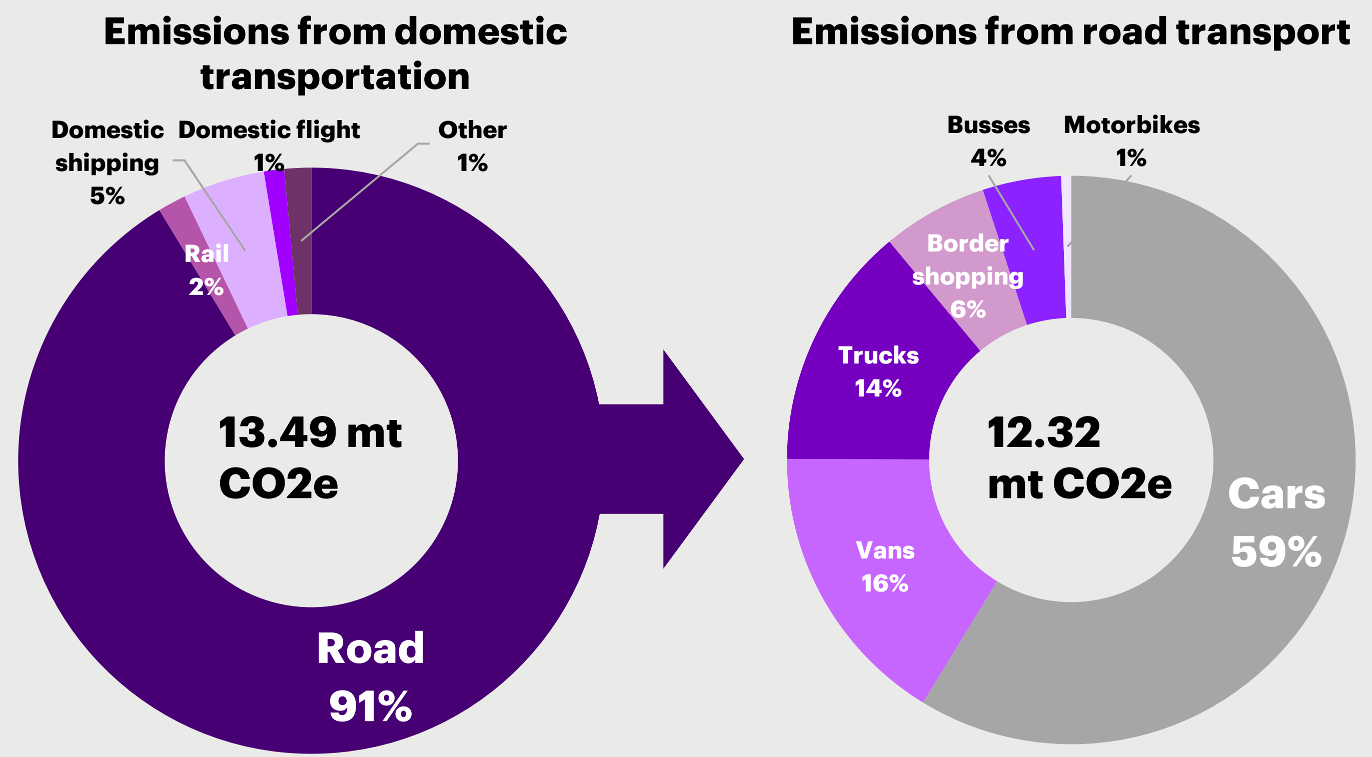
2. Petrol and diesel cars are the greatest contributors to emissions in road transportation

The domestic transport sector accounts for 29% of Denmark's CO2 emissions. This percentage is expected to increase in the coming years to 33% due to growing traffic. Denmark has set a target of reaching 775.000 electrified passenger cars in 2030.

90% of the emissions from the domestic transport sector come from road transport, from which **around 60% is from passenger cars.**

The combustion of **petrol and diesel** is the primary source of energy consumption and emissions in the transport sector. Petrol cars are **60%** of all cars on the road. Diesel cars come second with a ca. **30% share**. (1)

Electric cars account for around **1%** of the cars in road transportation. (2) The long lifetime of conventional cars, lack of suitable infrastructure and high initial costs are slowing the electrification of transport.



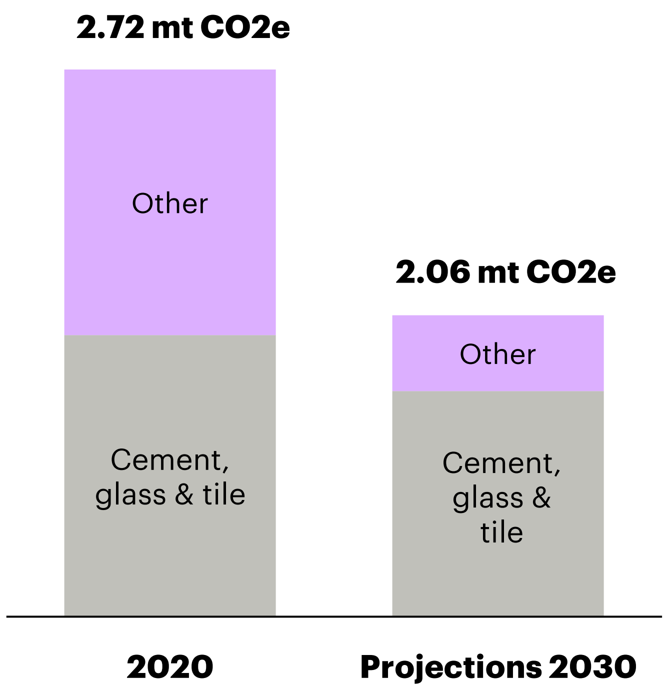
Source: *Climate Council*

The future emissions of the sector are thus mostly related to the number of cars on the road, the pace of the transition to EV's and biofuel blending in petrol and diesel.

Sources: (1) Statista (2) Denmark Statistics

3. Heavy industries such as cement production account for 16% of CO2e emissions in Denmark

Energy-related emissions in manufacturing



Reductions in energy-related emissions

The energy related emissions in manufacturing are related to burning fossil energy sources. Most of the GHG reductions towards 2030 are expected to come from fuel switching.

To produce cement, glass & tile, fuels are burned to reach very high temperatures. In the other processes where lower temperatures are required, electrification can be used instead of fossil fuels. Reaching high temperatures using electricity is costly and impractical with current technologies.

Cement industry: Aalborg Portland

Aalborg Portland is the only cement-manufacturing company in Denmark and the factory in Aalborg is the largest individual CO2 emitter in heavy industry. In 2021, Aalborg Portland emitted 2.2 million tonnes of CO2. (1) Aalborg Portland has recently announced that it will emit a maximum of 600,000 tonnes of CO2 by 2030, which is 73 percent less compared to current emissions. This ambitious target is largely dependent on development of technologies such as capture and storage of CO2 (CCS) and the development of alternative fuels. The first step in emission reduction is to use natural and biogas as well as biomass instead of coal and coke. As the aim is to get rid of all fossil fuels, more green technologies are needed. The next step of Portland is to invest in CCS. (1)

Sources: (1) Aalborg Portland

4. Agriculture is the largest source of emissions

Towards 2030, emissions from agricultural production are expected to remain at the same level as today. They make up 35% of the total emissions in Denmark, which is equivalent to 15.15 mt CO2e.

Use of land

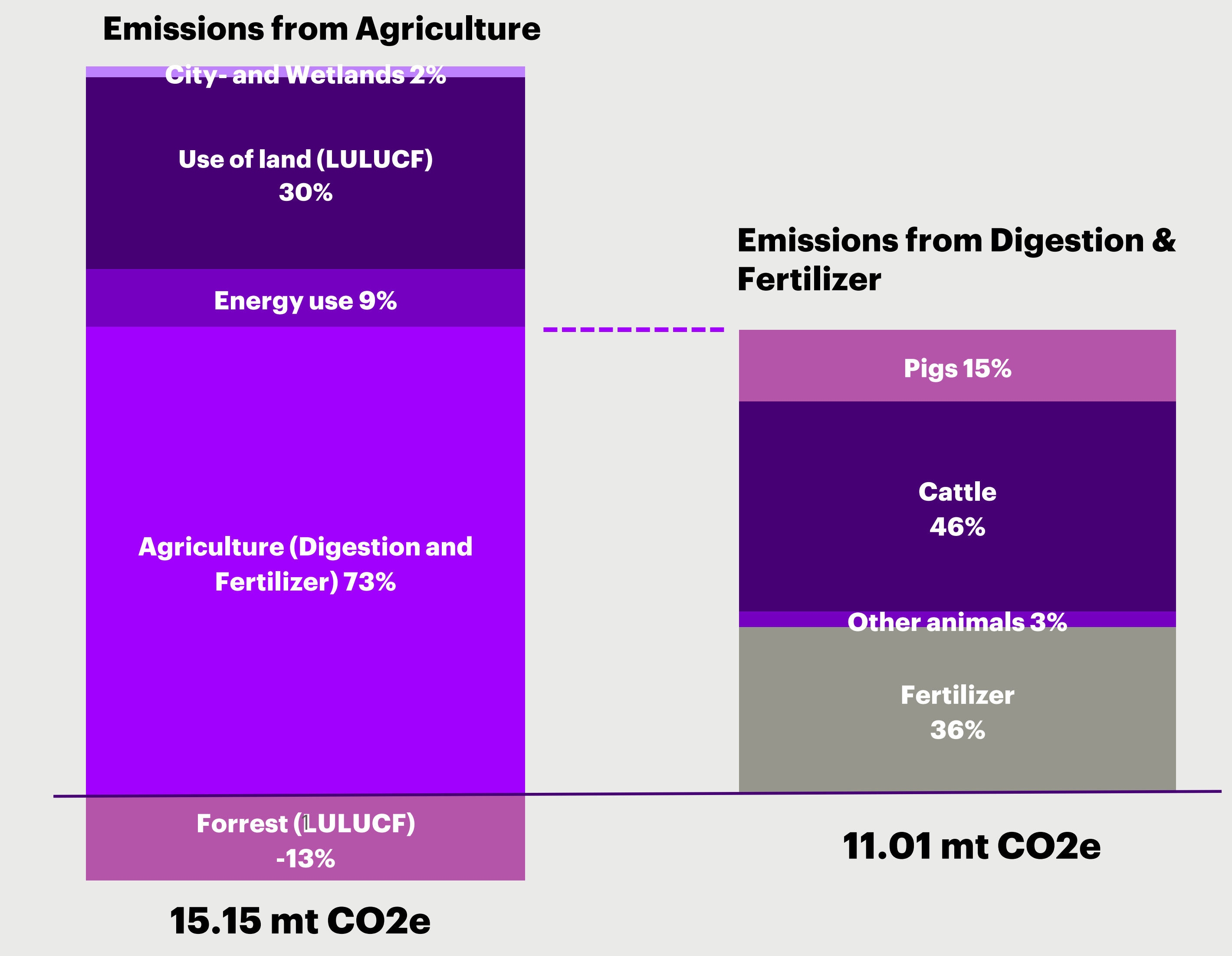
Peatlands build-up carbon due to the watery conditions that delay the decomposition process. If the peatland is damaged due to land cultivation, oxygen allows the release of CO2. Denmark's carbon rich peatlands make up only 7% of the agricultural cultivated area but emit 4.8 Mt Co2e per year due to land cultivation, corresponding to the annual CO2-emissions from roughly 1.8 million petrol- and diesel cars. (1)

Digestion and Fertilization

Fertilization
GHG emissions come from nitrous oxide (N2O) from manure management and fertilizer use, including artificial fertilizers and crop residues. (2)

Digestion of livestock (mostly cattle)
GHG emissions originate from methane (CH4) from livestock digestion and from manure management. (2) The most important end-use products from cattle are milk and meat.

Environmental impact is closely related to the number of livestock as well as the area cultivated for farming.



Sources (1) Klimarådet - Carbon rich peat soils (2) Klimafremskrivning 2022

5. Sustainable fuels are key in cutting emissions in aviation and shipping industry

The global transportation sector is a major polluter worldwide and contributes greatly to the individual footprints of Danes. Cross-border pollutions from shipping and aviation is a challenge that should be considered internationally.

Shipping

The shipping industry currently accounts for approximately **2.5% of global GHG emissions**. However, due to the growth of the global economy, the shipping industry's GHG emissions are expected to **grow by 50-250% towards 2050**, if the industry is not transformed. Cargo ships powered by sustainable fuels are 10-15% more expensive than traditional ones. One of the biggest concerns raised in the industry is the lack of adequate and readily available infrastructure capable of supporting carbon free alternative fuels and vessels. Therefore, ship owners are reluctant to make investments in carbon free-ships and fuels that they cannot rely on long-term. If maritime emissions are not reduced, they will account for 5-8% of global emissions by 2050, as other sectors are increasingly decarbonizing at a faster pace. (1)

Aviation

Globally, aviation is responsible for between **2-3 per cent of the world's CO2 emissions.** (2) Total CO2e emissions in Denmark (domestic and outbound international 2018) account for **approximately 3.1 million tonnes**. International routes account for approximately 95 per cent, and around 80 per cent of all passengers in Danish airports pass through Copenhagen Airport. (3) Sustainable Aviation Fuels come at a **price 2–5 times higher** than fossil jet fuels. Fuel costs represent approximately **20 percent of an airline's cost** base. (3)

The world's largest container shipping company Mærsk emitted **37.2 mt CO2e** in 2021, this is nearly as much as all of Denmarks emssions in 2021 (43.3 mt CO2e).

Denmark aims for fossil-fuel free domestic flights by 2030, however it is doubtful if technologies will be mature enough and if costs of sustainable fuels will be sufficiently low

Both shipping and aviation rely heavily on fossil fuels. There is an urgent need for affordable alternative sustainable fuels.

Sources (1) Zero Carbon Shipping (2) State of Green – SAS (3) Climate partnerships – Aviation

The green transition will not be possible without overcoming barriers

TECHNOLOGY

Grids needs to be upgraded at a quicker pace to accommodate the growing electricity demand. The grid needs to supply the flexibility and resilience, to support electricity generation from intermittent energy sources.

The supply chains for critical minerals and high-capacity batteries are highly concentrated. For example, China has a dominance in the supply chain of lithium. Additionally, there are bottlenecks around the manufacturing of chips. (1)

In the long-term scale constraints in materials hinder the clean energy transition as solar photovoltaic plants, wind farms and electric vehicles generally require more rare minerals to build than fossil fuel-based counterparts.

SKILLS & BEHAVIOR

Active support and engagement of energy consumers is indispensable to shift to a low-carbon society. This requires adjustments in excessive energy consumption. Especially in the sectors where low-carbon technologies are less mature, behavioral changes can significantly contribute to reduce emissions, such as in aviation.

A zero-carbon economy requires a switch towards ‘green’ jobs. The lack of skilled workers is a risk in accelerating the green transition. Reskilling and training workers will be essential to achieve the climate goal. (2)

Few people in Denmark are planning on cutting meat out of their meals. 8 out of 10 Danes are not ready to abandon meat (3).

REGULATIONS

Market barriers are hampering the green transition in for example the use of sustainable fuels in shipping and aviation sectors. The government can overcome these market barriers through instruments such as regulations.

The government plays a key role in supporting an environment which encourages the development of new innovative energy technologies.

Large scale solar and wind farm developers, as well as grid and network developers, have pointed at approval procedures and permits being a major barrier for the energy transition.

Sources (1) European Parlement (2) European Economic and Social Committee (3) 8 University of Copenhagen (ku.dk)

Key Question

What are the solutions which accelerate a clean energy transition in Denmark while delivering on value to the economy, the environment and society at large?

Solutions for speeding up the green transition in Denmark

1. Mature electricity backbone

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balance generation and consumption, while utilizing rapid and seasonal storage to balance supply with demand and allow for growing share of renewables.

~9.5 Mt
CO_2 reduction in 2030 across involved countries

77.3K
Jobs created due to hydrogen and the energy islands

€ 60 bn
Export potential of Denmark

704-1409MW
Potential flexibility due to demand response

2. Rapid transport electrification

Accelerate EV deployment in passenger cars through incentives, improved charging infrastructure and deterrents.

~2 Mt
CO_2 reduction in 2030

2.7K
Economy-wide jobs by 2030

~ €0.2 bn
Human health benefits per year from 2030

3. Industry decarbonization

Electrification of low energy intensive processes and utilize P2X technology to fuel high temperature manufacturing. Setting up industrial clusters for exchange of resources and further exploration of new technologies, such as carbon capture, to cut process-related emissions.

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Economy-wide jobs by 2030

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Export potential green hydrogen

1.4 %
Increase of GDP in 2035 due to industrial symbioses

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Up to 5.5 Mt
CO_{2e} reduction in 2030

10K
Economy-wide jobs by 2030

~ € 0.2 bn
Health benefits 2022-2030 due to a healthier diet

Green fuels for shipping and aviation

The construction of electrolyser plants for providing green fuels for shipping and aviation. The rise of new technologies in green fuels requires global support such as global pricing or a levy scheme.*

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System Value outcomes from solution areas

High priority System Value Dimension for Denmark: CO2 Emissions, Cost and Investment Competitiveness, Flexibility, Resiliency and Security

Medium priority System Value Dimension for Denmark: Job Impact, Air Quality & Health, Energy Productivity and Systemic Efficiency, System Upgrade

Legend: High benefit / Medium benefit / Minimal-to-no benefit

Solution Area	CO_2 Emissions	Cost and Investment Competitiveness	Flexibility	Job Impact	Air Quality & Health	Energy Productivity and Systemic Efficiency	System Upgrade	Resiliency and Security
1 **Mature electricity backbone: Digitalization, storage and energy islands**	**9.5 Mt** CO_2 reduction per year in 2030 in Europe.**	Investment of **541-746 mn euros** in hydrogen storage, cost and competitiveness will decrease as storage technologies become more mature & drives investment in other sectors	**704-1 409 MW** Flexibility potential in demand side response	**77.3K** Jobs created due to storage potential and the expansion of wind energy on the energy islands	High benefit	High benefit	High benefit	Medium benefit
2 **Accelerated EV adoption**	**~2 Mt** CO_2 reduction per year in 2030*	High benefit	High benefit	**2.7K** Jobs created	**~ €0.2 bn** In human health benefits per year from 2030	High benefit	Medium benefit	Minimal-to-no benefit
3 **Industry decarbonization*** *where possible*	**3.8 Mt** CO_{2e} reduction in industry processes*	Expected cost of 1000 DKK/ton CO2 on CCS in beginning. With rising natural gas prices electrification of industry & CCS become more cost competitive	Medium benefit	**63 000** Jobs from industry clusters & hydrogen	High benefit	Medium benefit	Medium benefit	Medium benefit

*Numbers are additional CO2 reductions on top of expected developments in 2030 as calculated by the Climate Council
**CO2 reductions are due to large amounts of wind power generated by the energy islands EV adoption from 2023-2030.

System Value outcomes from solution areas

High priority System Value Dimension for Denmark: CO_2 Emissions; Cost and Investment Competitiveness; Flexibility; Resiliency and Security

Medium priority System Value Dimension for Denmark: Job Impact; Air Quality & Health; Energy Productivity and Systemic Efficiency; System Upgrade

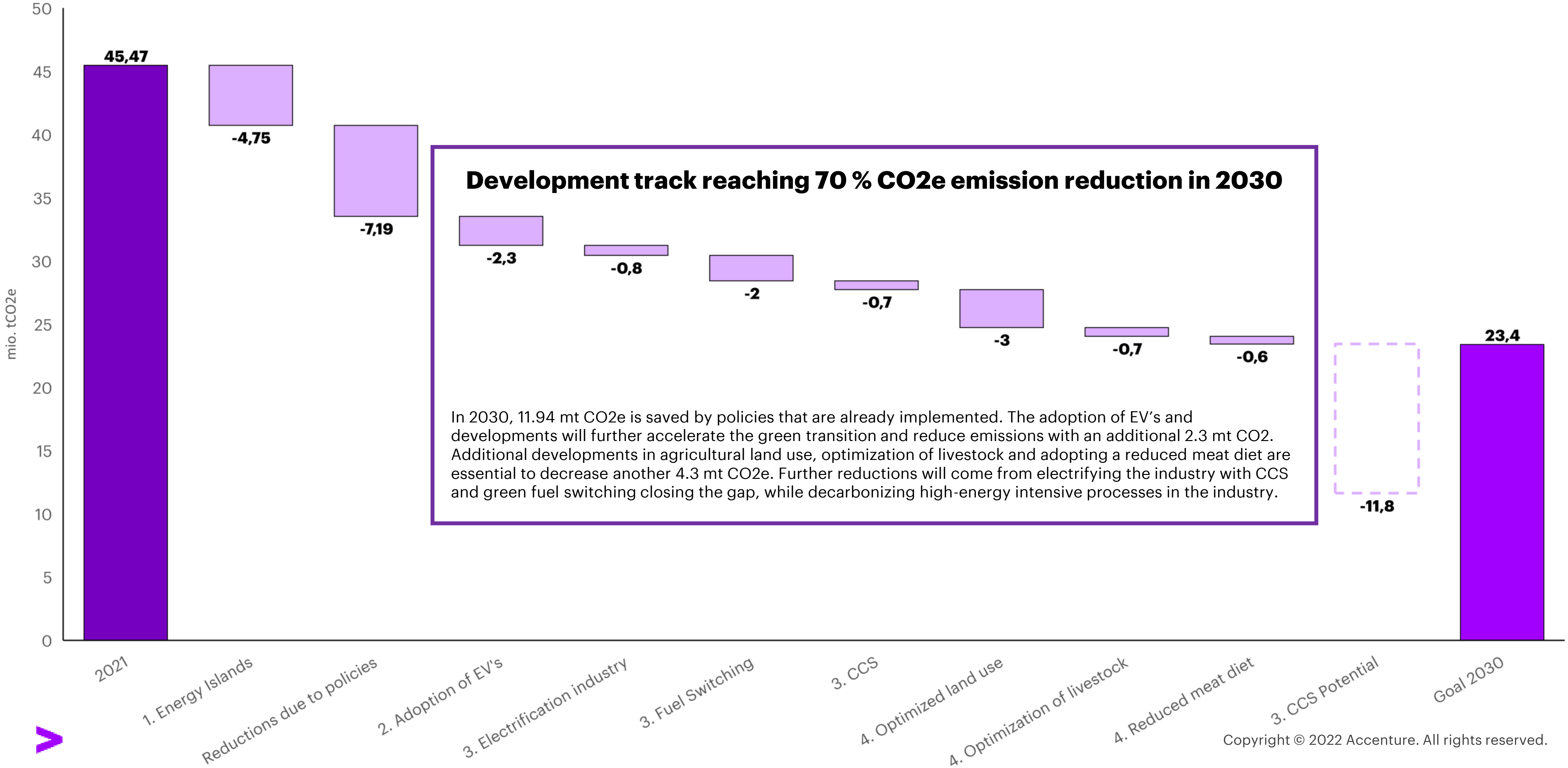
Solution Area	CO_2 Emissions	Cost and Investment Competitiveness	Flexibility	Job Impact	Air Quality & Health	Energy Productivity and Systemic Efficiency	System Upgrade	Resiliency and Security
4 Sustainable Agriculture	**Up to 5.5 Mt** CO_{2e} reduction in agriculture industries by 2030*	Expected average cost of 20-138 DKK/ton CO2e for rewetting carbon-rich peatlands	Minimal-to-no benefit	**10 000** Jobs from the plant-based alternatives industry by 2030	**~ €0.2 bn** Savings in health benefits 2022-2030 due to adoption of a healthier diet	High benefit	Medium benefit	Medium benefit
5 Green fuels for shipping & aviation	**850 000 tonnes** CO_{2e} saved annually by 2030 due to green fuels*	Medium benefit	Medium benefit	High benefit	High benefit	Medium benefit	Medium benefit	Medium benefit

High benefit / Medium benefit / Minimal-to-no benefit

Impacts are on a global level

*Numbers are additional CO2 reductions on top of expected developments in 2030 as calculated by the Climate Council

Roadmap for reaching 70% emissions reductions before 2030 in Denmark



1. Mature electricity backbone

Clean electricity generation will become the new foundation of the energy system. Existing solutions need to be deployed at scale in Denmark in order to integrate and balance the large amount of clean electricity in order to facilitate a stable and reliable power system that can cope with variability and uncertainty in generation and demand.

Challenges on supply side

- **90%** variable electricity generation in 2030
- Cyber(-physical) threats and extreme weather events
- Social resistance
- Geopolitical instabilities: Phase out of natural gas by 2030

ELECTRICITY GENERATION

Modern grid

- **The expansion of infrastructure and modernization of grid**
- **More storage capacity**
- **Offshore meshed grids**
- **Digital technologies to predict supply and demand**
- **Monitoring the grid**
- **Demand response**

Opportunities on demand side

- **1.3Mn** electric passenger cars on the road
- **12x** more heat pumps in 2030 compared to 2020
- **6.8 TWh** needed for data centers
- **4-6 GW** of electrolysis capacity in 2030

ELECTRICITY CONSUMPTION

Characteristics of modern grid

DYNAMIC	FLEXIBLE	RESILIENT	RELIABLE	SECURE	INTEGRATED With other critical infrastructure

1a. Mature Electricity Backbone - Digitalization and storage for the modern grid are core elements for the power system of the future

1a. Digitalization improves the availability of electricity

Fluctuations in energy supply from renewable sources will continue to increase as installed capacity of wind and solar go up. In order have a secure and reliable power supply, intelligent digital technologies are needed to provide data and information about the power grid.

Monitoring the grid

Given that 90% of Denmark's electricity production will come from variable energy sources in 2030, very high instantaneous power flows or sudden renewable drops are a risk for the power system, potentially causing disturbances in the grid such as power outages due to frequency distortions. Real-time insight into the system conditions makes it possible to monitor the grid and make predictions about maintenance and failures in the system. Having access to relevant, reliable information during extreme weather events is crucial for quick decision making, so that for example in case of an extreme weather event, affected areas can easily be located to enhance resiliency of the power grid. Simulating failures and automating the evaluation of the performance of the grid will ensure a safer and more reliable grid. Forecasting models and communication modules will allow flexibility of the system. Through forecasting of for example weather, grid flows can be predicted.

Demand response

Operation of the power system can be optimized by consuming electricity when generation levels are high and decrease the consumption of electricity in case of low generation levels by for example turning heat pumps on and off, charging EVs when VRE levels are high or store the surplus of electricity. Energinet has estimated the socio-economic value of flexible heat pump operation and flexible charging of hybrid cars to be 6.1 Billion DKK (4). Demand response can be implemented by virtual power plants which turn up energy consumption when availability of renewable energy is sufficient and turn down energy consumption when renewable energy is scarce (1). Buildings account for 40% of the total energy consumption in Denmark. Flexible consumption can thus partly be achieved by controlling the energy consumption of buildings such as shopping centers and office buildings. This could provide the electricity system with up to 100 MW balancing capacity. The total potential flexibility in demand-side response in Denmark is estimated to be **704–1 409 MW** (4).

1b. Storage elements are key in providing a reliable power system

Lithium-ion batteries are suitable for short-term storage (daily intermittency) due to their cost-competitiveness. The GridScale electricity storage system, where electric heat is stored in stones, will cost-effectively offer electricity supply for longer periods – from hours to about a week. The GridScale demonstration plant will be the largest electric storage facility in Denmark with a capacity of 10 MWh (7). According to the developers it could be, potentially, scaled up to a capacity of up to 1 GW and a storage capacity of 100,000 MWh.

As 90% of energy generation will be covered by variable renewable energy (wind and solar) in 2030, there will especially be more need for long-term storage, such as seasonal storage. Studies suggests that for 69% wind electricity generation and 21% solar generation, the corresponding **hydrogen storage** capacity is calculated to be **9% of the annual peak demand (4.9 TWh = 556 MW per year)** (5). The cost of producing hydrogen at offshore wind farms is 5.1 euros per kilogram of H2 and is expected to decrease to 3.7 euros per kg in 2030 (2). This means that producing 4.9 TWh of hydrogen for storage will cost around € 541-746 million in 2030. As a 50 MW green hydrogen plant creates 388 jobs (3), **4315 jobs** can be created by producing 536 MW of hydrogen. Two Power-to-X plants will be constructed in Esbjerg, which will be Europe's largest in its field, where the electricity generated by offshore wind farms is converted to green hydrogen (6).
Furthermore, Denmark's interconnectors play a significant role in the provision of flexibility, enabling a more effective use of renewables across the countries.

Benefits

4.3k
Jobs from hydrogen production for storage

556 MW
Of hydrogen storage, which means reduced reliance on imported energy (such as natural gas)

704-1 409MW
Potential flexibility due to demand response, meaning less need for energy imports from other countries

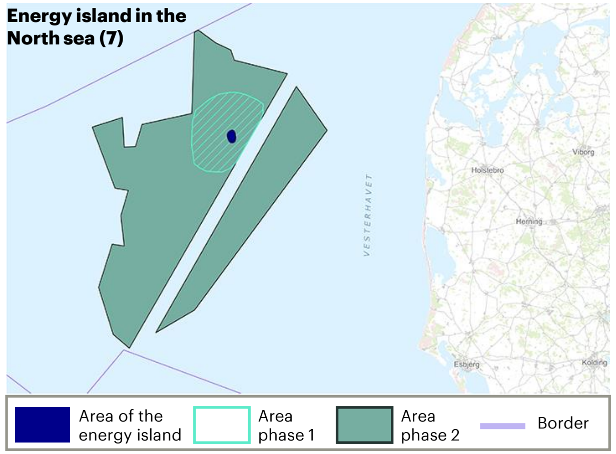
Sources: (1) DEA; (2) Projected green offshore hydrogen costs in Europe (3) Rhodium Group (4) A review of demand site flexibility potential in Northern Europe (5) Application of a high-detail energy system model (6) H2 Energy Europe (7) Aarhus University

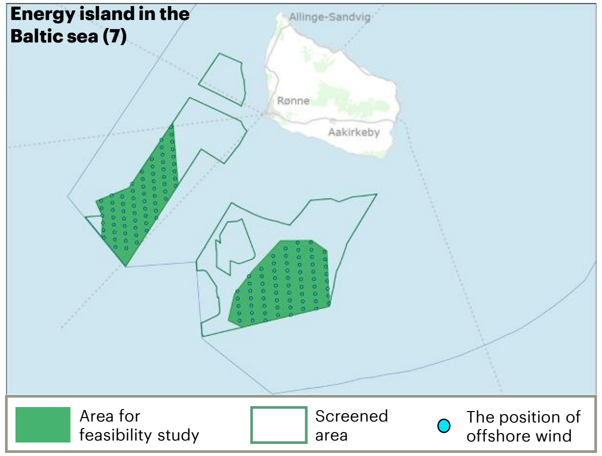
1b. Mature Electricity Backbone - The construction of two energy islands in the North Sea and Baltic Sea contribute to decarbonization in Europe

Energy islands contribute to phase out of fossil fuels in Denmark & Europe

In 2030 the energy islands are expected to be able to supply the average electricity consumption of at least 5 million households (1). The energy islands will be connected to several countries. The surplus of the electricity generated from the two islands will be used to produce hydrogen and other climate-neutral fuels for planes, ships and heavy industry. The total capacity is expected to be 12-13 GW of offshore wind in 2040. This means that **12-13 million households could be supplied with electricity**. (2) In 2033 the energy island in the North Sea will be finished with 3 GW of offshore wind power. The island in the North sea will provide an innovation zone with potential for large-scale energy storage and Power-to-X technologies. Ørsted and ATP plan to make the North Sea Energy Island a backbone in the future digitization of Northern Europe which in turn can attract large investments in renewable energy and the digital infrastructure (5). Around 2040 the capacity of the North Sea island will grow up to 10 GW. The generated power will either be used to supply Danish consumers, convert to green fuels or exported to neighboring countries.

The cost of the energy island in the North Sea is **28.2 billion EUR**, 8.4% of Denmark's annual GDP. The investment includes around 5 per cent for the establishment of the island, 35 per cent for the electrical infrastructure, such as HVDC connections etc., and 60 per cent for offshore wind farms (2). Links to European countries ensure cost-effectiveness of the energy islands.





Economical, environmental and societal impact of the islands

For each GW of wind capacity that is constructed, 1.9 million tonnes of CO2 emissions are saved per year (5).This means that the energy islands can save **9.5 million tonnes per year** in 2030 across Europe due to 5 GW of wind capacity on the energy islands and even 24.7 million tonnes per year in 2050. For example, the green electricity generated by the Energy Island is estimated to reduce CO2-emissions in Germany by 3.5 million tons yearly in 2030 (4).

Every new gigawatt offshore wind in Denmark generates growth in the Danish gross domestic product of approximately DKK 20.3 billion (= €2.7 bn), during the lifetime of the wind turbines, meaning a **4% increase in GDP** due to 5 GW of energy produced on the energy islands (5). Denmark is estimated to have a potential export gain of **60 billion EUR** from wind technology or energy efficiency solutions by 2030 (3). This number only takes into account the phase-out of coal in EU and might thus be even higher when considering phase-out of gas in EU (3). For every GW of offshore wind that is set up in Denmark, 14600 jobs are created. This means that in 2030 the construction of the energy islands will create **73,000 jobs in 2030** and even up to **189,800 jobs in 2050** (6).

System Value benefits

9.5 Mt
CO_2 Reduction per year in 2030 across Europe due to Energy Islands

4%
Increase in GDP in 2030 due to Energy islands

€ 60 bn
Export potential of Denmark due to phase out of coal in Europe

73K
Jobs created due to the construction of the energy islands in Denmark in 2030

Sources: (1) Energistyrelsen (2) DTU (3) Dansk Industri (4) Danish Ministry of Climate, Energy & Utilities (5) North Sea Energy Island (6) Wind Denmark (7) ENS

2. Aiming for an electrification rate of 40% of cars on the road in 2030 would lead to an additional reduction of 1.9 Mt of CO2

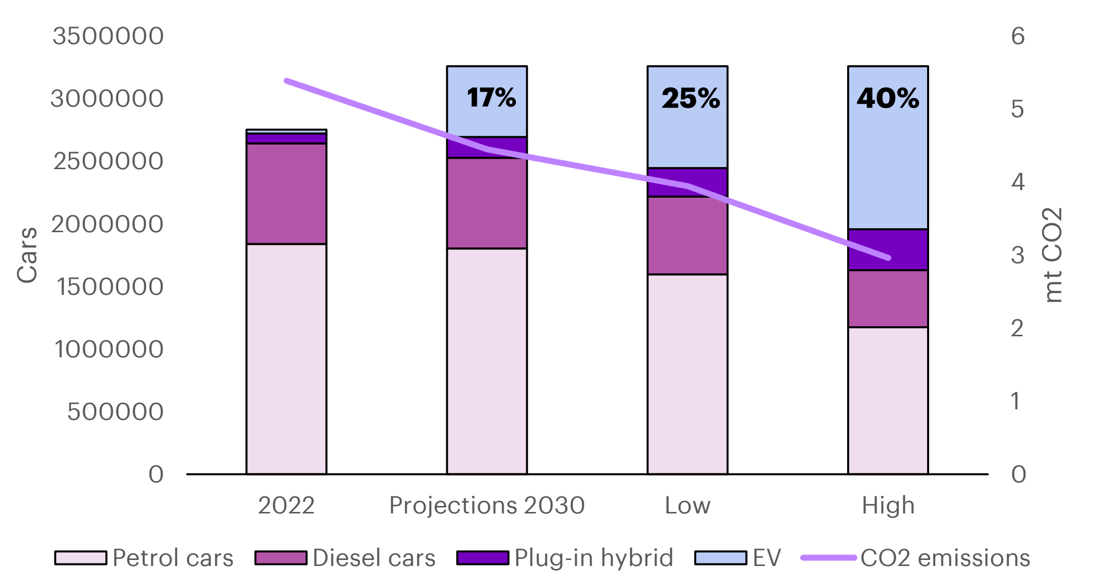
Currently, EV's make up only 1% of the total passenger cars on the road in Denmark. The projections show a 17% share of EV's in passenger cars in 2030. The effect of increasing the electrification rate in passenger cars is examined by observing two different scenarios. Replacing petrol and diesel cars with EV's could save Denmark **2.3 Mt CO2** emissions in a scenario where **40%** of all passenger cars are EV's in 2030, while driving **15% less kilometers** per year.

If all people buying a new car would buy an electric vehicle, Denmark would only reach a share 17% of electric cars in 2030 (1), meaning that in order to achieve an adoption rate of 40% EV's in 2030, new policies need to be implemented as an incentive to shift to zero- and low-emission vehicles. Furthermore, second-hand car buyers need to be incentivized to buy a (second-hand) EV. The adoption of EVs is thus mostly driven by policy support to make the investment into EV's more attractive compared to ICE vehicles for citizens. On the other hand, rising fossil fuel prices are already an incentive to switch a fossil fuel car for an EV.

Norway has boosted its share of electric vehicles on the road from 1.5% in 2014 to nearly 16% in 2021 by supporting the purchase of EV's by (re-)registration tax exemption. Furthermore, Norway introduced benefits for EV use such as circulation tax exemptions, waivers on fees (e.g. tolls, parking, ferries) and fuel tax. (2) Projections of the Norwegian Institute of Transport Economics show that in the most likely scenario, Norway will hit a share of 46% of ZEVs in 2030, this could even be 62% in the optimistic scenario. However, the car sales in 2022 are exceeding the projected sales, with EV's being 81.6% of all car sales per month compared to projections of around 62%. Meaning that Norway will likely end up having a passenger car stock above 46% but below 62% of electric cars in 2030. Assuming politicians, producers and consumers will face an even steeper learning curve in the coming years when it comes to electric vehicles, Denmark could be able to electrify 40% of their car fleet in 2030 if extensive measures are taken.

<u>Accelerators for high-adoption rate of EV's and reduction in the amount of driven km's per year</u>
Accelerators to encourage switching to EV's could include introducing low or zero-emission zones, a ban on sales of fossil fuel cars and tax exemptions/cuts for EV's. In order to reach a reduction of the average amount of kilometers driven per year per car incentives such as subsidized public transport, high speed trains and car-free cities could be introduced. Scotland, for example, plans to reduce driven km's per year by 20% in 2030 while introducing interventions in car parking, low-emission zones and promoting the benefits of car-sharing.

Reduction of emissions is proportional to reduction of fossil-fuel cars



System Value Impacts of accelerated EV adoption

Benefits

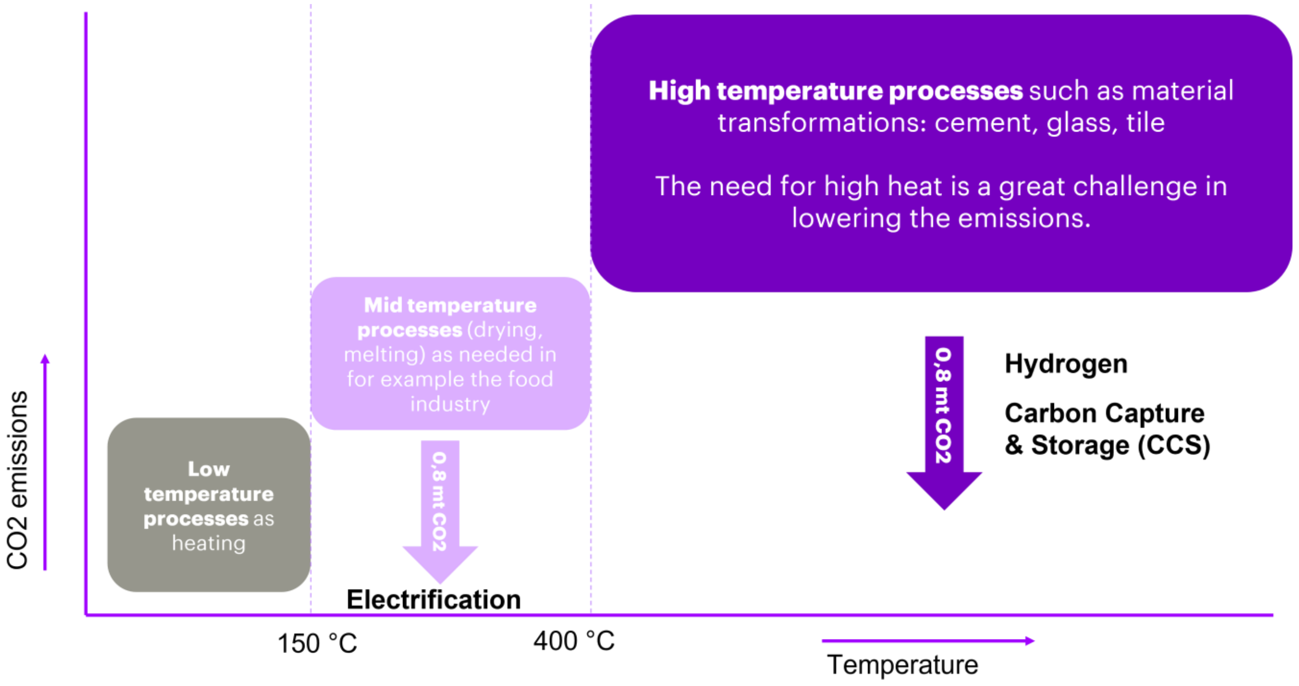
2.3 Mt
CO_2 Reduction per year in 2030 with high adoption rate scenario compared to the projections

2.7K
Jobs created in the industry in Denmark

€0.2 bn
In human health benefits per year from 2030

3. Reducing emissions from hard-to-abate energy intensive processes through carbon capture, fuel switching and industry clusters

Electrification is possible for low energy intensive processes - For the high energy intensive processes other solutions are needed.



Benefits

2.7 Mt	**53k**	**€0.5 bn**
CO_2 reduction potential in 2030	Jobs from the hydrogen industry (3)	Export potential green hydrogen (3) For comparison: Danish gas export was 1.5 md kr in 2019

Electrification

Almost 15 PJ of energy in the Danish food industry can be electrified. This is done to a large extent by using heat pumps, through which the final energy demand could be lowered to 6 PJ - 8 PJ depending on the heat pump technology and its development in the coming years. The remaining energy (around 0.5 PJ) could be supplied by biogas. This leads to a reduction of **0.8 Mt CO2** in carbon emissions. (1)

Biogas & Hydrogen

In the plastic, glass and cement industry **0.9 Mt CO2** could be saved by substituting natural gas with biogas and switching to sustainable fuels.

Green fuels will play an important role in further decarbonization of heavy industry which requires high temperatures. Hydrogen will be a key alternative fuel in 2050 and is an enabler for the green transition in energy-intensive industry. The EU hydrogen target is set at 40 GW for 2030, while the targets for electrolysis capacity among EU Member States now sum up to 28 GW by 2030 (4). The Danish government is aiming at 4-6 GW of electrolysis capacity by 2030 (4). Denmark's P2X strategy forecasts a potential of 1.3 – 5.1 Mt CO2 per year through hydrogen by 2030 and 4.1 – 8.2 Mt by 2050, where in Denmark's national CO2 balance, the use of PtX products can contribute to a maximum of 2 million tonnes of CO2 to the goal of 70% CO2 reduction (4).

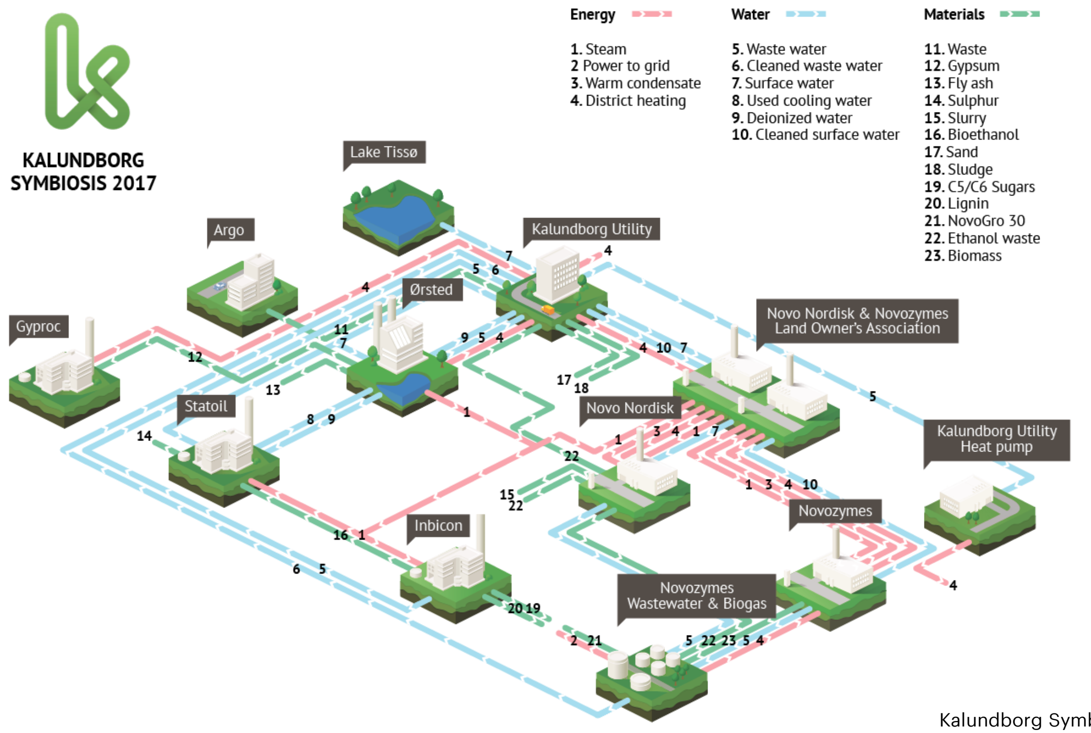
By replacing coal and petcoke with hydrogen in energy intensive processes in 2030, an additional **1 Mt CO2e** is reduced in industrial emissions. In 2030 the hydrogen industry could create **around 53000 jobs** (3). The hydrogen industry in Denmark has the potential of 10 GW electrolysis capacity which could lead to a CO2e reduction of 5 Mt (3).

Industrial Clusters

In industrial clusters multiple industries cooperate in the same geographical area. This creates an opportunity for shared hydrogen or carbon capture solutions or shared electrification solutions or energy efficiency solutions which are greater than the sum of individual company efforts.

Sources: (1) Elektrificering af fødevareindustrien - Vurdering af potentiale for elektrificering af dansk fødevareindustri — Welcome to DTU Research Database (2) https://www.icis.com/explore/resources/news/2021/08/17/10674754/denmark-s-ccs-consortium-aims-to-store-up-to-8m-tonnes-year-of-co2-by-2030/ (3) Brint i tal (brintbranchen.dk) (4) ENS – PtX Strategy

3a. Decarbonizing heavy industry through industrial clusters: Danish examples



Kalundborg Symbiosis flows
Image from TechTalk

Industrial clusters

An industrial cluster effectively reduces CO2 emissions by locating industrial energy consumers in close proximity to allow for exchange of resources. The industrial symbiosis in **Kalundborg** in Denmark is the **world's first industrial cluster** where the city's biggest companies collaborate across sectors, where the waste of an industrial process is used as raw material for another. In Kalundborg seven companies have successfully shared excess energy, water and materials for more than 50 years. This concept saved thousands of tons CO2 emissions each year.

Industrial Symbiosis Nord in North Jutland is another example where resource flows between companies allow for green solutions and collaborate within hydrogen, methanol and green fuels. Aalborg Portland is the oldest company in the industrial symbiosis network in Aalborg. It receives purified sand from the Port of Aalborg, which, in combination with lime, is the principle raw material in grey cement production. The lime-sludge which is created by production of cement is delivered to Nordjyllands Power Station which in turn delivers gypsum to Aalborg Portland. Aalborg Portland supplies surplus heat to Aalborg Utilities, providing district heating for approx. 30,000 households in Aalborg Municipality. On average, each company saves 264 MWh. (2)

While industrial symbiosis benefits the climate, it also creates new job opportunities and increases competitiveness. According to the Ellen MacArthur Foundation, stimulating a circular economy can create **10,000 new jobs** and **an increase in GDP of up to 1.4%** in Denmark alone in 2035. (1)

Potential benefits in 2030

10k
Jobs in 2035 from industrial symbioses

1.4%
Increase of GDP in 2035 due to industrial symbioses (1)

Sources: (1) Delivering the circular economy: a toolkit for policymakers (ellenmacarthurfoundation.org) (2) Industriel Symbiose Nord

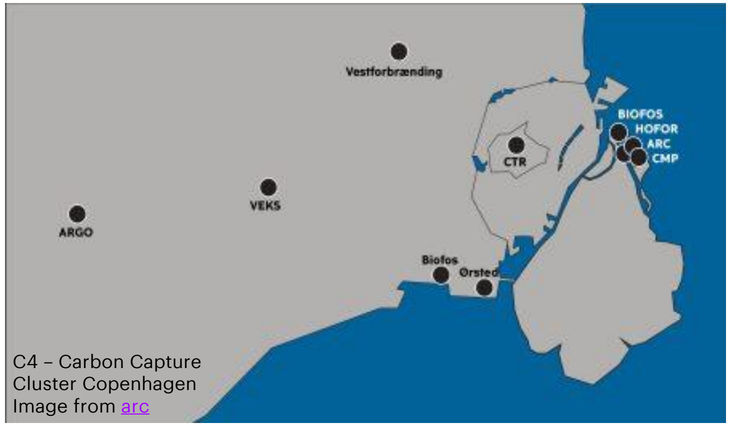
3b. Decarbonizing heavy industry through Carbon Capture & Storage

Carbon Capture & Storage

Carbon Capture & Storage (CCS) is a solution for processes where high temperatures are needed where electrification and the use of alternative fuels is not possible. Capturing CO2 is most effective when collected from the largest point sources such as power plants, waste incineration plants and cement plants. The potential of reducing emissions is **14 Mt CO2 per year by 2030**, while the climate council foresees a reduction of only 1.5 Mt CO2 in 2030. An additional reduction of **1 ,1 Mt CO2** through CCS is necessary to meet the target for 2030. Denmark has extensive opportunities to capture and store CO2. The Geological Survey of Denmark and Greenland (GEUS) estimates that the Danish subsoil has a total storage potential of between 12 and 22 billion tonnes of CO2, which is around 400-700 times Denmark's annual CO2 emissions. (1) In the past two years Denmark has made significant progress in supporting the development of CCS and has taken up two projects with the task to store CO2 in the North Sea's subsoil in depleted oil and gas fields so that the existing infrastructure related to current oil and gas operations can be re-used.

Carbon Capture Cluster Copenhagen

The cluster collaboration has members in the entire value chain from energy production to the absorption of waste heat in the district heating network and the shipment of captured CO2 to the storage site. The goal is to reduce CO2 emissions by **3 million tonnes** by capturing and storing CO2. (5) The partners are ARC, ARGO, BIOFOS, Copenhagen Malmö Port , CTR, HOFOR, Vestforbrænding, VEKS and Ørsted.



C4 – Carbon Capture Cluster Copenhagen
Image from arc

Greensand

Greensand is Europe's largest attempt to implement CCS technologies in industrial plants. The project uses the Nini West reservoir in the Danish North Sea for long-term CO2 storage. The Nini West reservoir is suitable for for injection and long-term storage of 0.45 million tonnes CO2 per year per well over a period of 10 years. The storage potential is in Project Greensand is ½-1 million ton of CO2 per year from 2025, increasing up to **8 million tons of CO2 per year by 2030**. The project is currently in the pilot phase of the injection trial. (2) The project includes the entire value chain from capture to transport and storage and has 29 project partners across the value chain. (3)

Project Greensand
Image from Greensand

Bifrost

Bifrost focuses exclusively on CO2 storage in the Harald field. The CCS operations in the Harald reservoirs are expected to begin in 2027 with an estimated startup storage capacity of **3 million tons** of CO2 per year (m/tpa). (4)

Potential benefit in 2030

14 Mt

Potential CO_2 reduction in 2030 due to CCS

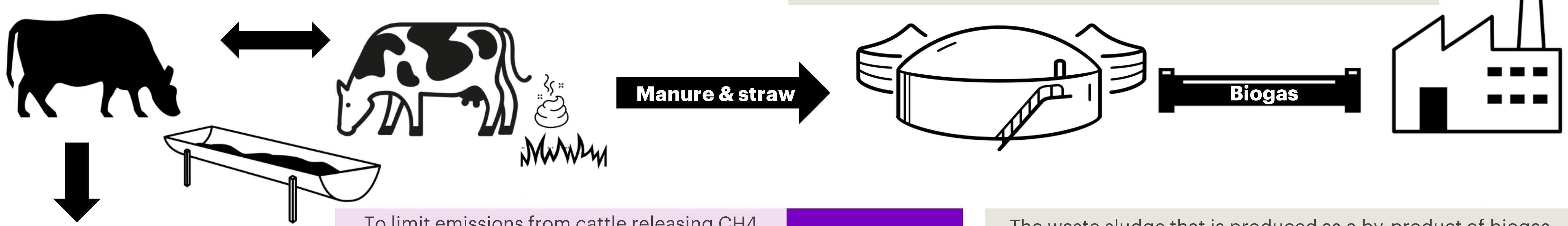
Sources: (1) CCS – capture and storage of CO2 | Dea (ens.dk) (2) The Rise of CCS in denmark (Global CCS Institute) (3) DKK 270 million for CO2 storage in the North Sea's oil fields (kefm.dk) (4) Project Bifrost: An innovative CO2 storage project (dtu.dk) (5) C4CPH

4. Improving livestock supply chain while optimizing land use could reduce GHG emissions in Denmark with 5.5 mt

For cattle and sheep, selective breeding towards maximized lifetime production could have efficiency-related emission reductions compared to average cattle and sheep. Emissions are reduced by replacing half of all cattle and sheep livestock in Denmark with **selected breeds** (1,5).

0.2 mt CO2e

Installing **biogas plants** on regions with large-scale industrial animal farms and high concentrations of animals reduces greenhouse gas emissions and provides an alternative to fossil fuels used in the industry. As Denmark is planning to phase out natural gas by 2030, adding biogas to the natural gas grid could be a great alternative for decarbonizing industrial processes where natural gas is required.



Reducing demand of livestock by investing in **plant-based meat substitutes** could also reduce emissions with up to 90% (6), reducing meat consumption by 33% could **reduce emissions by 0.6 Mt CO2e** and create upwards of **10 000 job opportunities** (7) while saving **171 million euros** until 2030 in health benefits due to a healthier diet adoption.

To limit emissions from cattle releasing CH4 while digesting, some fats and oils can be added to livestock food which could reduce CH4 emission by 30% (2,3), while **Nordic seaweed** has proved 90% reductions (4).

0.5-1.7 mt CO2e

The idea of producing the same amount of food on less land area enables reforestation of some farmlands. A reforestation of 5% of Danish farmlands could **reduce emissions by 1.4Mt CO2e** yearly (1,10).

1.4 mt CO2e

Denmark's cultivated carbon rich peatlands, could be rewetted. This means drowning the soil. If 85% of the carbon rich soils is rewetted, an additional **1.6 mt CO2e** could be saved.

1.6 mt CO2e

The waste sludge that is produced as a by-product of biogas production can be used as **recycled fertilizer**. An alternative is to use biochar from pyrolysis as a high-quality compost to store biogenic carbon in soil, reduce use of water and fertilizer and **create negative emissions.**

System Value Impacts of Sustainable agriculture actions

Benefits

5.5 Mt	10k	€ 0.2 bn
CO_{2e} reduction yearly in agriculture industries by 2030 *	Jobs from the plant-based alternative industry by 2030 *	Savings in health benefits due to a healthier diet*

* Numbers and alternatives are not exhaustive, but provides a starting point of selected values

Sources:(1) Accenture analysis (2) Science direct (3) Climate Econometrics (4) Globalbar (5) Teagasc (6) Gfi (7) Gfi Europe (8) Nature.com (9) Klimarådet (10) World resources institute (11) GNI

Denmark has a leading position in the development of green fuels for heavy transport

2023

In **2023**, Maersk will introduce the world's first container vessel on **carbon neutral methanol** in Northern Europe.

2024

Construction of the world's largest world's largest and most advanced industrial scale electrolyser production plant by Topsoe which will be operational by **2024** with **an annual capacity of 500 MW**, scalable to 5 GW.

2030

Establishment of a **1.3 GW electrolyser** by **Green Fuels for Denmark** powered by 2-3 GW offshore wind from the energy island Bornholm, which holds the potential to replace >270.000 tpa. of fossil fuel consumption in **2030**, equivalent to a 1.77% reduction in Danish CO_2 emissions. The fully scaled production facility will reduce annual CO_2 emissions by **850,000 tons** and will provide primarily jet fuel, that can replace approximately 30% of the total fuel consumption at Copenhagen Airport

2040

Mærsk has committed to **net zero GHG emissions** across all their scopes and businesses towards 2040.

2050

It is possible to reach zero carbon shipping in 2050 due to the rising of technologies and commitment levels. But bridging the cost gaps between fossil and alternative fuels requires additional measures, such as global carbon pricing by changing consumption behavior or a levy scheme. A carbon pricing of USD 50/tCO2e would decrease emissions by ~**85 Mt CO2e/year in 2050** (4). One of the main accelerators for decarbonization is global political support.

The aim of the **Getting to Zero Coalition**: Accelerating maritime shipping's decarbonization with the development and deployment of commercially viable deep sea zero emission vessels by 2030 towards full decarbonization by 2050. This is a partnership between the Global Maritime Forum and the World Economic Forum with Denmark being one of the leaders in the mission.

Sources: (1) The Climate Partnerships, (2) State of Green, (3) iea (4) Zero Carbon Shipping