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Report

Framework conditions, policies and projections for clean energy export from Norway

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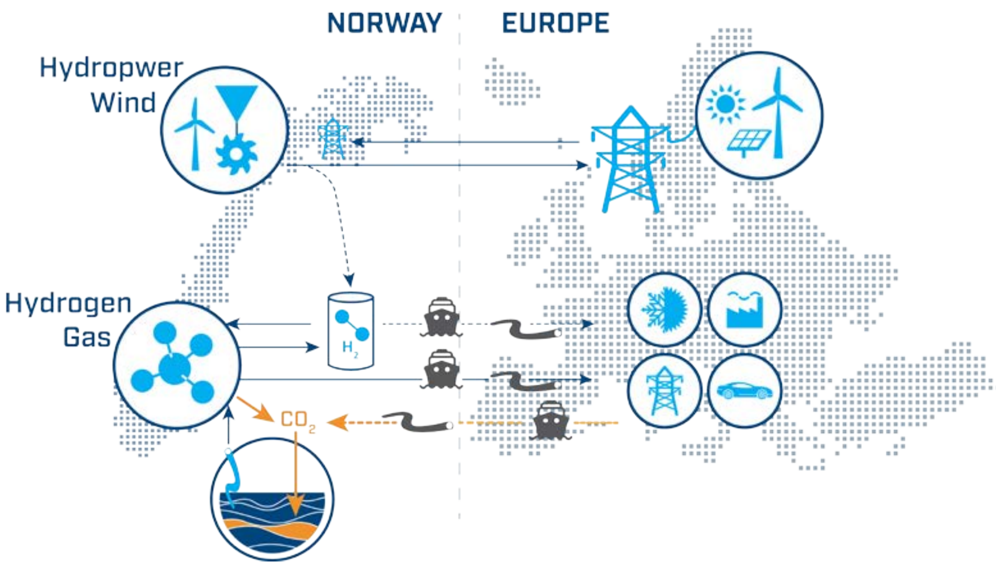

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ABSTRACT

This report aims at providing an overview of the main policies, instruments and uncertainties that will influence the potential for clean energy export from Norway to Europe in the coming years. A large portion of the Norwegian economy is related to the export of fossil fuels and approximately 80% of our goods exports go to the EU. The EU aims at achieving a net-zero emission economy by 2050, which is likely to affect Norwegian exports. Significant changes in our energy system will be required to meet emission reduction targets and low emission energy carriers will play an important role in the future.

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1 Introduction, goal and ambition of this report

This report was prepared as a part of the CleanExport pre-project, which will be continued in a knowledge-building (KPN) project from spring 2020, financed by the Norwegian Research Council. This report aims at providing an overview of relevant framework conditions, policies and projections that can influence the potential for export of low-carbon energy from Norway to Europe in the future towards 2050. It serves as an input for further research and energy system model development in the next part of the CleanExport project. Further, the aim is to support the alignment of clean energy export scenarios for Norway with future energy policies and emission reduction targets and resulting energy demand, as well as consider technical limitations imposed by the infrastructure for connecting Norway to the European mainland. How the currently ongoing corona pandemic may affect future energy demand in Europe has not been addressed.

A large portion of the Norwegian economy is related to the export of fossil fuels. The share of energy exports, especially exports of crude oil and natural gas, in total exports of Norway has significantly increased over the past 50 years, now fluctuating between 40% and 50%, see Figure 1. In addition, Norway is during some years a net exporter of electricity based on hydropower. For instance, in 2018 a net export of around 10 TWh was reported[1]. The European Union is Norway's largest export market, with about 80% of all goods exports. When looking specifically at oil and gas, the European Union imports an even larger share (up to 90% according to OECD data[2]). The EU receives more than 10% of its oil imports and more than 30% of its gas imports from Norway[3].

While oil and gas are expected to remain important globally, the transition to a renewable energy system and a net-zero emission economy in the EU in 2050 as envisioned in its long-term strategy Clean Planet for All[4] can put pressure on the Norwegian economy. Significant changes in our energy system will be required in order to meet emission reduction targets, and both renewable and other low emission energy carriers will play an increasingly important role in the future. Norway can continue to be a major energy supplier to Europe if required investments in infrastructure are made, building on its vast potential with respect to e.g. hydropower, wind energy and hydrogen.

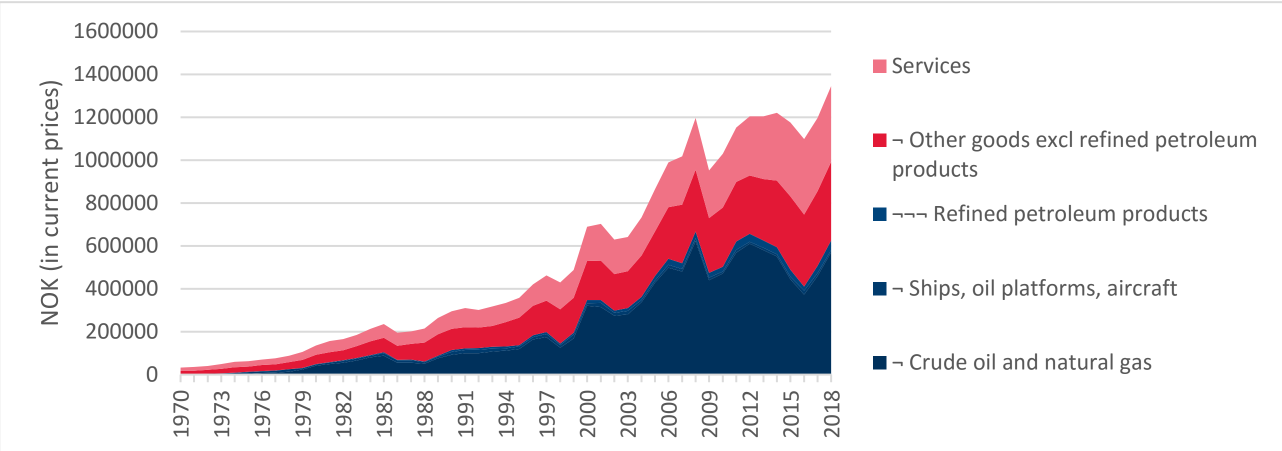

Figure 1: Exports of Norway 1970-2018. Source: based on Statistics Norway, Table 07336: Exports of goods and services by product, contents and year.

[1] Statistics Norway, table 08307. https://www.ssb.no/statbank/table/08307/tableViewLayout1/ (Visited 29.01.2020)
[2] OECD Bilateral Trade in Goods by Industry and End-use (BTDIxE), ISIC Rev.4 https://stats.oecd.org/Index.aspx?DataSetCode=BTDIXE_I4
[3] https://ec.europa.eu/eurostat/statistics-explained/pdfscache/46126.pdf
[4] https://ec.europa.eu/clima/policies/strategies/2050_en

A key challenge is to understand how to optimally integrate different energy carriers into the energy system. This will be investigated in the main CleanExport research project, where an integrated modelling tool capable of investigating both renewable and fossil energy sources will be developed. Adequate scenarios will in this upcoming research be identified and modelled to reveal the most suitable alternatives for decarbonising Norwegian energy export. Eventually, the results from such a modelling tool could be used to elaborate strategic recommendations on how to maintain Norway's role as an energy exporting country. The main research project will, furthermore, focus on enabling the planning of clean energy export from Norway to Europe, i.e. from renewables or decarbonised fossil fuels and combinations of these.

From an overall perspective, the potential for clean energy export from Norway to Europe is affected by two main factors: the European demand for and the Norwegian surplus of clean energy. Furthermore, as illustrated in Figure 2, these factors are influenced by a range of framework conditions on both the European and Norwegian side.

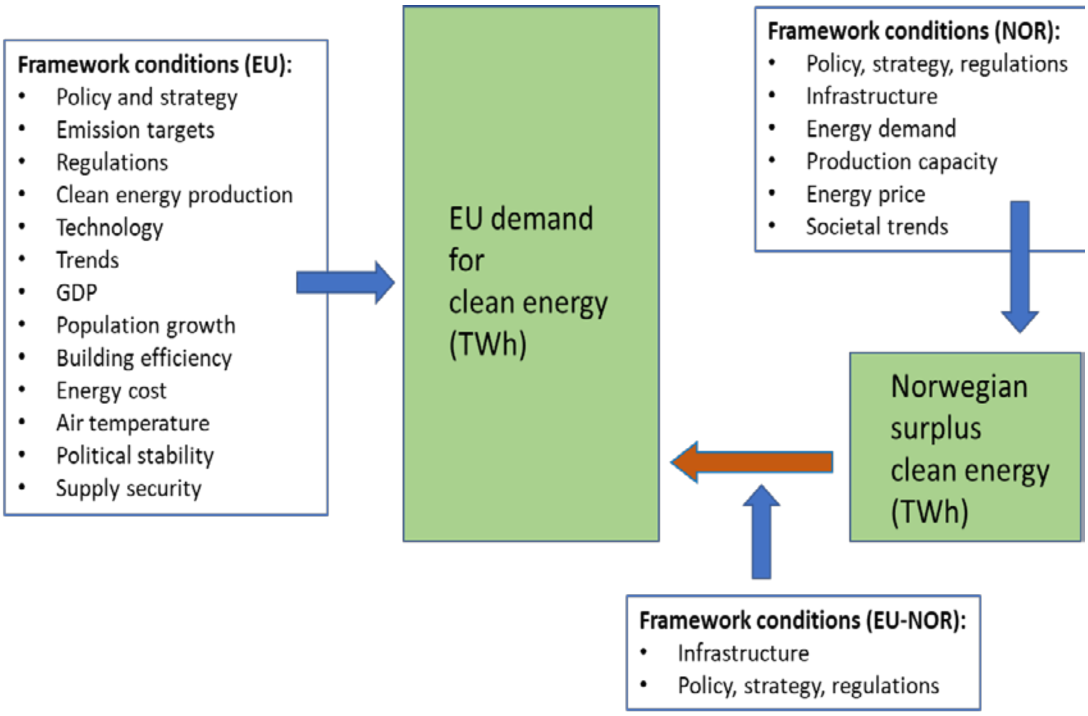

Figure 2: Framework conditions affecting the European demand for and the Norwegian surplus of clean energy.

Obtaining a complete overview of relevant framework conditions and drivers is important in order to define realistic and well-informed scenarios that can be investigated using the Energy systems modelling tool that will be developed in CleanExport. However, obtaining such an overview can be challenging, since there are numerous factors that must be taken into consideration, and that may change during the lifetime of the project.

Samuel et al. (2013) reviewed the literature on determinants of energy demand based on econometric analysis and found that the most important factors are: per capita real GDP, industrial growth, real price of energy, population, air temperature, financial development variables, capital stock, foreign direct investment, and energy efficiency. Results from Sineviciene et al. (2017) show that GDP growth is a key factor increasing both energy efficiency and energy consumption. The research results on energy efficiency relations show that CO_2 emissions per capita, a fixed capital and the share of industry in the economy are other important drivers. While there is a large body of literature on determinants of total energy demand, the share of clean energy in total energy consumption is strongly influenced by policy mix (Rogge & Reichardt, 2016). Within sustainability transition studies, policy mix is the focus of a new strand of research, addressing the complexity of the interaction between instruments, policy processes and strategies interacting across fields and governance level, as well as in geography and time.

The main focus of the report will be on framework conditions affecting the *European demand for clean energy*. It will be based on publicly available information and is divided into four main sections: policies and regulations, economic and societal trends, energy technologies and infrastructure for energy export and other market factors. The main purpose is to provide relevant information for scenario development in the main CleanExport research project. Furthermore, there is an ambition that the information gathered in this report can be of use for policy makers as well as other research groups that are addressing similar topics.

2 Climate policies and regulations

2.1 Chapter summary

- *What is the conclusion from what has been presented?*

Energy policy is directly related to climate and emission targets. The IEA's Policy Database collects information on energy related policies on country-level as well as for the EU. This database covers all sectors and all types of policies and regulations, thus giving a fairly complete picture of the entire world. IRENA provides a detailed background on various types of renewable energy policies and measures.

- *Relevance for the ambitions of the report*

Reviewing the European Union's long-term strategies as well as national energy and climate plans provide the context and framework conditions for the policies, rules and regulation and aids in understanding the bigger picture for energy export possibilities from Norway. Especially, regulations regarding the electricity market will become important with increasing connectivity between the Norwegian and the European grid. Information on planned investments in energy infrastructure will support a better estimation of Europe's self-sufficiency, especially for electricity generation from renewables. In addition, the development of infrastructure for hydrogen use is relevant in this context.

- *Is there something we know will change?*

The Paris Agreement requires countries to review and update their energy and climate policies every 5 years. In February 2020, all parties of the Paris Agreement had to submit the first update of their Nationally Determined Contributions (NDCs). The new policies, rules and regulations have not been reviewed in this report.

- *When will revisions take place?*

Revisions of the NDCs submitted in February are currently compiled and will be submitted in October 2020.

- *Parameters that should be included in modelling*

Electricity market regulations including Trans-European Networks - Energy (TEN-E) Regulations, expected investments in renewable energy technologies, especially electricity and infrastructure for hydrogen (or resulting capacities in the EU), but also for other technology using energy.

This chapter focuses on climate policies and regulations that are relevant for the development of the future European energy system. Policies indicate ambitions for the future and point towards a direction of development, whereas regulations provide concrete, binding targets that are fixed by law. Since policies can lead to regulations over time, it is relevant to include both when considering the future energy system. The following aspects are considered in this chapter:

- IEA's policies database, providing an overview of policies for different sectors
- EU's 2050 long-term strategy

- The EU 2030 Climate and Energy Framework
- The European Green Deal
- National Energy and Climate Plans
- Overview of relevant EU regulations

Progress towards the EU's goals and updates about the continuously adapted strategies are published in the Strategic Energy Technologies Information System[5].

2.2 Climate policies and emission reduction targets

2.2.1 The IEA's Policies Database

The IEA's Policies Database[6] collects information on energy-related policies that are already in force ('current policies') or planned ('stated policies') to reduce greenhouse gas emissions, improve energy efficiency and support renewable energy development and deployment. This information is then for example used in the development of the IEA World Energy Outlook (WEO)'s current and new policy scenarios. The IEA differentiates between policies addressing climate change, renewable energy policies and measures, energy efficiency, methane, and carbon capture utilisation and storage. For the WEO they regroup these into cross-cutting policies, power sector policies and measures, transport sector policies and measures, industry sector policies, and building sector policies. The current and planned policies in the EU taken into account in the WEO are summarized below.

Cross-cutting policies

Cross-cutting policies are broad frameworks that affect different sectors. For the EU, they include Climate and Energy Package/Framework, Nationally Determined Contributions (NDCs), Emissions Trading Systems (ETS), and phasing out of fossil fuel subsidies. The EU submitted a common NDC with a binding target to reduce at least 40% of its annual GHG emissions by 2030, compared to 1990, with no contribution from international market-based mechanisms[7]. This target is included in the 2030 Climate and Energy Framework, described below.

The National Emission Ceilings (NEC) Directive was launched in 2016 and set national emission reduction commitments for five air pollutants: nitrous oxide (NOx), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), ammonia (NH_3) and fine particulate matter ($PM_{2.5}$). The new targets for 2030 aim to reduce in half the health impacts of air pollution compared with 2005, and it comprises reduction targets of 63% of NOx, 40% of NMVOCs, 79% of SO_2, 19% of NH_3, and 49% of $PM_{2.5}$.

The differences in cross-cutting policies for the EU between the current policies and new (planned) policies scenarios have mostly been described in the climate and energy plans, as well as in the European Green Deal. A further assumption for the new policies IEA scenario is the phasing out of all fossil fuel subsidies in the next ten years to all net-importing countries, as well as net-exporting countries where specific policies have been announced. Although the phasing out of fossil fuel subsidies is part of EU climate goals[8], there is overall a lack of a comprehensive overview of subsidies in place and policies to phase them out in the National Energy and Climate Plans[9].

Policies for the power sector

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5 https://setis.ec.europa.eu/
6 https://www.iea.org/policies/
7 https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx
8 https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf
9 https://www.odi.org/sites/odi.org.uk/files/resource-documents/12895.pdf

The current policies for the European power sector are in line with the 2020 Climate and Energy Package. Under the ETS, all power and heat generation plants are covered. In its current third phase (2013-2020), a single EU-wide cap on emissions was implemented, diverging from the previous system of national caps, and 300 million emissions allowances were distributed to support innovative CCS and renewable energy technologies under the New Entrants' Reserve[10] under the NER 300 programme.

Regarding operating power infrastructure, the current policies point to a decrease in barriers to combined heat and power (CHP) with the implementation of the Energy Efficiency Directive[11], a reduction in operating nuclear power plants with the early retirement of all nuclear plants in Germany by the end of 2022, and a reduction in the construction of new coal power plants. In 2017, Eurelectric, the Union of the Electricity Industry which represents 3500 electricity companies in 32 European countries, pledged to not invest in new coal power plants after 2020[12]. The commitment was signed by national energy companies in 26 of the 28 EU countries, leaving only Greece and Poland out of this target. However, the Greek Prime Minister announced in September 2019 plans to phase out coal by 2028[13].

New policies further accelerate the decarbonisation of the power sector in Europe, in line with the European Green Deal and the 2030 Climate and Energy Framework. The fourth phase of the ETS, covering from 2021 to 2030, focuses on, among other measures, increasing the pace of annual reductions allowances in 2.2%, making sure the emissions allowances reflect technological progress in order to maintain the European industry's competitiveness and avoid carbon leakage, and help industry and the power sector to meet innovations and challenges of a low-carbon transition via funding mechanisms.

In line with the European Green Deal and the aim for a net-zero carbon emissions Europe in 2050, a set of European countries have committed to the phasing out of all coal power plants by 2030[14]: Austria already in 2020; France and Sweden by 2022; Portugal and Slovakia by 2023; the United Kingdom by 2024; Italy and Ireland by 2025; Greece by 2028; Finland and the Netherlands by 2029; and Denmark and Hungary by 2030. Additionally, Germany has committed to phase out coal by 2038 (with option by 2035), and there are ongoing phase-out discussions in Spain and in the Czech Republic.

Policies for the transport sector

The Renewable Energy Directive[15] established that the share of energy from renewable sources should be of, at least, 10% of final energy consumption for the transport sector in all EU countries. In addition, fuel suppliers should reduce by at least 6% of the life cycle GHG emissions per unit of energy of fuels used by road vehicles, partly by using blending of biofuels in liquid fossil fuels. Due to the concerns on emissions from indirect land-use changes (iLUC) from biofuel production[16], conventional biofuels (produced from cereal and other starch-rich crops, sugars and oil crops and from crops grown primarily for energy purposes) cannot exceed 7% of total energy consumption of the transport sector in any EU country from 2020.

Under the new Clean Energy for All Europeans package[17], there is an increase for the share of renewable energy sources for at least 14% of final energy use of the transport sector by 2030, and the inclusion of a new

[10] https://ec.europa.eu/clima/policies/innovation-fund/ner300_en
[11] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1574946904047&uri=CELEX:32019H1659
[12] https://cdn.eurelectric.org/media/2170/eurelectric_statement_on_post-2020_mff-2017-030-0681-01-e-h-52A59627.pdf
[13] https://cordis.europa.eu/article/id/413274-greece-is-first-balkan-country-to-announce-a-coal-phase-out-date-the-revolution-has-already-s
[14] https://beyond-coal.eu/coal-exit-tracker
[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015L1513
[16] https://pubs.acs.org/doi/abs/10.1021/es101946t
[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG

requirements on high iLUC-risk biofuels. These are the biofuels, bioliquids and biomass fuels for which production crops lead to occupation of land with high carbon stock. These high-iLUC risk biofuels will not be able to be counted towards the renewable share of energy for the transport sector by 2030, and should be substituted by biofuels from crops with low risk of indirect land-use change, no competition with food crops, and advanced biofuels (for example, from waste and algae). The share of advanced biofuels should be of at least 3,5% of total energy use in the transport sector by 2030.

The current CO_2 emissions targets, for 2020, for passenger cars and light-duty vehicles are of 130 g/km and 175 g/km, respectively. From 2021 onwards, the targets are for 95g/km and 147g/km, respectively. Besides that, manufacturers are given additional incentives to produce and sell zero- and low-emission cars, under 50g CO_2/km. There are increasing support for alternative fuels and vehicle powertrains, including sales and stock share targets for electric vehicles (EVs). Additionally, a common methodology for the assessment and reporting of full life-cycle CO_2 emissions of cars and vans should be developed by 2023[18]. A number of European countries have signalized the phasing out of gasoline and diesel cars, including Denmark, Ireland, France, the Netherlands, Norway, Slovenia, and the United Kingdom. However, these commitments are yet to be translated into policies.

Until 2020, there were no CO_2 emissions regulation for heavy-duty vehicles (HDV) in the EU. The Third Mobility Package includes a target of reducing GHG emissions from road transport by at least 60% in 2050, and as a part of this strategy, new CO_2 emission standard for HDV have been proposed in 2018, setting emission targets for manufacturers for 2025 and 2030. Incentives for zero- and low-emission vehicles would be given to vehicles emitting less than 350g CO_2/km, which is less than half of the average of all the HDV fleet[19].

Emissions in the domestic aviation is currently regulated by the ETS, which accounts for flights leaving from and arriving to countries in the European Economic Area. There is currently not concrete plans to expand the geographic scope of the flights covered by the ETS. The current European Advanced Biofuels Flightpath aims to get the aviation industry to use 2 million tonnes of biofuels by 2020. The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), by the International Civil Aviation Organization, aims to stabilize global aviation emissions in 2020 levels, by requiring airlines to offset future emissions growth.

New policies aiming to include maritime shipping emissions in the EU reduction targets are currently in development. From 2018, large ships over 5000 gross tonnage loading or unloading cargo or passengers at ports in the European Economic Area are required to monitor and report their CO_2 emissions. The initial targets from the International Maritime Organization aim to reduce total annual GHG emissions from shipping by at least 50% by 2050, compared to 2008.

Industry sector policies

The Industrial Emissions Directive (IED) is the main EU instrument for regulating emissions from industrial activities, and it sets emission limits based on best available techniques (BAT) to around 50 000 installations throughout the EU. Key environmental data from industrial facilities by more than 30 000 industrial units are reported in the European Pollutant Release and Transfer Register (E-PRTR)[20]. Due to the large volume of emissions, for activities such as large combustion plants (with thermal inputs equal or greater than 50 MW), waste incineration and co-incineration plants, solvent using activities, and titanium oxide production, there are also EU-wide emission limit values for pollutants. Emissions from medium combustion plants are regulated by a separate Medium Combustion Plants Directive, which sets SO_2, NOx and particular matter

[18] https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en
[19] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018PC0284R(01)
[20] https://ec.europa.eu/environment/industry/stationary/e-prtr/legislation.htm

emissions limits for plants between 1 MW and 50 MW, while smaller appliances (such as heaters, boilers, motors, pumps, fans and compressors) are covered by the Ecodesign Directive.

The Energy Efficiency Directive and its extension to 2030 sets minimum energy efficiency standards and labelling for a variety of products such as boilers, mandatory and regular energy audits for large enterprises, incentives for the use of energy management systems, encouragement for small and medium enterprises to undergo energy audits, and technical assistance and targeted information at small and medium enterprises.

Building sector policies

The Energy Performance of Buildings Directive and Energy Efficiency Directive are the two main frameworks setting the policies for energy efficiency in buildings. These directives aim to achieve a highly energy efficient and decarbonised building stock by 2050, create a stable environment for investment decisions, and enable consumers and businesses to make more informed choices, leading to energy savings. These directives establish long-term renovation strategies, with indicative milestones for 2030, 2040 and 2050, according to each National Energy and Climate Plans. They also promote solutions such as smart technologies for automation and control systems, such as for regulating temperature; a common standard for reporting national energy performance requirements across the EU countries; and the use of energy performance certificates for rented or sold buildings.

One of the inclusions of the amendment as part of the Clean Energy for all Europeans pack is that all new buildings must be "Nearly Zero-Energy Buildings" (NZEBs) from 2020 onwards, and this requirement is mandatory for all new public buildings from 2019. Energy efficient renovations rates should be at least 3% per year of buildings owned and occupied by central governments.

2.2.2 EU 2050 long-term strategy

A Clean Planet for All[21] is the EU's 2050 long-term strategy for a prosperous, modern, competitive and climate-neutral economy by 2050. It was adopted by the EU in December 2018 at the COP24 in Katowice, Poland. The strategy itself does not intend to launch new policies, but it rather sets the direction of travel of EU climate and energy policy. The IPCC special issue report on a global warming of 1.5 °C has clearly influenced the EU's strategy goals, which aims at achieving a **net-zero greenhouse gas economy by 2050.** The strategy outlines a vision for the economic and societal transformations required to achieve net-zero emissions by 2050. It presents eight different scenarios for how these transformations can take place, and calls for joint action along a set of seven main strategic building blocks:

1) Maximise the benefits from Energy Efficiency including zero emission buildings
2) Maximise the deployment of renewables and the use of electricity to fully decarbonise Europe's energy supply
3) Embrace clean, safe and connected mobility
4) A competitive EU industry and the circular economy as a key enabler to reduce greenhouse gas emissions
5) Develop an adequate smart network infrastructure and inter-connections
6) Reap the full benefits of bio-economy and create essential carbon sinks
7) Tackle remaining CO_2 emissions with carbon capture and storage

The energy system, which today stands for more than 75% of the EU's GHG emissions, reaches net-zero emissions in all scenarios. As can be seen from Figure 3, renewable energy sources are expected to deliver a much larger share of the gross inland consumption than today. In 2050, they make up between 50 and 60%, depending on the level of ambition. Natural gas consumption is significantly reduced compared to today's levels.

[21] https://ec.europa.eu/clima/policies/strategies/2050_en

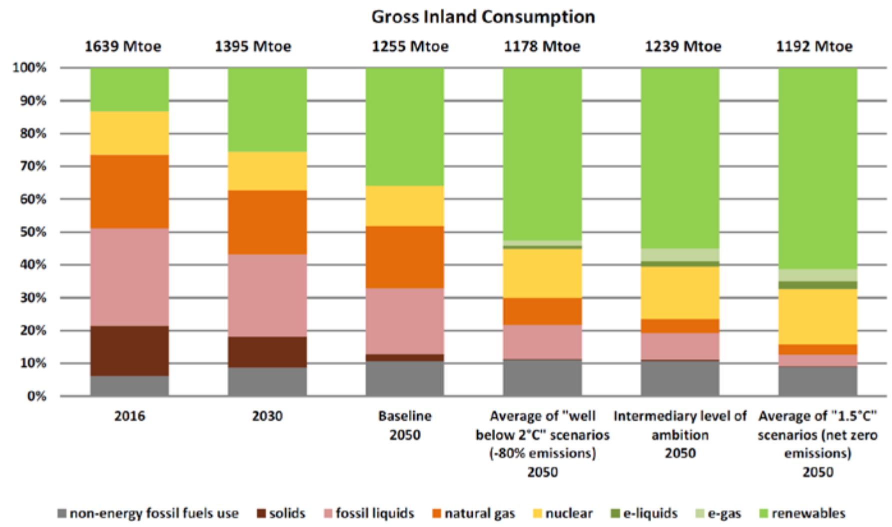

Figure 3: Fuel mix in gross inland consumption. Source: A Clean Planet for All [https://ec.europa.eu/clima/policies/strategies/2050_en]

2.2.3 EU 2030 Climate and Energy Framework

For the period 2021-2030, the EU has a climate and energy framework[22] which includes EU-wide targets and policy objectives. It was adopted by the European Council in October 2014. The key targets for 2030 are:

1) At least 32% share of renewable energy
2) At least 32.5% improvement in energy efficiency
3) At least 40% cuts in greenhouse gas emissions (from 1990 levels)

In order to reach the GHG emission reduction targets, the sectors covered by the EU emissions trading system (ETS)[23] will have to cut emissions by 43% compared to 2005 levels. The ETS covers approximately 11 000 power stations and manufacturing plants, as well as aviation activities in the 28 EU member states plus Iceland, Liechtenstein and Norway. The ETS is governed by the EU centrally and has been revised for the period after 2020 to ensure that these targets are met.

For the sectors not covered by the ETS, a 30% reduction in GHG emissions compared to 2005 is required by 2030. Examples of non-ETS sectors are transport (excluding aviation), agriculture, waste, industrial plants not covered by the ETS and the municipal and housing sector. Each member state has individual binding targets for their emission reductions, as described in the National Energy and Climate Plans (NECPs). The level of ambition varies between member states, e.g. due to expected differences in economic growth in the period towards 2030.

2.2.4 The European Green Deal

The European Green Deal[24] was announced in December 2019 and is a package of measures presented by the new European Commission lead by Ursula von der Leyen. This new growth strategy aims to align the financial system and policies in order to reach the ambition of a net-zero greenhouse gas emission society by 2050. It does not replace the previously described Clean Planet for All strategy or 2030 climate and energy framework. An overview of its various elements is shown in Figure 4.

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[22] https://ec.europa.eu/clima/policies/strategies/2030_en
[23] https://ec.europa.eu/clima/sites/clima/files/factsheet_ets_en.pdf
[24] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (visited 12.02.2020)

Figure 4: The various elements of the European Green Deal. Source: Communication COM (2019) 640 from the European Commission.

Currently, an initial roadmap of the key policies and measures needed to achieve the European Green Deal has been made. As indicated in Figure 4 it covers a wide range of categories, but in this report we have chosen to make a summary of the plans that are most relevant for the CleanExport project.

- The Commission will propose the first European climate law, which will ensure that the transition to a net-zero emission society is irreversible.
- A plan for revision of EU's greenhouse gas emission reductions target will be presented by summer 2020. The 2030 GHG emission reduction target will be increased to at least 50% and towards 55% compared to 1990 levels. The previous target was 40%.
- In order to deliver the increased emission reductions, all relevant climate-related policy instruments will be reviewed and possibly revised. This includes the *Emissions Trading System* and ensuring that taxation is aligned with climate objectives.
- The Commission will propose a carbon border adjustment mechanism for selected sectors, to reduce the risk of carbon leakage. This measure is especially relevant if large differences in climate ambitions should persist as the EU increases its climate ambitions.
- Development of a power sector largely based on renewables, complemented by rapid phasing out of coal and *decarbonising gas*.
- Supporting the development of infrastructure and technologies for energy transport, such as smart grids, hydrogen networks, CCS and energy storage.
- Presenting a *Sustainable Europe Investment Plan* to help meet additional funding needs. The Commission has estimated that an additional annual investment of €260 billion is required to achieve the current 2030 climate and energy targets.
- Proposition of a *Just Transition Fund*, to support regions and sectors most affected by the transition to a low-emission society. The goal is to avoid leaving behind those that currently depend most on fossil fuels or carbon-intensive processes.

2.2.5 National Energy and Climate Plans

Each member state in the EU was obliged to submit a draft of its National Energy and Climate Plan for the period 2021-2030 by December 2018. The draft plans have been reviewed by the Commission and a communication (COM/2019/285)[25] published in June 2019 gave an assessment of the 28 contributions. Additionally, specific recommendations for each member state are available. Finalised plans were submitted

[25] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52019DC0285

by the end of 2019. All member states must also submit long-term climate and energy strategies by 1 January 2020, which will cover the period towards 2050.

In Figure 5, the non-ETS sector emission reduction targets for each member state for 2030 compared to 2005 are shown. The reduction targets vary greatly between the different countries, from 40% reduction for Sweden and Luxembourg to 0% for Bulgaria.

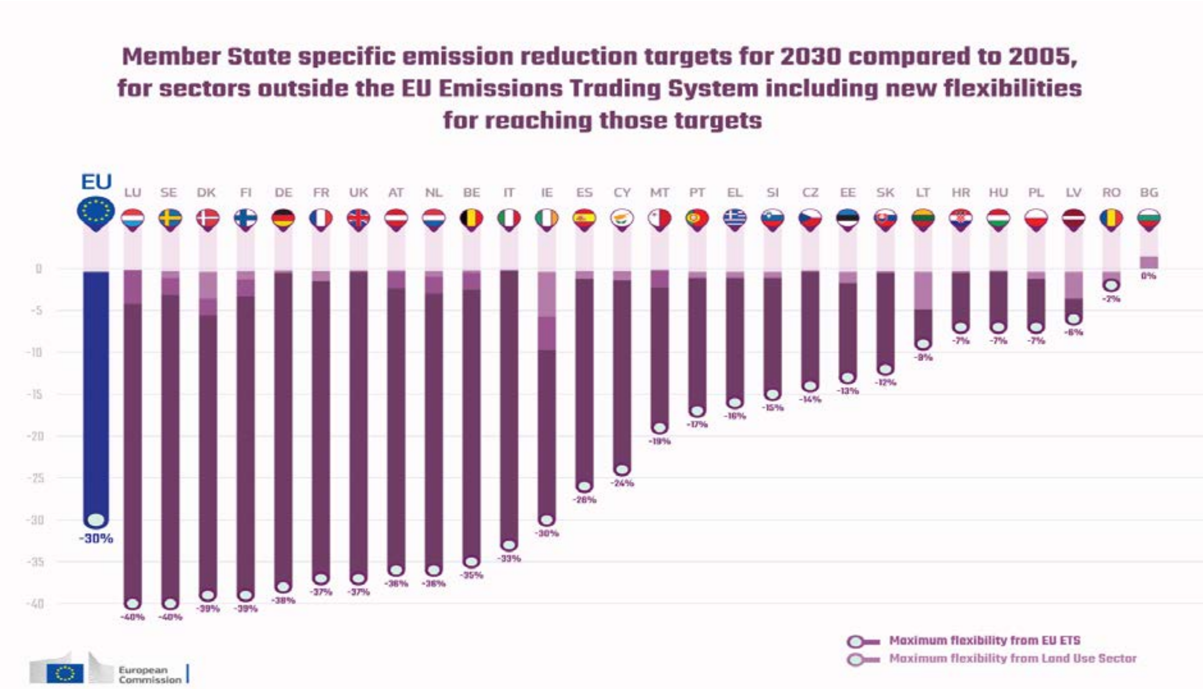


Figure 5: Non-ETS sector emission reduction targets for each EU member state for 2030 compared to 2005. Source: https://ec.europa.eu/clima/policies/effort_en (downloaded 2019-04-26).

The NECPs also include goals for the share of renewables in the 2030 energy mix. Figure 6 shows the values reported in the draft plans from December 2018, for the countries where this information was available.

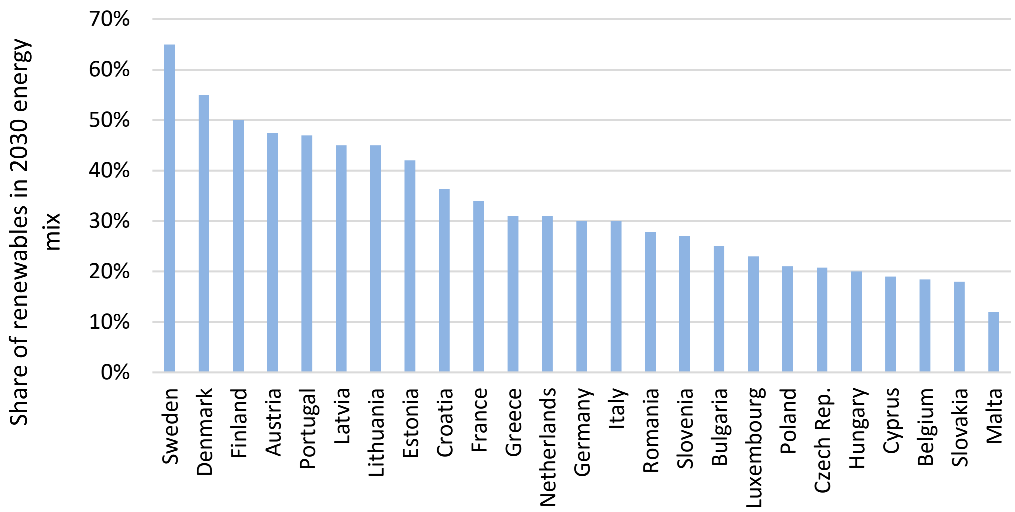


Figure 6: Share of renewables in 2030 energy mix, from draft NECPs submitted in December 2018.

2.2.6 Renewable energy policies around the globe

Renewable energy targets can take many forms, varying in how they are measured, the extent to which they are integrated with e.g. other aspects of national policy, relevant laws, standards and sectoral plans. IRENA (2017) provides an overview of types of renewable energy policies and measures adopted, as presented in the following graphic:

NATIONAL POLICY	REGULATORY INSTRUMENTS	FISCAL INCENTIVES	GRID ACCESS	ACCESS TO FINANCE[a]	SOCIO-ECONOMIC BENEFITS[b]
◆ Renewable energy target ◆ Renewable energy law/ strategy ◆ Technology-specific law/ programme	◆ Feed-in tariff ◆ Feed-in premium ◆ Auction ◆ Quota ◆ Certificate system ◆ Net metering ◆ Mandate (*e.g.*, blending mandate) ◆ Registry	◆ VAT/ fuel tax/ income tax exemption ◆ Import/export fiscal benefit ◆ National exemption of local taxes ◆ Carbon tax ◆ Accelerated depreciation ◆ Other fiscal benefits	◆ Transmission discount/ exemption ◆ Priority/ dedicated transmission ◆ Grid access ◆ Preferential dispatch ◆ Other grid benefits	◆ Currency hedging ◆ Dedicated fund ◆ Eligible fund ◆ Guarantees ◆ Pre-investment support ◆ Direct funding	◆ Renewable energy in rural access/cook stove programmes ◆ Local content requirements ◆ Special environmental regulations ◆ Food and water nexus policy ◆ Social requirements

Figure 7: Overview of types of renewable energy policies and measures (IRENA 2017, p.30).

The most rapid development has been in the power sector, where grid access policies have played an instrumental role in attracting investment in renewables, supported by regulatory policies. While feed-in tariffs/premiums and quotas were most important in the early 2000s, the growing share of variable new energy (VRE) in recent years has shifted the emphasis towards deeper integration of renewables in the overall design and functioning of energy systems. The adoption of net metering and renewable energy auctions, whose main strength relates to flexibility, price and commitments, has increased (IRENA 2017). System and market solutions to increase flexibility are more in focus. Flexibility measures are often grouped in six categories: supply, demand side, transmission & distribution networks, storage, market design, and system operation and management (IRENA 2017). While natural gas still plays an important role on the supply side the quest for sustainability has brought more attention to non-variable renewables, and this is also an area where hydrogen may come into play. On the demand side, smart systems for time-shifting and/or reducing demand, including more active consumer involvement, are in focus. When it comes to transmission and distribution, systems with more diverse and geographically dispersed supply and demand are planned for, to create greater overall balance. Electricity storage is a key source of flexibility, where pumped storage hydropower, batteries, thermal and electrical options, such as super-capacitors, but also hydrogen (power-to-gas or fuel cells) comes in. Market design is another area where tariff structure and other tools continually are refined, in order to increase sustainability. Measures for improved system operation, such as more sophisticated control, quotas and compensated VRE curtailment are likewise important.

IRENA (2017) sees less progress when it comes to heating and cooling for buildings and industry or in transportation. As regards heating, there are few credit and financial incentives, a lack of local technical and financial skills, and insufficient public awareness of available technologies and application options. However, EU has a dedicated Heating and Cooling Strategy, focusing action on stopping energy leakage from buildings, maximising the efficiency and sustainability of heating and cooling systems, supporting efficiency in industry and reaping the benefits of integrating heating and cooling into the electricity system

(EC COM 2016)[26]. Most member states are on track to achieve the targets for heating and cooling in their National Renewable Energy Plans. The RES share of energy in heating is highest in the Baltic and Nordic Member States (ranging from 43% in Estonia to 67% in Sweden).

When it comes to transport, policy to set up charging infrastructure has been slow in many countries, and biofuels are associated with adverse effects, such as indirect land-use change and further social/environmental concerns. The European Commission White Paper on Transport[27] specifies 10 goals that are expected to lead to new EU policies to increase the efficiency of Europe's transport sector. The main target of the White Paper is to reduce greenhouse gas emissions by 60 % compared with 1990 levels, by 2050. A key assumption is that technologies that contribute to lower greenhouse gas emissions, such as the electrification of road transport and development of sustainable fuels, will be increasingly available, especially after 2030. More recently, the Commission published a 'European Strategy for Low-Emission Mobility'[28] with three priority areas for action:

1. [Further] increasing the efficiency of the transport system;
2. Speeding up the deployment of low-emission alternative energy for transport; and
3. Moving towards zero-emission vehicles.

Still, total transport demand is predicted to continue growing during the 2020-2030 period in line with 2010-2020 patterns (1 % a year for passenger transport (passenger km) and 1.5 % for freight transport (tonne km)) and at lower rates between 2030 and 2050 (0.7 % a year for passenger transport and 0.8 % for freight transport). Transport in the EU still relies on oil for 94% of its energy needs. Europe imports around 87% of its crude oil and oil products from abroad, with a crude oil import bill estimated at around €187 billion in 2015. The Clean Power for Transport package aims to facilitate the development of a single market for alternative fuels for transport in Europe. National Plans for Alternative Fuels Infrastructure have been established, but only 14 member states have so far included provisions for hydrogen/fuel cell solutions. Generally, the market uptake of alternative fuels is slow, with the Commission concluding that additional policy action is required (COM 07/08/2019)[29].

Generally, Stern (2019) emphasizes that decarbonization options such as coal to gas switching, hydrogen (with or without CCS) and biogas/biomethane may be important, immediate and low cost in some countries, but marginal or irrelevant in others. For this reason, there can be no single narrative for gas decarbonization, but different narratives, depending on existing infrastructure, available resources, geographies, and policies (national and regional).

2.3 Regulations

Current and future regulations play an important role in determining Europe's demand for clean energy, as well as the possibilities for Norway to export clean energy to other European countries. The 'Energy Union' provides and overall framework for the EU's energy regulations and policies. It focuses on five aspects[30]

- Energy security, solidarity and trust
- A fully integrated European energy market
- Energy efficiency as a contribution to moderation of demand

[26] https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v14.pdf
[27] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52011DC0144
[28] https://eur-lex.europa.eu/resource.html?uri=cellar:e44d3c21-531e-11e6-89bd-01aa75ed71a1.0002.02/DOC_1&format=PDF
[29] https://ec.europa.eu/transport/themes/urban/cpt_en
[30] https://energifaktanorge.no/en/eu-lovgivning/eus-energi-og-klimapolitikk/

- Decarbonising the economy
- Research, innovation and competitiveness

Especially relevant regulations are the EU's energy security regulations[31] and the Trans-European Networks - Energy (TEN-E) Regulation[32]. The most relevant security legislation in this context is the rule for diversification of gas supply sources and routes. On the one hand this means that Norway will not be able to supply 100% of the EUs gas demand, but on the hand, this means that no matter what, the EU will always partly import gas from Norway. In addition, the security regulations define the size of the oil stocks, and measures to prevent and respond to potential gas or electricity supply disruptions. The TEN-E regulation is an EU law "which aims to assist national governments and companies to better interconnect electricity and gas infrastructure across national borders", thus providing clear rules for gas and electricity exports/trade between Norway and the EU for public and private companies in the energy market.

Laws for decarbonizing the economy and mitigating climate change were established during the Kyoto protocol period in the early 2000s and include, *i.a.*, Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for *greenhouse gas emission allowance trading* within the Community; Decision No 280/2004/EC (revised) of the European Parliament and of the Council of 11 February 2004 concerning a mechanism for *monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol*; the Climate and Energy Package: “20-20-20” targets from March 2007; Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions *to meet the Community’s greenhouse gas emission reduction commitments up to 2020*; Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the *promotion of the use of energy from renewable sources*; Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency.[33]

The EU's new energy rulebook supporting its long-term strategy towards a climate neutral Europe, "Clean Energy for all Europeans package", contains eight different legal acts, that were adopted by the European Parliament and Council in 2018 and 2019, listed in Table 1. These can be grouped into five main areas of action[34]

1. Energy performance in buildings
2. Energy efficiency
3. Renewable energy
4. Governance regulation
5. Electricity market design

While the first two primarily influence overall energy demand, the latter three are of direct relevance for Norway's prospects to export clean energy to Europe. The renewable energy directive sets a binding target of 32% renewables in the EU's energy mix by 2030. In 2017, this share was at 17.5%, with individual countries having shares between 7% (Luxembourg) and more than 50% (Sweden).[35] Exporting clean energy to the neighbouring country Sweden is one option, while recognising that Sweden is itself a net exporter of renewable energy. Altogether, export opportunities for Norway are vast since many European countries will continue to depend on energy imports. The governance regulation has been in force since December 2018 and requires each member state to make a detailed plan on how they intend to reach energy and climate targets until 2030 (the National Energy and Climate Plans – NECPs, also see Section 2.2.5). Based on these plans, it will be possible to identify regulations that influence clean energy export potentials for Norway on a country by country basis. This may become important in light of the more decentralised nature of renewable

[31] https://ec.europa.eu/energy/en/topics/energy-security
[32] https://ec.europa.eu/energy/en/consultations/evaluation-ten-e-regulation
[33] https://www.uio.no/studier/emner/jus/jus/JUS5911/v13/undervisningsmateriale/lecture-eu-climate-change-and-energy-law.pdf
[34] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans
[35] https://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics

energies. While crude oil and natural gas exports of Norway to the EU are dominated by supplies to the UK, Germany and the Netherlands, where there are large refineries, hydrogen could for example be delivered to other countries as well. For electricity and gas, exports will of course be limited to those countries, where the grid is connected, i.e. Denmark, Germany, the Netherlands, and the UK, as well as the land connections to Sweden and Finland. The design of the electricity market is based on four of the eight dossiers, all of which were adopted by the Council in May 2019: a new electricity regulation, and related electricity directive, risk preparedness and a regulation strengthening the Agency for the Cooperation of Energy Regulators (ACER). These are more flexible and market oriented than previous regulations and are adapted to foster a faster integration of renewables.

Table 1 Clean energy for all Europeans package - legislative process

	European Commission Proposal	EU Inter-institutional Negotiations	European Parliament Adoption	Council Adoption	Official Journal Publication
Energy Performance in Buildings	30.11.2016	Political Agreement	17.04.2018	14.05.2018	19/06/2018 - Directive (EU) 2018/844
Renewable Energy	30.11.2016	Political Agreement	13.11.2018	04.12.2018	21/12/2018 - Directive (EU) 2018/2001
Efficiency	30.11.2016	Political Agreement	13.11.2018	04.12.2018	21/12/2018 - Directive (EU) 2018/2002
Governance of the Energy Union	30.11.2016	Political Agreement	13.11.2018	04.12.2018	21/12/2018 - Regulation (EU) 2018/1999
Electricity Regulation	30.11.2016	Political Agreement	26.03.2019	22.05.2019	14/06/2019 - Regulation (EU) 2019/943
Electricity Directive	30.11.2016	Political Agreement	26.03.2019	22.05.2019	14/06/2019 - Directive (EU) 2019/944
Risk Preparedness	30.11.2016	Political Agreement	26.03.2019	22.05.2019	14/06/2019 - Regulation (EU) 2019/941
ACER	30.11.2016	Political Agreement	26.03.2019	22.05.2019	14/06/2019 - Regulation (EU) 2019/942

Source: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

2.4 European taxonomy on sustainable finance

The final report on EU taxonomy contains recommendations relating to the overarching design of the Taxonomy, as well as guidance on how companies and financial institutions can make disclosures using the taxonomy. The report is supplemented by a technical annex containing an updated list of technical screening criteria for economic activities that can substantially contribute to climate change mitigation or adaptation, including an assessment of significant harm to other environmental objectives[36].

3 Economic and societal trends (influencing European energy demand)

3.1 Chapter summary

- *What is the conclusion from what has been presented?*

While globally energy demand is expected to increase, EU's total energy demand is estimated to decrease slightly over the next decades, due to a decreasing population and further improvements in energy efficiency. Fuel switching implies an absolute increase in electricity demand. While the share of renewables is rising, the penetration level depends on the policy scenario. Uncertainties remain high due to the lack of credible consistent coordinated policy efforts.

- *Relevance for the ambitions of the report*

Major energy scenarios assume similar trends for GDP growth and other factors influencing energy demand. While scenarios differ across reports, they usually describe scenarios following current trends and more ambitious sustainable scenarios. A limitation is that each report only uses about three to five different scenarios reflecting current and more ambitious trends but does not show the full range of possibilities and how different factors influence the outcomes individually.

- *Is there something we know will change?*

Global markets will look differently after the Corona-crisis that started in March 2020. It is difficult to foresee which effects it will have on the energy transition.

- *When will revisions take place?*

In February 2020, all parties of the Paris Agreement had to submit the first update of their Nationally Determined Contributions (NDCs) that follow a 5-year cycle since 2015. Revisions of these NDCs will be submitted in October 2020. The studies reviewed here are mainly based on the 2015 plans, so that it will be valuable to look at updated scenarios in late 2020/beginning of 2021.

- *Parameters that should be included in modelling*

Considering the structure of the economy is more important than identifying the best projection for total GDP growth. Short- to medium-term projections are based on a lot more empirical detail, while long-term projections aggregate over sectors and regions and loose specificity. Sector-specific development prospects, especially that of the energy-intense industry should be considered. In addition, migration patterns due to political instabilities, climate change and a lack of work force in Europe may significantly alter population projections, which are one of the main determinants of total energy consumption.

In environmental impact analysis, energy demand is often decomposed into three terms following the IPAT equation (Chertow, 2008), Impact is influenced by the population size, affluence and technology. Here, impact relates to energy demand, the size of the population, per capita income reflects affluence, and energy intensity of production reflects technology: $\text{Energy demand} = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{Energy}}{\text{GDP}}$. The different socio-economic factors identified by Samuel et al (2013) show that, while mathematically beautiful, this decomposition does not reveal enough detail about the actual economic structure underlying the second term. Recall that the identified socio-economic factors are population, per capita real GDP, industrial growth, real price of energy, financial development variables, capital stock, foreign direct investment.

[36] https://ec.europa.eu/info/publications/sustainable-finance-technical-expert-group_en

While GDP per capita is a major driving force, the composition of GDP also has a significant influence, specifically the share of different industries in GDP as well as the existing and expected capital stock development. While 'industry structure' relates to the value-added side accounting of GDP, 'capital stock' reflects the expenditure side of GDP, showing the complexity of the final two terms of this simple decomposition. Table 3 shows the differences between value-added and expenditure side accounting of GDP. In short, a primary and secondary activities (agriculture, mining and manufacturing) are usually more energy intensive than activities in the tertiary sector, i.e. services. Hence, an industry structure with high shares of primary and secondary activities in Value Added will lead to a higher energy intensity of GDP. For the expenditure side, we have that capital formation, e.g. infrastructure development, machinery and equipment investments etc., are more energy intense than for example consumption by final households. After a short description of population and GDP per capita trends, we summarize different expectations about future energy demand by industry and households.

3.2 Population trends

Population development is a major driver for energy demand and used for all projections. The major sources for medium- and long-term population growth forecasts are the World Population Prospects from the United Nations Department of Economic and Social Affairs[37]. Most major outlook and trend reports, such as the IEA World Energy Outlook, the IEA Energy Technology perspectives, different OECD reports, e.g. the Global Material Resources Outlook to 2060 or The long view: Scenarios for the World Economy to 2060, Equinor's Energy Perspectives as well as the academic literature use these data. The UN's population prospects cover all countries in the world and data are available since 1950. The methodology and sources depend on each country, but generally take into account fertility rates, child, adult and overall mortality, as well as international migration patterns. The IMF uses short term forecasts from national statistical offices for its World Economic Outlook that usually covers the next 5 years.

Uncertainty about population prospects increases significantly with the length of the projection period as can be seen in Figure 8. By 2050 the Europe's population is expected to be about 5% (±3%) smaller than today. An increase in energy demand from population

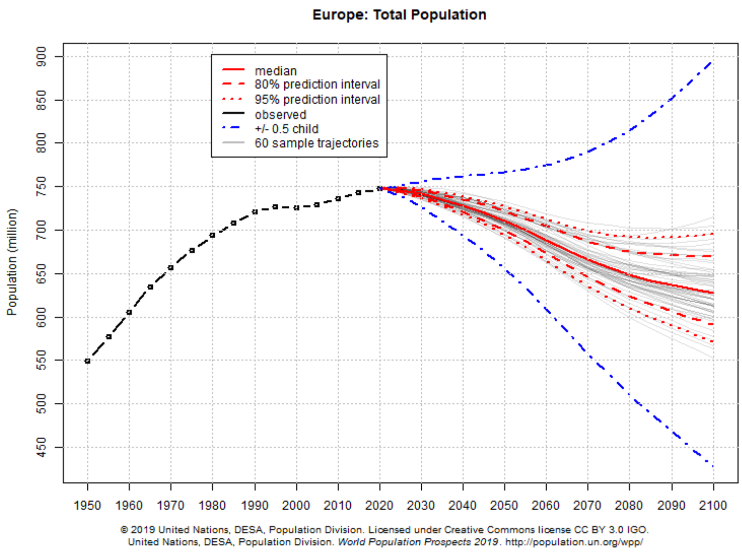


Figure 8: Population forecasts for Europe. Source: World Population Forecast 2019. UN Department of Economic and Social Affairs. https://population.un.org/wpp/Graphs/ Probabilistic Projections.

[37] https://population.un.org/wpp/

3.3 Projected economic growth

While the literature is very clear about the population data to use, there are many different GDP forecasts by statistical offices, international organizations, academic institutions, and private consultancies based on an even higher number of different methodologies. When using the energy demand estimates, described in the next section, it is important to understand the assumptions that underly the GDP estimates. We will therefore focus on those GDP estimates that are used by the various energy outlooks.

The IEA's World Energy Model[38] is based on some external macro-economic drivers such as population, GDP growth, energy and CO_2 prices, subsidies and other policies. For GDP growth, they use own estimations based on the International Monetary Fund (IMF)'s World Economic Outlook. Similar to the population projections, the IMF also uses data from national statistical offices for the short-term economic projections, but these are further analysed and processed by the IMF[39]. For energy demand estimations in the context of energy production planning, the IMF's short- to medium-term GDP projections for the next five years are especially relevant as they are detailed with respect to single countries and anchored in the respective national statistics.

Long-term economic projections that are then implemented in the World Energy Model or for example developed by the OECD, generally just estimate an average annual growth rate differentiating between the years up to 2030 and then 2030 to 2060, see Table 2. Long-term growth rates vary substantially, though differences between the OECD Euro area projection and the IEA's Europe and European Union projection can be explained by the country grouping. EU countries, that are not yet in the Euro area are expected to grow faster than newer EU member states. While the OECD's Long View projections are based on a purely economic model using a Cobb-Douglas production function that includes physical capital, trend employment and labour-augmenting technological change and explicitly models policy channels, the OECD's Global Material Resources Outlook to 2060 uses the ENV-Linkages model[40], which is a global CGE model with detailed industry linkage modelling based on GTAP data[41]. Alternatives to CGE models based on GTAP, that also consider interindustry-linkages and bilateral trade at the product level, but that are better in allowing for large structural changes (McCarthy, et al., 2018), are macro-econometric input-output models, such as E3ME (Mercure, et al., 2018a, Mercure, et al., 2018b), GINFORS (Distelkamp & Meyer, 2019, Lutz, et al., 2010, Meyer & Ahlert, 2019), or the Bilateral Trade Model[42] (Bardazzi & Ghezzi, 2018).

Table 2 GDP per capita growth rates. Source: The Long View: Scenarios for the World Economy to 2060, OECD 2018; IEA World Energy Model, Macro Drivers [43]

	OECD Long View Baseline Scenario				IEA World Energy Model			
	Potential GDP per capita				**Compound average annual growth rate**			
	2000-07	**2007-18**	**2018-30**	**2030-60**	**2000-18**	**2018-30**	**2030-40**	**2018-40**
Europe					1.8 %	1.7 %	1.5 %	1.6 %
European Union					1.6 %	1.6 %	1.4 %	1.5 %
Euro area	1.3 %	0.7 %	1.1 %	1.7 %				
Norway	2.3 %	1.0 %	1.0 %	1.6 %				

[38] https://www.iea.org/reports/world-energy-model/macro-drivers
[39] https://www.imf.org/external/pubs/ft/weo/2019/02/weodata/index.aspx
[40] https://www.oecd.org/env/45334643.pdf
[41] https://www.gtap.agecon.purdue.edu/
[42] https://www.e3me.com/, https://www.gws-os.com/de/index.php/energy-and-climate/models/model-details/ginfors-e.html, http://www.inforum.umd.edu/services/models/btm.html
[43] https://www.iea.org/reports/world-energy-model/macro-drivers (26.02.2020)

World	5.6 %	4.6 %	3.4 %	2.4 %	3.7 %	3.6 %	3.1 %	3.4 %

The IEA WEO (2018) stresses that "the way that economic growth translates into energy demand growth varies substantially depending on each country's economic structure and stage of development, as well as pricing and efficiency policies". Countries with high expected growth in manufacturing, will have higher energy demand relative to GDP growth than countries with higher growth in the service industries. Developing countries and emerging economies, that are still building a lot of infrastructure and have a relatively higher share in gross fixed capital formation on the expenditure side, will also have a higher direct and indirect energy demand. The structure of the economy can be measured using the aggregated tables from the system of national accounts, see Table 3.

Table 3 Value Added and Expenditure side of GDP. Source: Own presentation based on United Nations DESA Statistics Division National Accounts Main Aggregates Database[44]

SNA93 Table 2.4
Industries

Item	SNA93 Item Code
Agriculture, forestry and fishing	A
Manufacturing, mining and quarrying and other industrial activities	B+C+D+E
Manufacturing	C
Construction	F
Wholesale and retail trade, transportation and storage, accommodation and food service activities	G+H+I
Information and communication	J
Financial and insurance activities	K
Real estate activities	L
Professional, scientific, technical, administrative and support service activities	M+N
Public administration and defence, education, human health and social work activities	O+P+Q
Other service activities	R+S+T
Equals: VALUE ADDED, GROSS, at basic prices	B.1g
Plus: Taxes less Subsidies on products	D.21-D.31
Plus: Taxes on products	D.21
Less: Subsidies on products	D.31
Equals: GROSS DOMESTIC PRODUCT	B.1*g

SNA93 Table 1.1
Expenditures of the gross domestic product

Item	SNA93 Item Code
Final consumption expenditure	P.3
Household final consumption expenditure	P.3
NPISHs final consumption expenditure	P.3
General government final consumption expenditure	P.3
Individual consumption expenditure	P.31
Collective consumption expenditure	P.32
Gross capital formation	P.5
Gross fixed capital formation	P.51
Changes in inventories	P.52
Acquisitions less disposals of valuables	P.53
Exports of goods and services	P.6
Exports of goods	P.61
Exports of services	P.62
Less: Imports of goods and services	P.7
Imports of goods	P.71
Imports of services	P.72
Plus: Statistical discrepancy	
Equals: GROSS DOMESTIC PRODUCT	B.1*g

While the IEA assumes the same growth rates no matter which energy future, Equinor (2019) differentiates GDP growth rates between its three scenarios. Similar to the OECD's Long View, GDP growth rate estimations consider the different input factors (capital, labour, and additionally natural resources), corresponding productivity trends as well as political reforms and international cooperation. Equinor's projections with compound global annual growth rates until 2050 of 2.5% in the business-as-usual scenario 'Reforms', 2.2% in a more protectionist world, scenario 'Rivalry' and 2.6% in the low emission scenario 'Renewal', are more conservative than the OECD's and IEA's which are around or slightly above 3%.

3.4 Projected developments in European energy demand

Future energy demand estimates are of interest not only for policy makers, but also for energy companies. **Equinor**, for example, annually publishes its own "**Energy Perspectives**" (Equinor, 2019), which is compiled independently of Equinor's strategy, but used together with other resources by the company's management. The main findings of the 2019 report indicate that globally energy demand is rising, together with CO_2 emissions, despite a record high in solar and wind power installations, gas is the fastest growing fossil energy carrier and costs for renewables continue to decrease. Different trends in economic growth, energy efficiency, technological development, market regulations and geopolitics and their interplay result in many different possible scenarios for energy demand and production around the world. Equinor summarizes these in three possible scenarios, Reform, Rivalry and Renewal. The former two aim to represent a continuation in current trends with the main difference being some cooperation regarding climate policies in 'Reform' and a focus on national energy security and individual climate policies in 'Rivalry'. 'Renewal'

[44] https://unstats.un.org/unsd/snaama/

assumes immediate global cooperation together with a restructuring of industry and significant changes in consumption behaviour.

The **International Energy Agency** publishes two sets of scenarios, the **World Energy Outlook (WEO)** and the **Energy Technology Perspectives (ETP)**. The ETP scenarios are set-up climate target based, showing how current technology and cost developments can achieve different degrees of warming. The most recent version from 2017 differentiates between a Reference Technology Scenarios, reflecting todays commitments and plans, the 2-degree scenario and the beyond 2-degree scenario. Technology deployment is adjusted in the scenarios to reach the climate goals. The WEO, which is published annually, differentiates the scenarios according to policy, not according to technological development: 1) Current policies scenario: No change in policies from today, 2) Stated Policies Scenario, previously known as New policies scenario (NPS): Includes policies and targets announced by governments, and 3) Sustainable development scenario (SDS): On track to meet goals related to climate change, i.e. in line with Paris agreement. The biggest difference between the 2019 and 2018 WEO is the extension of the SDS to 2050 and the inclusion of 'Policies promoting production and use of alternative fuels and technologies such as hydrogen, biogas, biomethane and CCUS' for different sectors in the SDS. In addition, a small part of conventional oil production is replaced by tight oil production and NGLs, and expectations for electricity generation from wind and solar PV are corrected upwards. The latter upward correction of availability of renewable electricity sources can be seen for all projections in the last decade.

The **EU** itself publishes scenarios together with its strategies such as EU Energy Roadmap 2050[45] published in 2011, The EU Reference Scenario 2016 – Energy, transport and GHG emissions: Trends to 2050[46], or a A Clean Planet for All[47] from 2018. The EU is also a member of Mission Innovation[48], a global initiative supporting the clean energy transition through increasing innovation capacity. This emphasizes the importance of research and development for the composition of the energy mix in the future. The most recent development of the EU and the Energy Union are reported in the strategic energy technologies (SET) plans[49].

The **IPCC** relies on efforts from the academic community using complex **integrated assessment models** that, at an aggregated sectoral and regional level, integrate energy technologies, energy use choices, land-use changes and societal trends into one model to assess anthropogenic climate impacts[50]. The representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs) are designed to paint a picture of possible future socio-technical developments and what is necessary to achieve climate targets. They show large variation and help in understanding the large range of uncertainties involved in projecting energy demand.

3.4.1 Energy demand projections by sector

Energy demand is reduced in all sectors according to all the different scenarios, see Figure 9 and Figure 10 for the most recent long-term scenarios by IEA and EC. In the more ambitious climate/sustainable development scenarios, the largest changes compared to today's situation will achieved in the transport sector, while energy use by industry changes least. This can be explained by energy costs having had a large share in total costs historically, so that energy efficiency improvements are starting to slow down. For transport and buildings (residential and service/tertiary sector) however, energy efficiency improvements

[45] https://ec.europa.eu/energy/sites/ener/files/documents/roadmap2050_ia_20120430_en_0.pdf & https://ec.europa.eu/energy/sites/ener/files/documents/sec_2011_1565_part2.pdf
[46] https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf
[47] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN
[48] http://mission-innovation.net/
[49] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118272/set_plan_report_2019_online.pdf
[50] https://www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change

possibilities are still high and especially in these sectors energy demand depends on the size of the population and related housing, service and transport demand. If population is expected to decline fast than increases in demand per capita, energy demand decreases as well, though at a lower rate.

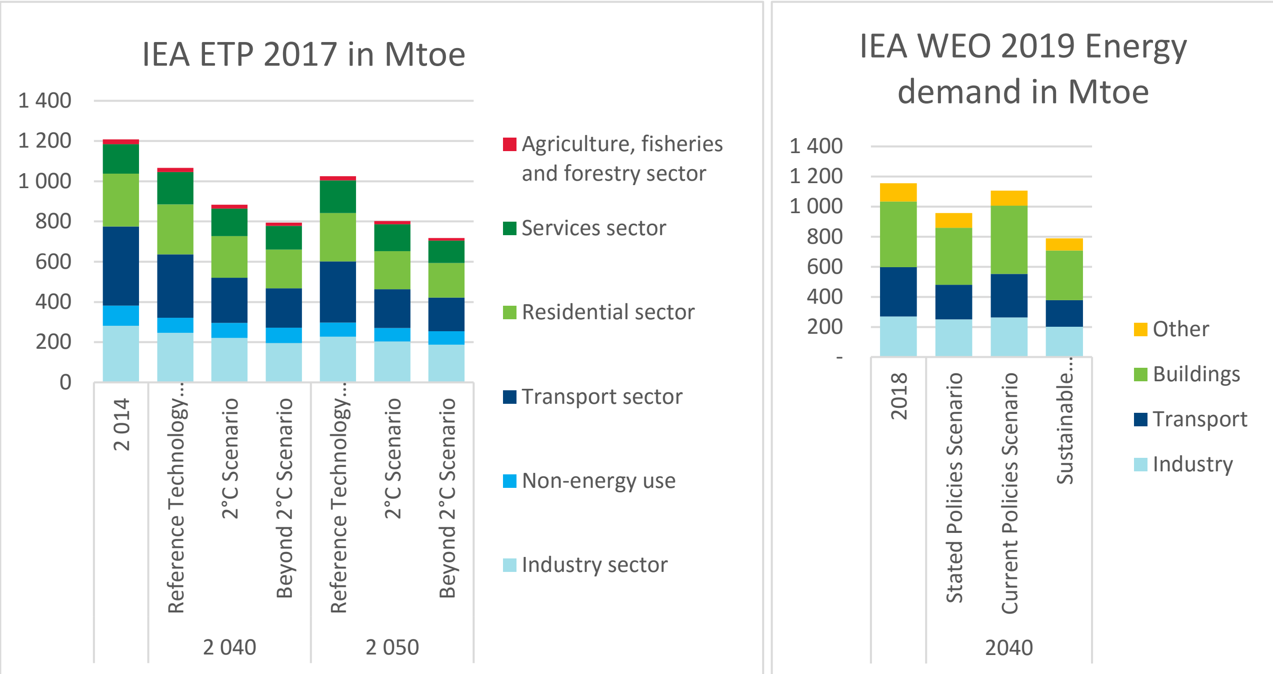
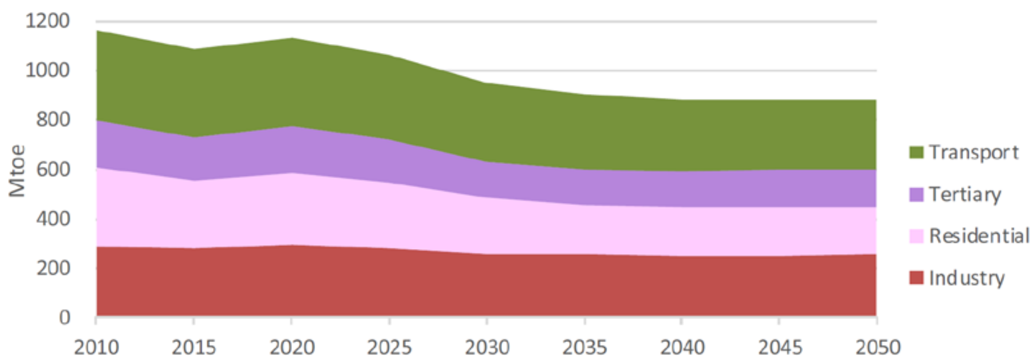


Figure 9: Final Energy Demand (PJ) in EU by sector in IEA ETP 2017 and IEA WEO 2019



Note: "Tertiary" includes the energy consumed in the agricultural sector.

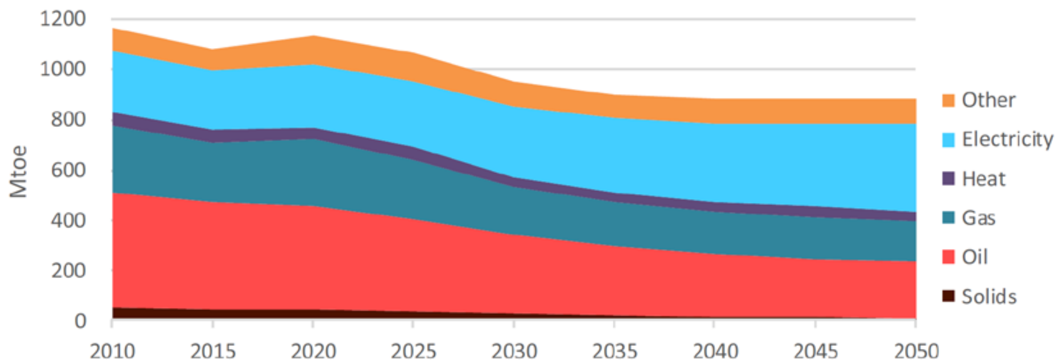
Source: Eurostat (2010, 2015), PRIMES.

Figure 10: Final Energy Demand by sector as used in "A clean Planet for All". Source: EC (2018) IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773: A Clean Planet for all, A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. All rights reserved.

3.4.2 Energy demand projections by fuel/energy carrier

The baseline scenario of the EU long term strategy, A clean planet for all, clearly shows the increasing importance of electricity in the final energy mix, Figure 11. In the more ambitious climate scenarios, this trend is even stronger. This is also true for the other sets of scenarios, including both IEA ETP (2017) and

IEA WEO (2018), Figure 12. Not only the share of electricity, but total electricity demand increases over time and the more ambitious the climate targets are, while the use of coal is almost completely phased out and oil decreases significantly. Europe's demand for gas, however, increases over time, and is only slightly reduced in the more ambitious climate scenarios. This is due to the fact that gas is the least emission intense energy carrier of the fossil fuels, carbon-capture and storage technologies for gas are available, and gas is a variable energy carrier that is available quickly, when others are not. This is especially true for electricity generation, where gas power plants can be started and paused depending on the availability of the intermittent power sources such as solar and wind.



Note: "Other" includes biomass and waste.

Source: Eurostat (2010, 2015), PRIMES.

Figure 11: Final Energy Demand as used in Figure 10 "A clean Planet for All". Source: EC (2018) IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773: A Clean Planet for all, A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. All rights reserved.

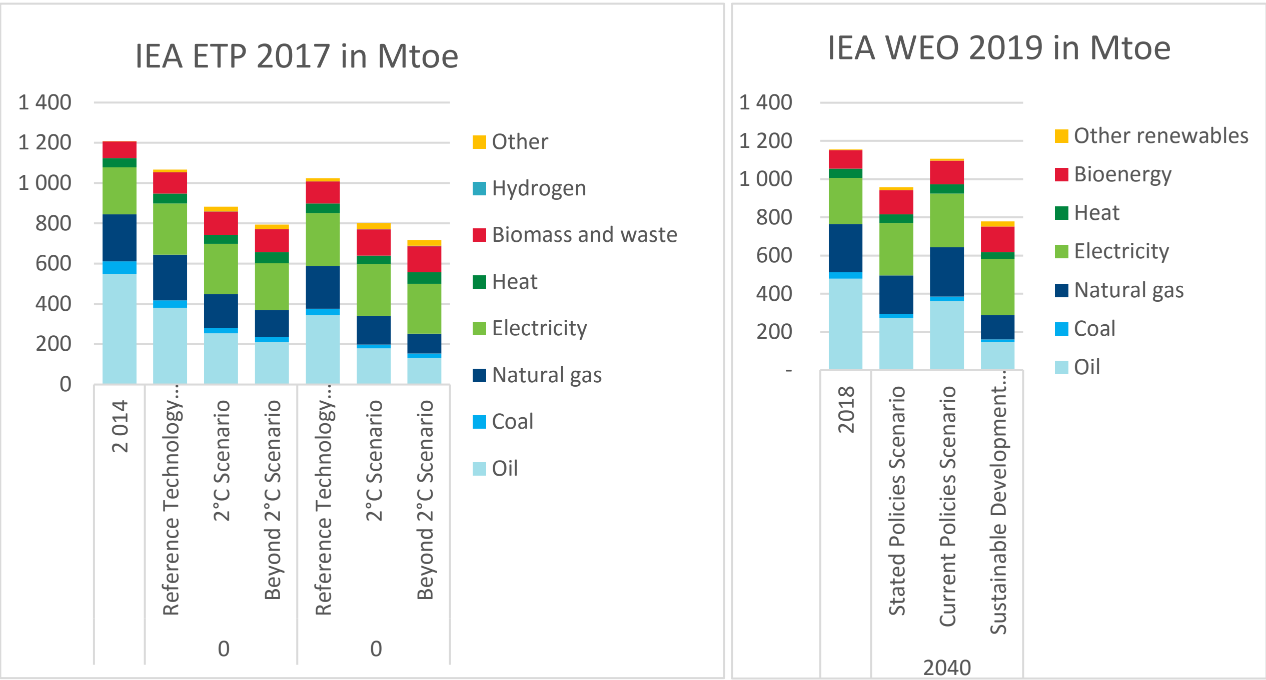


Figure 12: Final Energy Demand in the EU by energy carrier in IEA ETP 2017 and IEA WEO 2019

3.4.3 Changes in electricity production

In Figure 13, the renewable energy share in the electricity, heat and transport sector by region in 2017 vs. 2040 is shown. The largest increase in renewables share is expected to come in the electricity sector. In 2040, over 60% of electricity generation in the EU is estimated to come from renewables. It is evident from Figure 14 that electricity generation from renewables is expected to increase towards 2040. In the 2018 WEO's NPS already, the IEA estimates that renewable energy sources will dominate the electricity generation in the EU in 2040, as shown in Figure 14. Wind, nuclear, hydropower and solar PV are expected to be the largest renewable contributors, but also natural gas will continue to play a large, though slowly decreasing, role.

According to Bloomberg NEF, 80% of Europe's electricity will come from wind and solar and 10% from other renewables by 2040[51], which is in line with the more ambitious climate scenarios of the EU A Clean Planet for all strategy, see Figure 15. In Germany, Bloomberg NEF expects the share of renewables to be as high as 96% in electricity production. However, the remaining 4% will still be generated by gas electricity plants for peak hours and system stabilization.

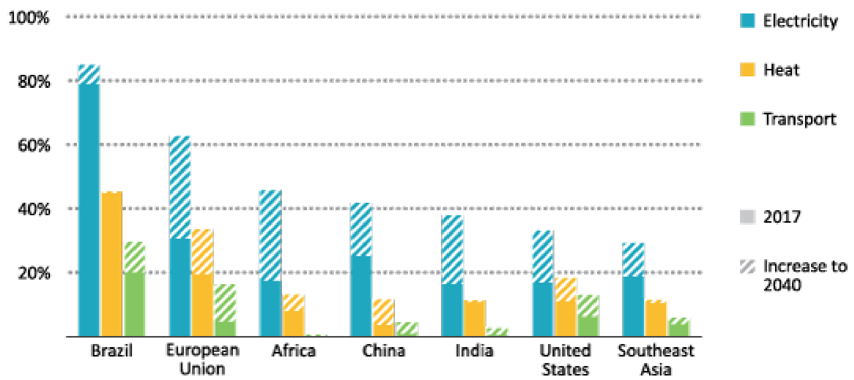


Figure 13: Renewable energy share by category and region in the NPS, in 2017 and 2040. Excludes traditional use of biomass. Source: IEA (2018) World Energy Outlook. All rights reserved.

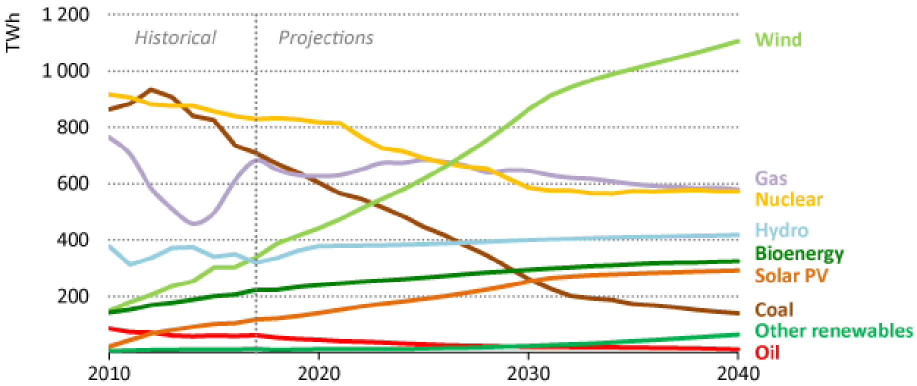
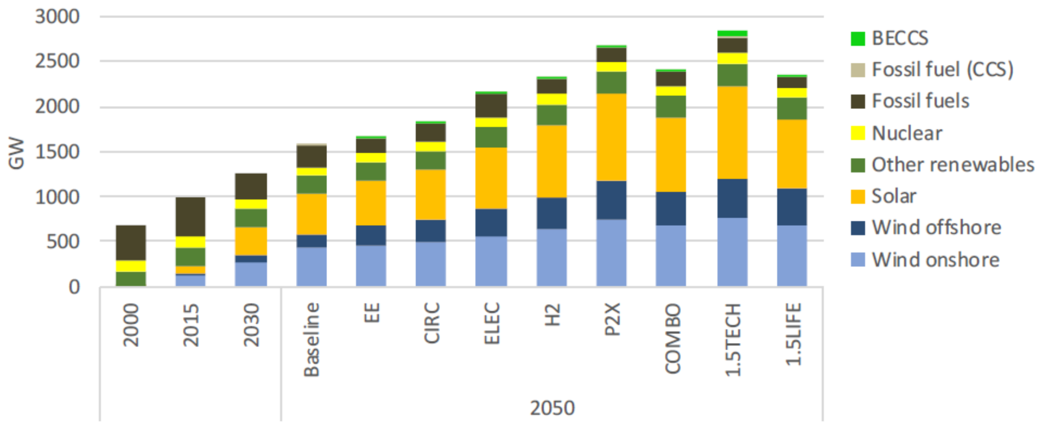


Figure 14: Electricity generation by source in the European Union in NPS. Source: IEA (2018) World Energy Outlook. All rights reserved.

[51] https://bnef.turtl.co/story/neo2019/page/3/3?teaser=true



Source: Eurostat (2000, 2015), PRIMES.

Figure 15: Power generation capacity as used in Figure 24 "A clean Planet for All". Source: EC (2018) IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773: A Clean Planet for all, A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. All rights reserved.

3.4.4 Continued European energy import dependency, an export opportunity for Norway

While neither of the IEA reports publish data on energy trade, the EU expects a continued import dependency on energy products, especially for oil and gas products, see Figure 16. This is also assumed in Equinor's Energy Perspectives 2019. A clean planet for all, Europe's strategy for 2050, clearly points out that import dependency, while present in all scenarios, will significantly decrease in more ambitious climate scenarios as energy imports are primarily made of oil and gas. Coal is completely phased out in the baseline scenario long before 2050. Given continuous use of nuclear power (with a very diversified supply market) and significant increases in wind and solar power, Europe can, theoretically, be self-sufficient for electricity production. Estimates from the IEA ETP (2017) show that electricity generation within the EU is larger than final demand, Figure 18, but this does not include the energy industry's own use. In addition, the variability in these energy sources is high, not only throughout a year, but even more throughout each single day. Therefore, diversification in supply regions is a must, and increased exchange possibilities for electricity between Norway and EU countries will need to be realized (NVE, 2019).

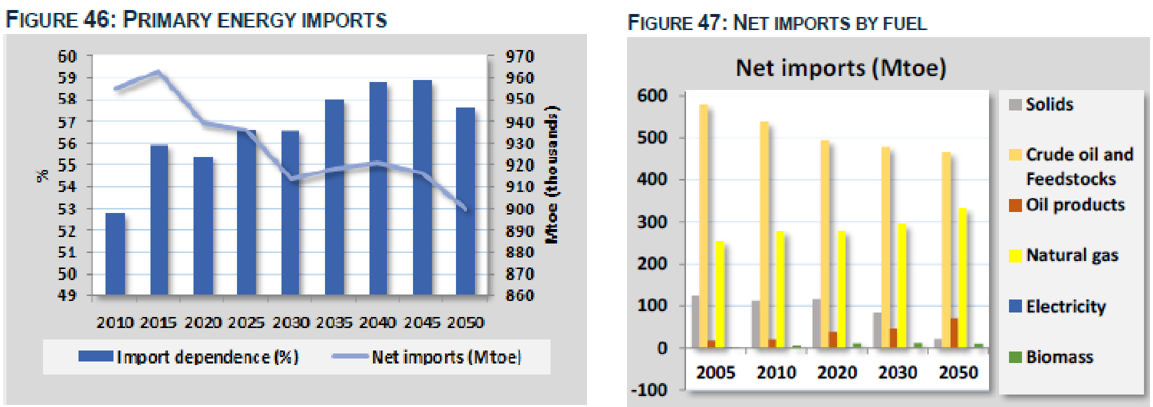


Figure 16: Energy imports up to 2050. Source: EU Reference Scenario 2016, p. 71/72. All rights reserved.

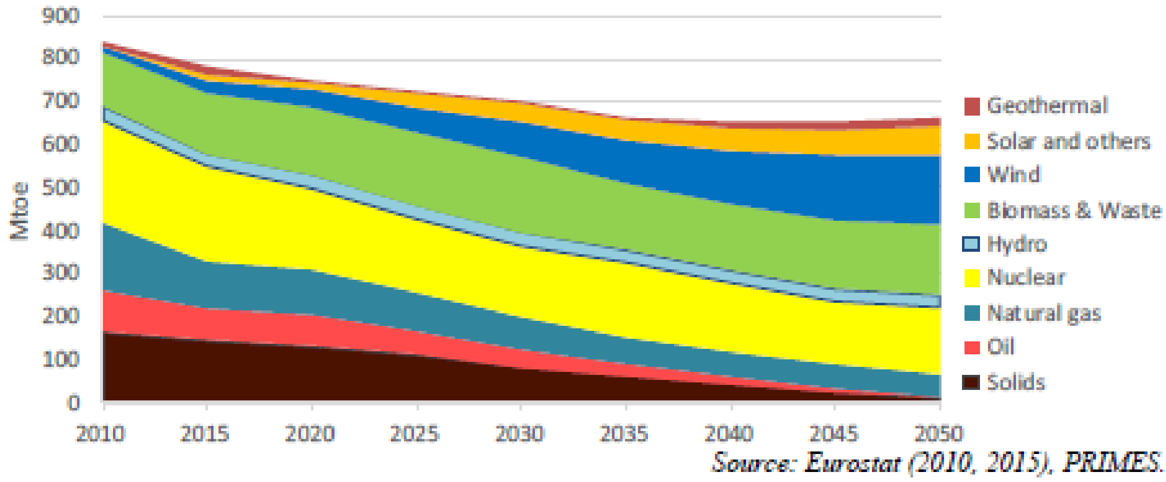


Figure 17: Final Energy Supply as used in Figure 7 "A clean Planet for All". Source: EC (2018) IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773: A Clean Planet for all, A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. All rights reserved.

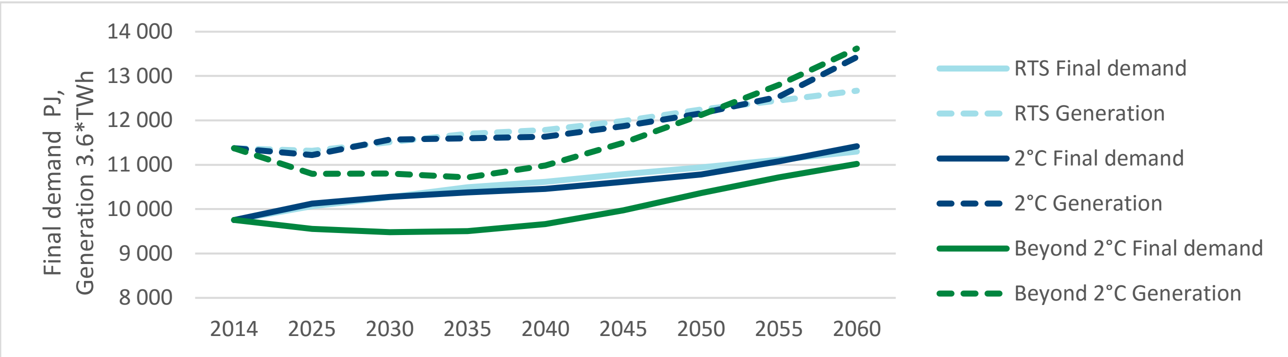


Figure 18: Electricity in the EU Final Demand and Generation. Data for Generation was given in TWh in the source and converted to PJ, using 1PJ = 3.6TWh. Source: IEA ETP 2017

Natural gas currently is one of Norway's largest energy export goods. While neither the production nor the use of gas can currently be considered as clean, there are possibilities to decrease emissions in the future. Equinor, for example, aims to fully decarbonize its offshore production of oil and gas by 2050, with a medium-term goal of a 40% reduction in emissions by 2030[52]. For decreasing the emissions from using the gas, carbon capture and storage and transport technologies need to be in place.

Stern (2019) provides a comparative overview of scenarios and time frames for decarbonization, with resulting gas demand projections for the EU. The comparison (Figure 19) includes the trajectory from IEA's World Energy Outlook (2018), as well as projections based on scenario studies by three leading oil and gas companies: Shell, BP and Equinor. The projections indicate a relatively stable situation towards 2025 but accelerating decline from 2030. Stern argues that the traditional 'gas advocacy' propositions linked to switching from coal and oil and backing up intermittent renewables do not properly address the priorities of EU and its member states. Given the high level of commitment to the COP21 decarbonization targets and

[52] https://www.equinor.com/en/news/2020-01-06-climate-ambitions-norway.html

the projected availability of biomethane and hydrogen from power to gas, he suggests that commercial scale decarbonised gas projects must be established by the mid-2020s (ibid.).

The distribution of global gas demand by sectors from the IEA WEO (2018) is shown in Figure 20. The industry is the largest contributor to growth in the total gas demand, but also a large increase is seen in the power sector in the period 2025-2040.

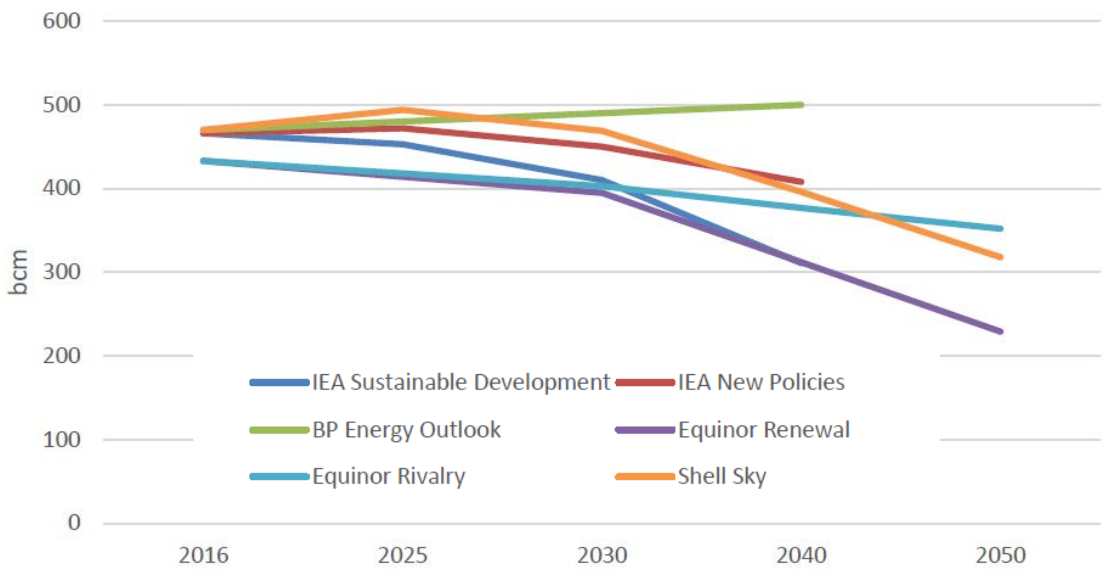


Figure 19: European Union: gas demand projections to 2050 (bcm). Stern 2019:12, based on IEA (2018), pp.550-551. BP (2018), p.54. Equinor (2018), p.57. Shell Sky Scenario.

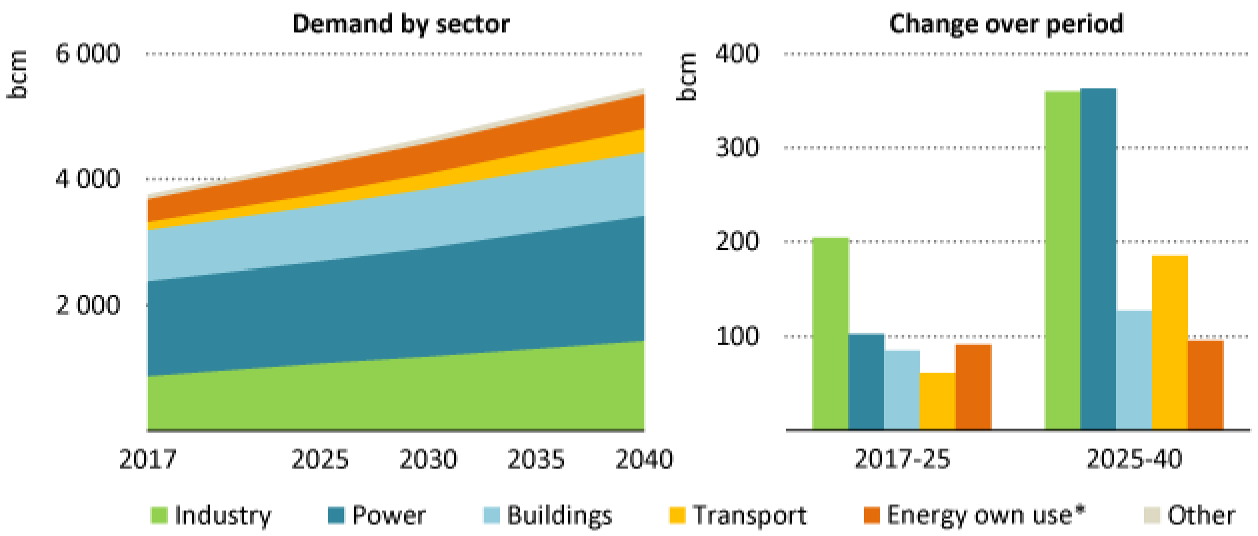


Figure 20: Global gas demand by sector in NPS. Source: IEA (2018) World Energy Outlook. All rights reserved.

4 Energy technologies and infrastructure for energy export

4.1 Chapter summary

- *What is the conclusion from what has been presented?*

Although a widespread CO_2 transport infrastructure is not yet available, the European Projects of Common Interest (PCIs) on CO_2 transport indicate how this infrastructure might look in the future. An extensive gas pipeline network already connects Norway and Europe, and this infrastructure could be utilized in future energy export and CO_2 transport scenarios. Norway has several long-distance electrical cables going to Europe and transmission capacity from the Nordic region will be doubled compared to today's levels by 2030. CO_2 capture technologies will be important in a future decarbonised energy system, and several technologies are now at pilot and demonstration scale, indicating that a wide range of technologies will be available in the future.

Hydrogen provides for a more robust energy system, by complementing electricity as energy carrier. The importance of hydrogen as an energy carrier becomes especially evident in integrating the energy-, transport-, industry- and the residential heating sector. This way hydrogen links different sectors and contributes to increase the operational flexibility (sector coupling).

Internationally, hydrogen is subject to increased attention both in industry and policy, and leading energy and technology companies are engaging and planning or large investments in the hydrogen technologies. European policies are heavily focusing on the key future role of hydrogen for decarbonization.

- *Relevance for the ambitions of the report*

Given the European energy and climate strategies, the question is how much hydrogen will be produced internally in Europe and how much hydrogen is it realistic to assume will be imported from other countries, including Norway.

- *Is there something we know will change?*

A European Hydrogen Roadmap has recently been launched, estimating a seven-fold increase in the hydrogen demand in 2050 as ambitious scenario. Even in a business as usual scenario, the hydrogen demand is expected to double from 2020 to 2050 to 780 TWh. For comparison, the Norwegian natural gas export is currently in the range of 1200 TWh, which is predominantly delivered to Europe covering 25-30 % of the European natural gas demand.

- *When will revisions take place?*

The European energy system is already undergoing significant changes, and the share of renewables is increasing. Increasing the ambitions for energy efficiency, share of renewables and CO_2-emission reductions are being discussed in the EC, both in the 2030 and 2050 perspective. Revisions are expected to take place relatively soon.

- *Parameters that should be included in modelling:*

Expected European hydrogen demand, in various scenarios, as well as the political ambitions for introducing renewable energy sources in Europe and the competition from other potential suppliers of hydrogen to Europe.

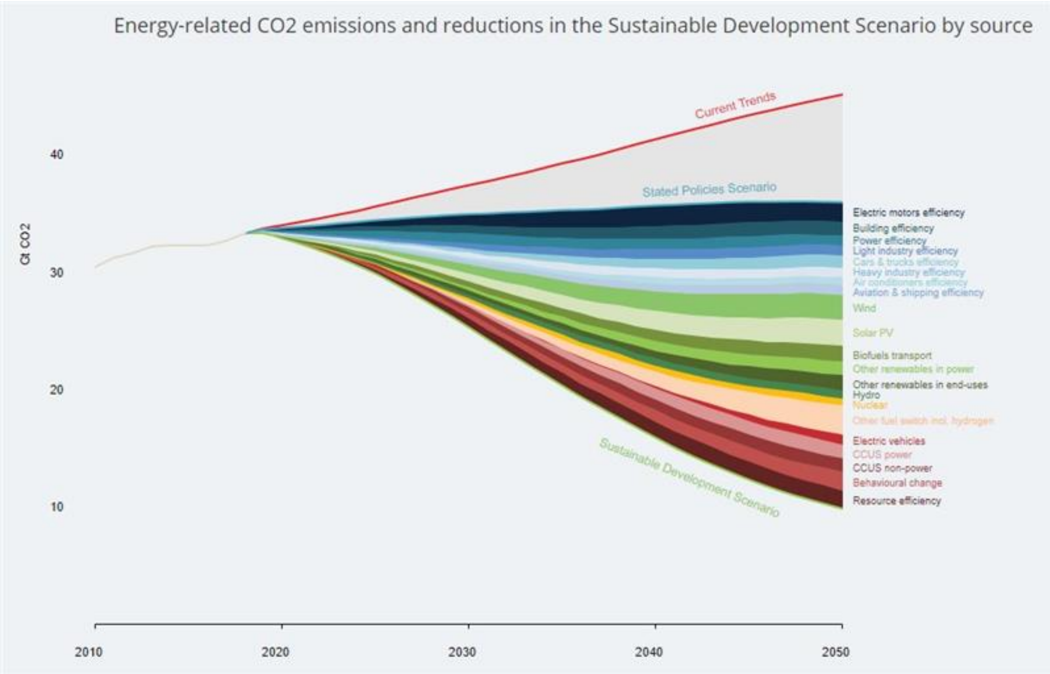
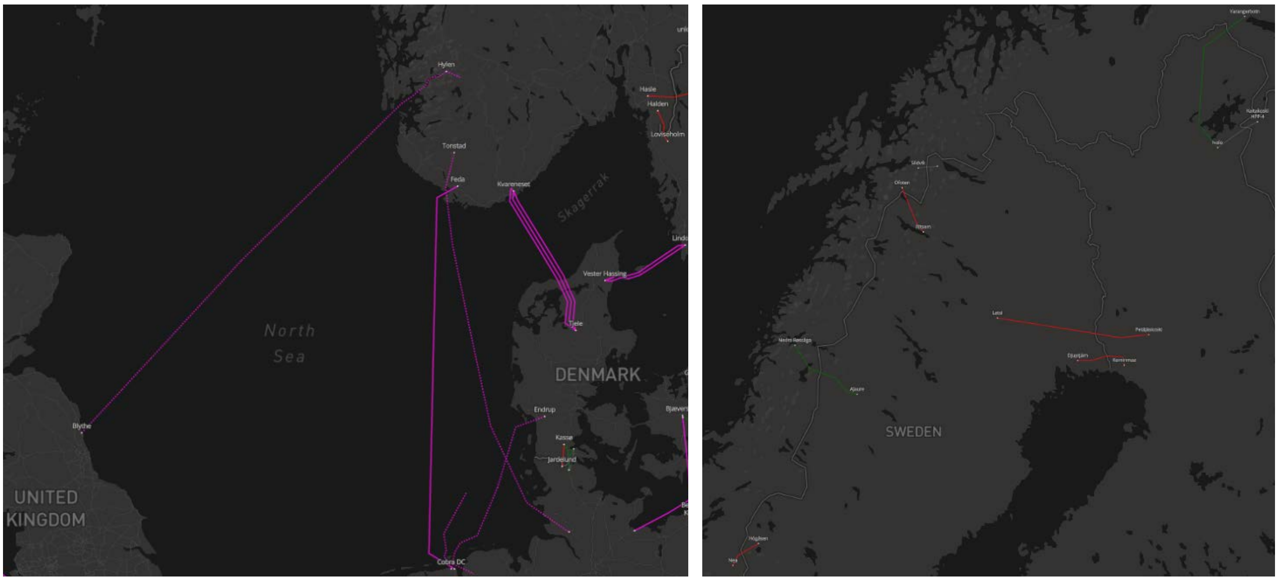


Figure 21: Technologies' contribution to GHG emission reduction. Source: IEA (2018) World Energy Outlook. All rights reserved.

4.2 Exchange of electric power between Norway and Europe

Norway currently has cross-border interconnectors[53] to Russia, Finland, Sweden, Denmark and the Netherlands. These connections are shown as solid lines in Figure 22. Southern Norway has the largest potential for export of electricity, because a number of high voltage direct current (HVDC) interconnectors, indicated by pink lines in the figure, are already in operation in this region. The stapled lines in Figure 22 (a) shows that two additional HVDC cables are planned, which will connect southern Norway to the United Kingdom and Germany. These are scheduled for completion in 2021 and 2020, respectively. Additionally, a cable connecting Norway and Scotland is planned[54].

[53] https://www.entsoe.eu/data/map/
[54] http://webfileservice.nve.no/API/PublishedFiles/Download/201101044/2996938 (25.03.2020)



(a) (b)

Figure 22: Overview of existing and planned cross-border power cables. (a) In the area around southern Norway. (b) In the area around northern Norway.

In Figure 23, the planned increase[55] in transmission capacity toward 2030 in and out of the Nordic region is shown. The capacity for export will almost double compared to today's levels, to approximately 120 TWh/y.

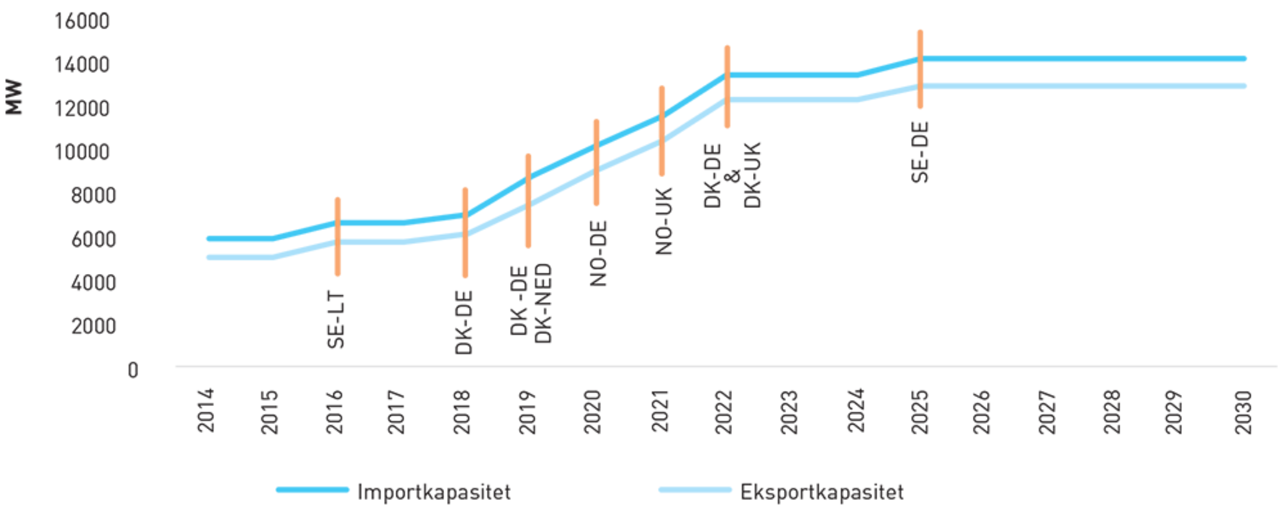


Figure 23: Planned increase in transmission capacity in and out of the Nordic region toward 2030.

4.3 Gas pipeline network between Norway and Europe

About 95% of Norwegian gas is transported via a network of subsea pipelines to other European countries[56] and the remainder is transported as liquefied natural gas (LNG) from the Melkøya facility in Finnmark. As can be seen from Figure 24, Norway is connected to Germany, Belgium, France and the United Kingdom

[55] https://energifaktanorge.no/en/norsk-energiforsyning/kraftnett/
[56] https://www.norskpetroleum.no/en/production-and-exports/exports-of-oil-and-gas/

through this pipeline network. Its transport capacity is currently about 120 billion Sm^3 dry gas per year, approximately 1100 TWh/y.

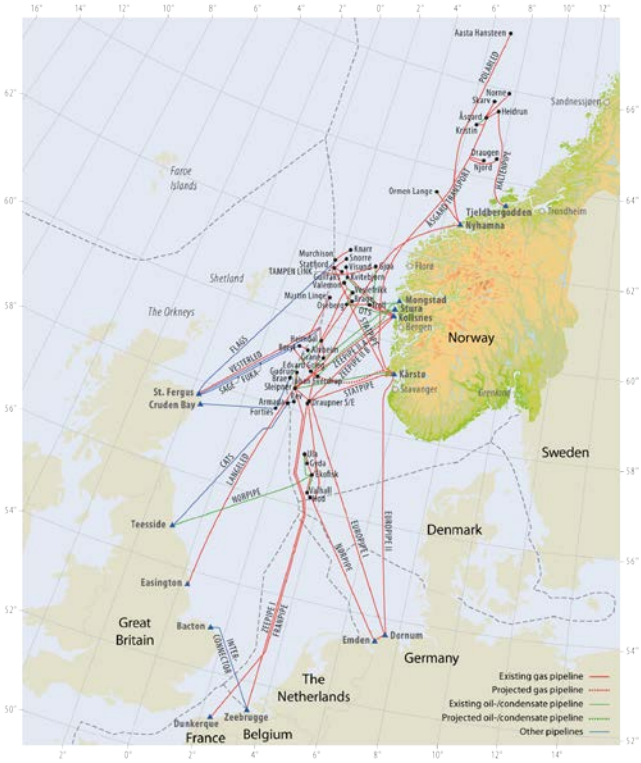


Figure 24: An overview of the gas pipeline network on the Norwegian continental shelf. Source: Norwegian Petroleum Directorate.

4.4 Hydrogen's role as an energy vector for decarbonisation

The key role of hydrogen in the transition towards a sustainable, low carbon society has become more evident, especially over the last decade. Hydrogen enables a more diverse and more robust energy system, by complementing electricity as energy carrier. IEA illustrated this well in their Technology Roadmap (2015) [57], showing how hydrogen links different sectors and contributes to increase the operational flexibility.

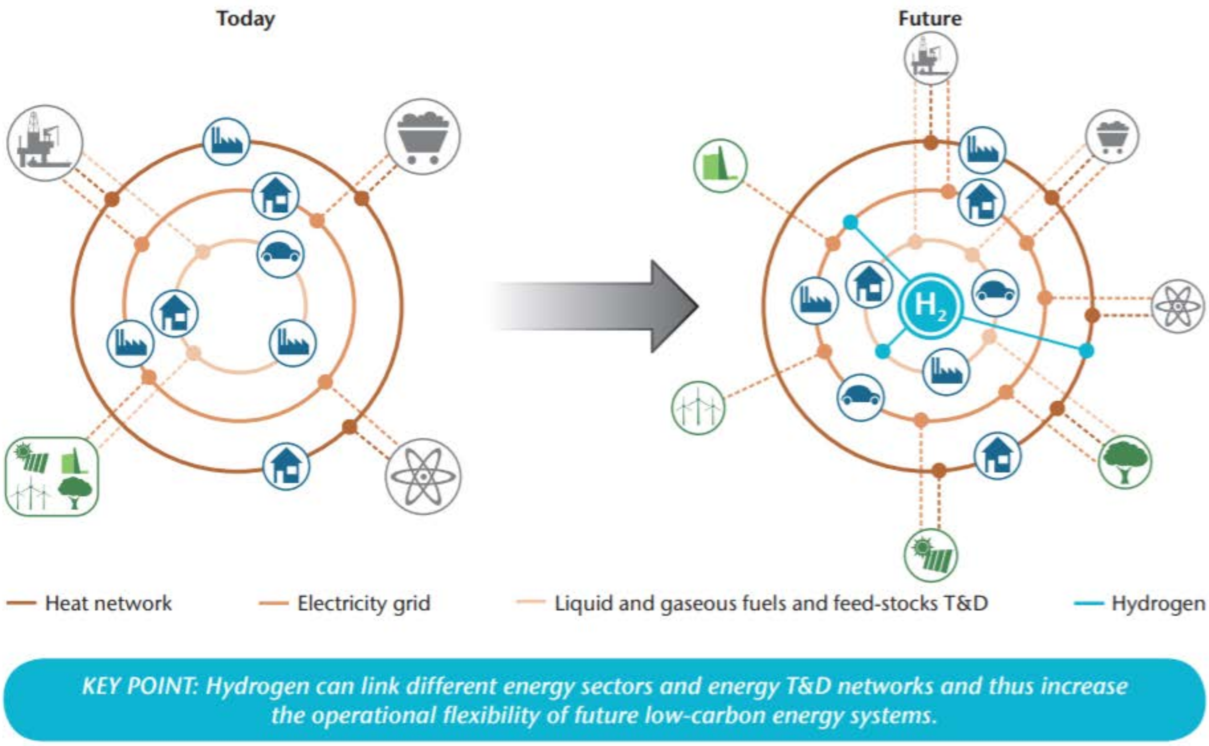


Figure 25. IEA's view on how hydrogen may provide for a more flexible low-carbon energy system in the future[57].

The potential of hydrogen as an energy carrier becomes especially evident in integrating the energy-, transport- industry- and the residential heating sector, as shown in the IEA figure above. The key function of hydrogen is typically denoted *sector coupling*, as described by IRENA[58]. Hydrogen will furthermore facilitate an increased introduction of renewables, due to its ability to store energy and thereby contribute to mitigate the mismatch between power production and demand, as the share of renewable energy increases.

The recently released report *Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition*, concludes that at scale decarbonisation of key the segments require the use of hydrogen in large quantities. The report exhibits 7 main roles of hydrogen in the energy transition as shown in Figure 26. These are further discussed below.

[57] Technology Roadmap Hydrogen and Fuel Cells, p.10, https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHydrogenandFuelCells.pdf
[58] https://www.irena.org/energytransition/Power-Sector-Transformation/Sector-Coupling

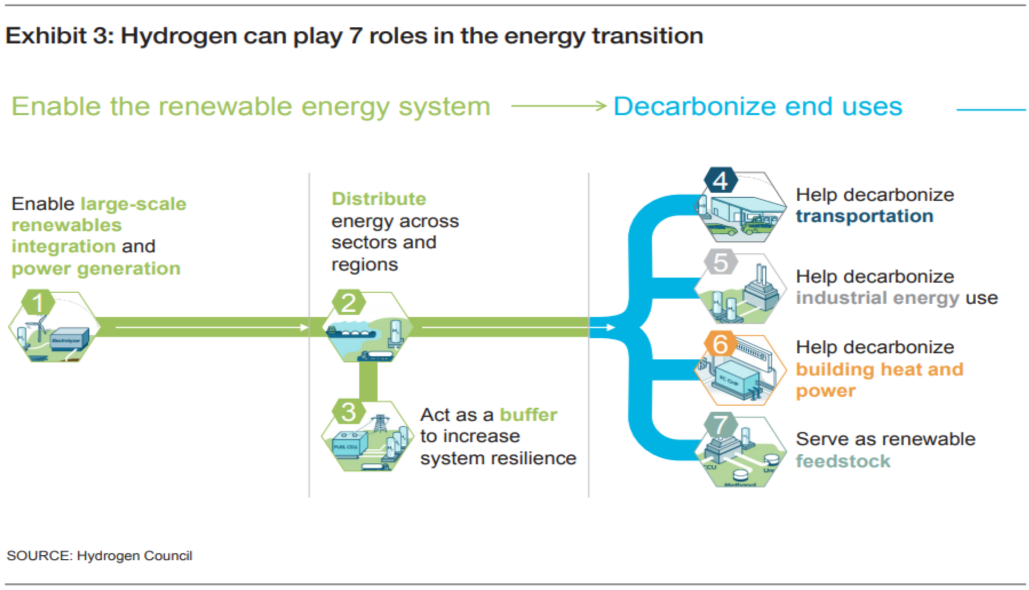


Figure 26: The 7 main roles hydrogen can play in the energy transition. *Source: Hydrogen Council*[57].

Through introducing hydrogen in the energy system, one can increase the deployment, utilisation and value of renewable energy production. This will on long term enable a larger portion of intermittent renewable energy in the primary energy mix. On a European level, the need for flexibility and energy storage to balance the production from non-dispatchable energy sources has increased dramatically during the last 10-15 years. This is especially evident in countries like Germany and Denmark where renewable wind and solar power generation already covers more than 20 % of the annual electricity demand. During certain periods, renewable energy sources can provide more than 100 % of the demand in these countries/regions, and one can observe negative electricity prices. One example is shown in Figure 27.

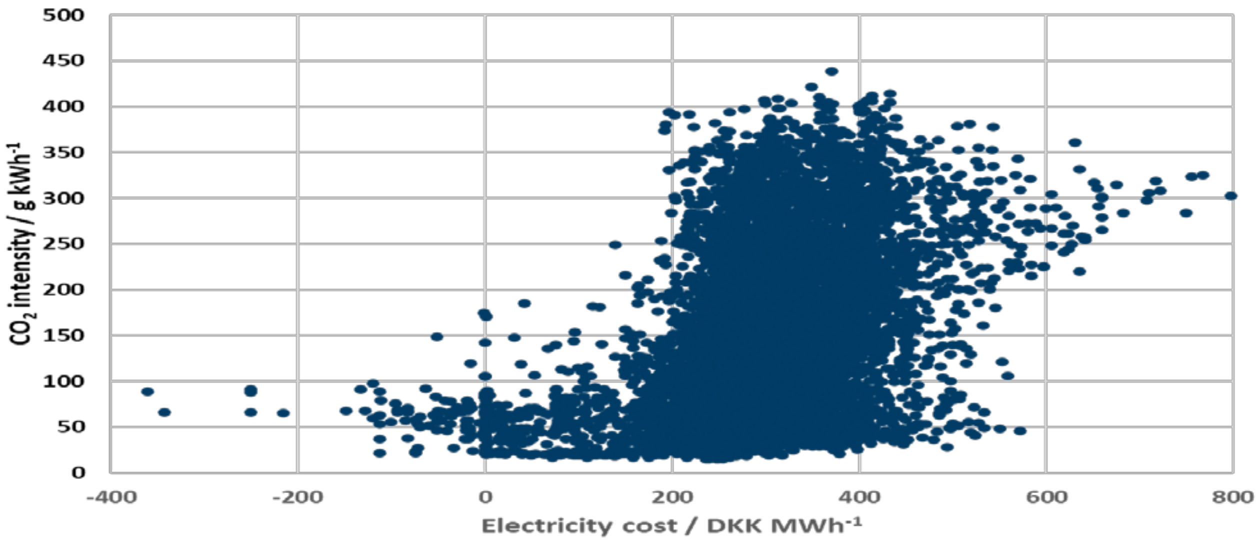


Figure 27. Electricity cost in Denmark during 2019, showing negative figures during windy periods. The diagram is plotted by SINTEF based on data from www.energinet.dk.

Additional energy storage in the power system can make the integration of variable renewable energy (VRE) much more efficient. Simulations of how this storage may be covered by hydrogen have been made by several entities, as shown in Figure 28[59].

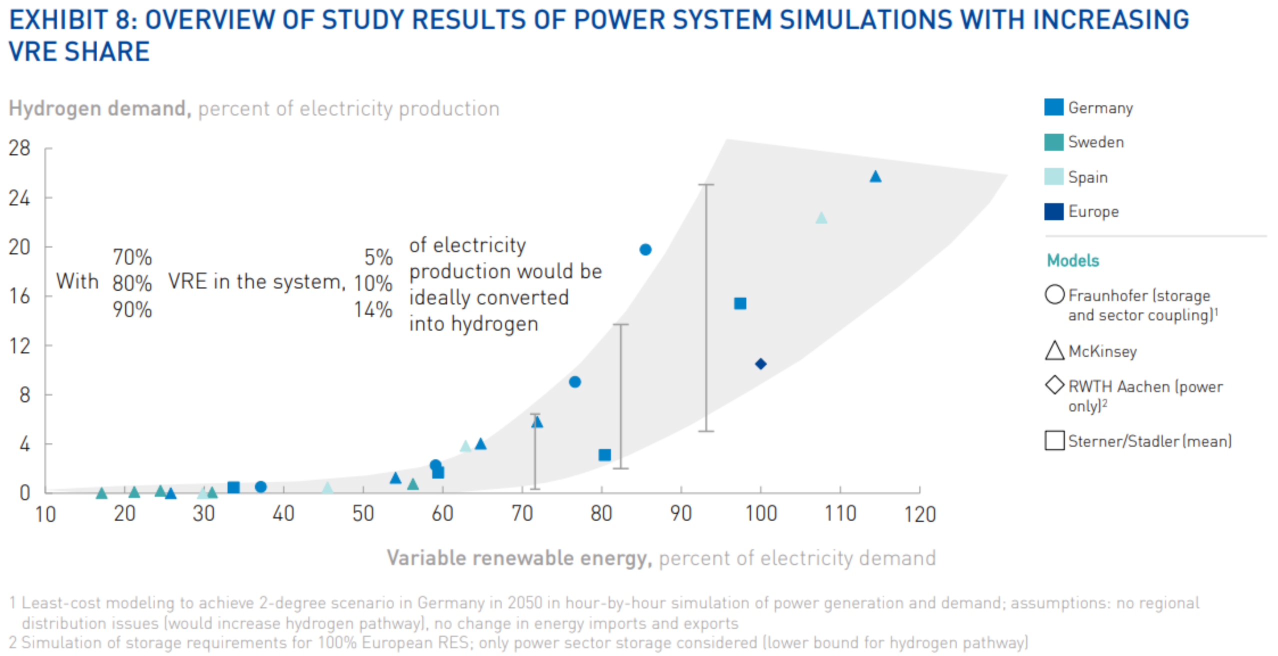


Figure 28.Simulations of how energy storage may be covered by hydrogen in Europe as the share of variable renewable energy (VRE) increases. Source: Hydrogen Roadmap for Europe[59].

4.4.1 International initiatives, industrial and political engagements on hydrogen

Internationally, industrial companies have since 2017 joined forces by establishing the *Hydrogen Council*[60], which is a global CEO-level advisory body providing long-term vision on the important role of hydrogen technologies toward in the energy transition. The Council currently has 81 member companies that works to increase visibility around the hydrogen solutions currently available, to advocate for the important role of hydrogen technologies in helping to meet climate goals, energy security and competitive targets and to provide recommendations to a number of key stakeholders on how to achieve their goals. International hydrogen strategies and roadmaps have recently been reviewed by CRC Future Fuels[61], showing a high and increasing focus on hydrogen as energy carrier globally.

In June 2019, IEA launched a report entitled *The future of hydrogen*[62]. In this report IEA's 7 key recommendations to scale up hydrogen are to:

1. Establish a role for hydrogen in long-term energy strategies.
2. Stimulate commercial demand for clean hydrogen.
3. Address investment risks of first-movers.
4. Support R&D to bring down costs.

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59 Hydrogen Roadmap for Europe, page 23 https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf
60 https://hydrogencouncil.com/en/
61 Advancing Hydrogen: Learning from 19 plans to advance hydrogen from across the globe, https://www.futurefuelscrc.com/blog/2019/07/new-report-shows-global-hydrogen-focus
62 The future of hydrogen - Seizing today's opportunities https://www.iea.org/publications/reports/thefutureofhydrogen/

5. Eliminate unnecessary regulatory barriers and harmonise standards.
6. Engage internationally and track progress.
7. Focus on four key opportunities to further increase momentum over the next decade.

At the request of the government of Japan under its G20 presidency, the International Energy Agency (IEA) has produced this landmark report to analyse the current state of play for hydrogen and to offer guidance on its future development. The G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth was arranged June 15-16, 2019 in Karuizawa, Japan. Japan's Government has, moreover, hosted two Hydrogen Energy Ministerial Meetings, during October 2018 and September 2019[63], respectively. The meetings gathered a high number of energy ministers from all over the world.

In July 2018, Mission Innovation[64] recognised the role of hydrogen by launching the 8th Innovation Challenge, on Renewable and Clean Hydrogen (IC#8). The pathway for the second phase of MI was laid out in February 2020[65]. Norway takes part in Mission Innovation, and IC#8 on hydrogen is one of the task forces, where the Norwegian Ministry of Petroleum and Energy, the Norwegian Hydrogen Forum and SINTEF are actively involved.

4.4.2 European policies and roadmaps on hydrogen

There has over the two last decades been an increasing focus on hydrogen in Europe and several policies, strategies and roadmaps have been established specifically on hydrogen the latest years. Under the European 7th Framework program, the first European public-private partnership (PPP) entitled Fuel Cells & Hydrogen Joint Undertaking (FCHJU) was established in 2008 and has since been continued under Horizon 2020.

In *The European Green Deal*[24], hydrogen is stated to be a key instrument for meeting the objectives of a climate neutral Europe, supplying clean, affordable and secure energy, and a clean and circular economy. Hydrogen can contribute to the objective of climate neutrality through smart sector integration, while contributing on the objective of energy supply through deployment of technology and infrastructure, such as hydrogen networks for green and blue hydrogen with CCS that can also enable sector integration. In the document, it is stated that *"Priority areas include clean hydrogen, fuel cells and other alternative fuels, energy storage, and carbon capture, storage and utilization".*

During the Stakeholders Forum for FCHJU in November 2019, Frans Timmermans, First Vice-President EC said during his opening speech: *"The green energy transition is not an option but a necessity. I see a pivotal role for clean hydrogen".*

The *Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition*[66] report published by Hydrogen Europe, lays out a pathway for the large-scale deployment of hydrogen and fuel cells until 2050 and quantifies the associated socio-economic impacts. Hydrogen Roadmap Europe concludes the following:

- Hydrogen is required to achieve the energy transition in Europe
- Hydrogen may close up to ~ 50 % of the gap towards a 2°C target
- Points at import of H_2 from regions with abundant wind energy
- Cost optimal de-carbonization solution include both water electrolysis and reforming of natural gas

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[63] HEMM2018: https://www.nedo.go.jp/english/ZZHY_00002.html, and HEMM2019: https://h2em2019.go.jp/en/
[64] http://mission-innovation.net/about-mi/overview/
[65] http://mission-innovation.net/2020/02/11/pathway-towards-the-second-phase-of-mission-innovation/
[66] https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

The Roadmap asks for immediate and concerted action to establish a masterplan for decarbonization for the European Union.

Among the bullet points above, the latter two are especially of importance for Norway. With abundant unexploited wind resources, e.g., along the coast of Central Norway and in Finnmark, Norway has the potential to export renewable based hydrogen to Europe. Furthermore, the inherent scenarios carried out in this roadmap study, assessing a pure renewable energy sources and similarly a pure fossil-based hydrogen production, points at a combination of these being the most cost optimal de-carbonization solution for Europe. Hence, there may be ample room for Norwegian natural gas as source for large scale hydrogen production, given that the carbon dioxide is captured and stored in a suitable location.

The Hydrogen Strategy for North Germany[67] is the result of close cooperation of a number of Federal States and of comprehensive and constructive involvement of active players from the areas of business, research and administration. The Hydrogen Strategy for North Germany is a clear statement that the establishment of a hydrogen economy is politically wanted in North Germany, and that planning provides for this to happen based on certain guidelines.

At least 500 megawatts of electrolysis capacity for green hydrogen shall be installed in North Germany by 2025, and at least five gigawatts by 2030. There is already a large number of offshore wind farms in the constantly windy coastal waters and great potential for further expansion has been identified in this area. It is stated that thanks to the large number of annual operating hours of offshore wind turbines that may be combined with photovoltaics field facilities on the coast, conditions are particularly favourable here in the North for achieving a high level of utilisation for electrolysis units. This could result in lower production costs for green hydrogen.

4.4.3 Hydrogen's role and market demand in a European perspective

Europe has since 2003 had hydrogen on the strategic agenda, kicked off by the High-Level Group, which paved the road for establishing the hydrogen program Fuel Cells and Hydrogen Joint Undertaking (2008) as a satellite to the 7th Framework Program. The second phase of the program was launched 2014 under Horizon 2020. The corresponding budgets for the first and second phase where 670 M€ and 1330 M€, respectively. The Third phase is now under preparation, under the auspice of Hydrogen Europe, entitled Clean Hydrogen for Europe (https://hydrogeneurope.eu/), with a tentative budget of 2 600 M€ for the Horizon Europe timeframe (2021-2027).

The *Clean Hydrogen for Europe* EU public- private partnership build and expand the FCH 2 JU and focuses on the convictions that the hydrogen transition in the EU will require hydrogen at large scale and that hydrogen technologies and systems will play a key role in the EU's industrializing policy.

March 10th, 2020, the Commission published a communication entitled A New Industrial Strategy for Europe[68].
In this document, it is specifically stated that: *"Clean Hydrogen is a prime example of where this can have a real added value. It is disruptive in nature and requires stronger coordination across the value chain. In this spirit, the Commission will shortly propose to launch the new European Clean Hydrogen Alliance."*

67 https://fuelcellsworks.com/news/germany-northern-regions-launch-hydrogen-strategy/
68 https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf

4.4.4 Current market and estimates for future demand for hydrogen in Europe

Hydrogen has several areas of usage in industry, from chemical industry and petrochemical industries, as well as in electronics and glass manufacturing. The refining and chemical production industries represent the largest users of hydrogen, together accounting for 87% of the yearly 325 TWh EU hydrogen feedstock, as illustrated in Figure 29. This compares to an annual amount of around 9,8 Mtons. For comparison, the total hydrogen consumption in Europe was estimated in the CertifHy project[69] at 7 Mtons in 2013, based on figures from the Linde group.

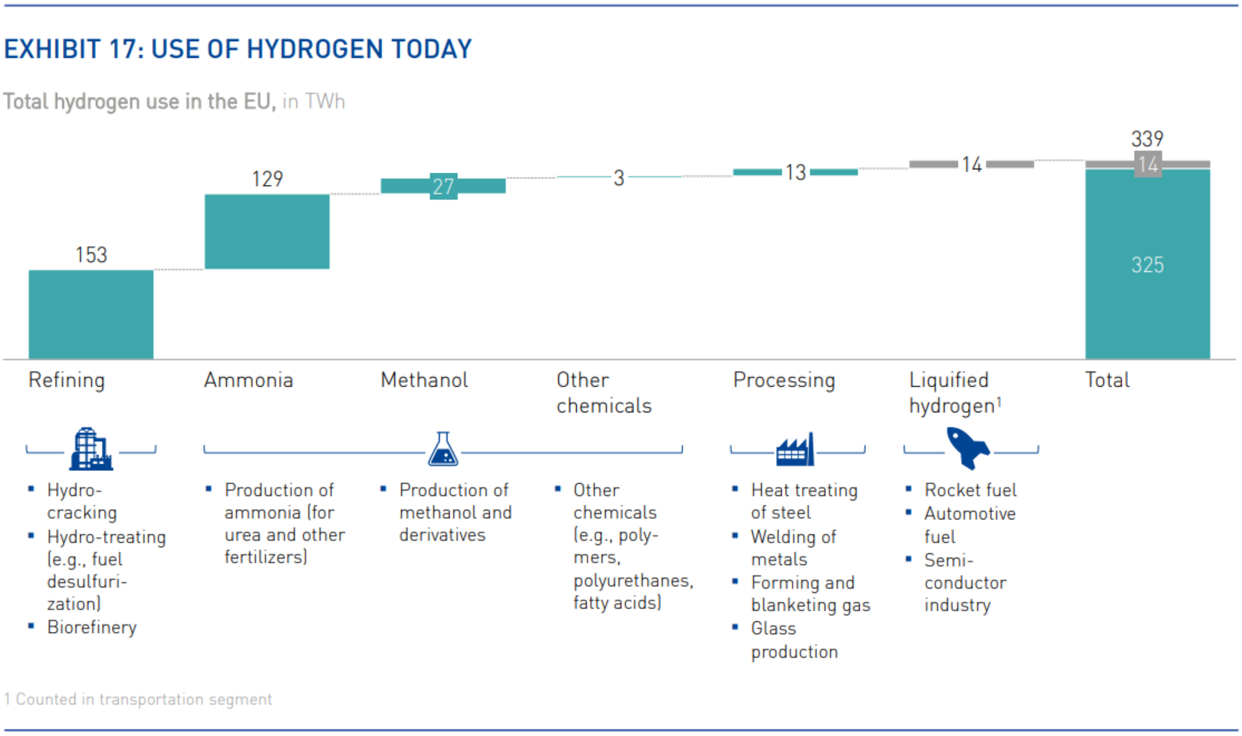


Figure 29. The use of hydrogen in Europe today in TWh, divided by sector. Source: Hydrogen Roadmap for Europe.[70]

According to Hydrogen council, their goal is that 12 % of the world's industrial energy demand will be covered by hydrogen in 2050, while for heating purposes this goal is 23 % of the higher heating value needs, 8 % medium-quality heating value needs, and 4 % of the lower heating value needs.

The demand for hydrogen to be expected in Europe, is estimated by the Hydrogen Roadmap Europe team[71] and shown in Figure 30.

69 http://www.certifhy.eu/images/D1_2_Overview_of_the_market_segmentation_Final_22_June_low-res.pdf

70 Hydrogen Roadmap for Europe, p.40. Calculated based on lower heating value (LHV) for hydrogen (33.3 kWh/kg), https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf.

71 Hydrogen Roadmap Europe, p.49, https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

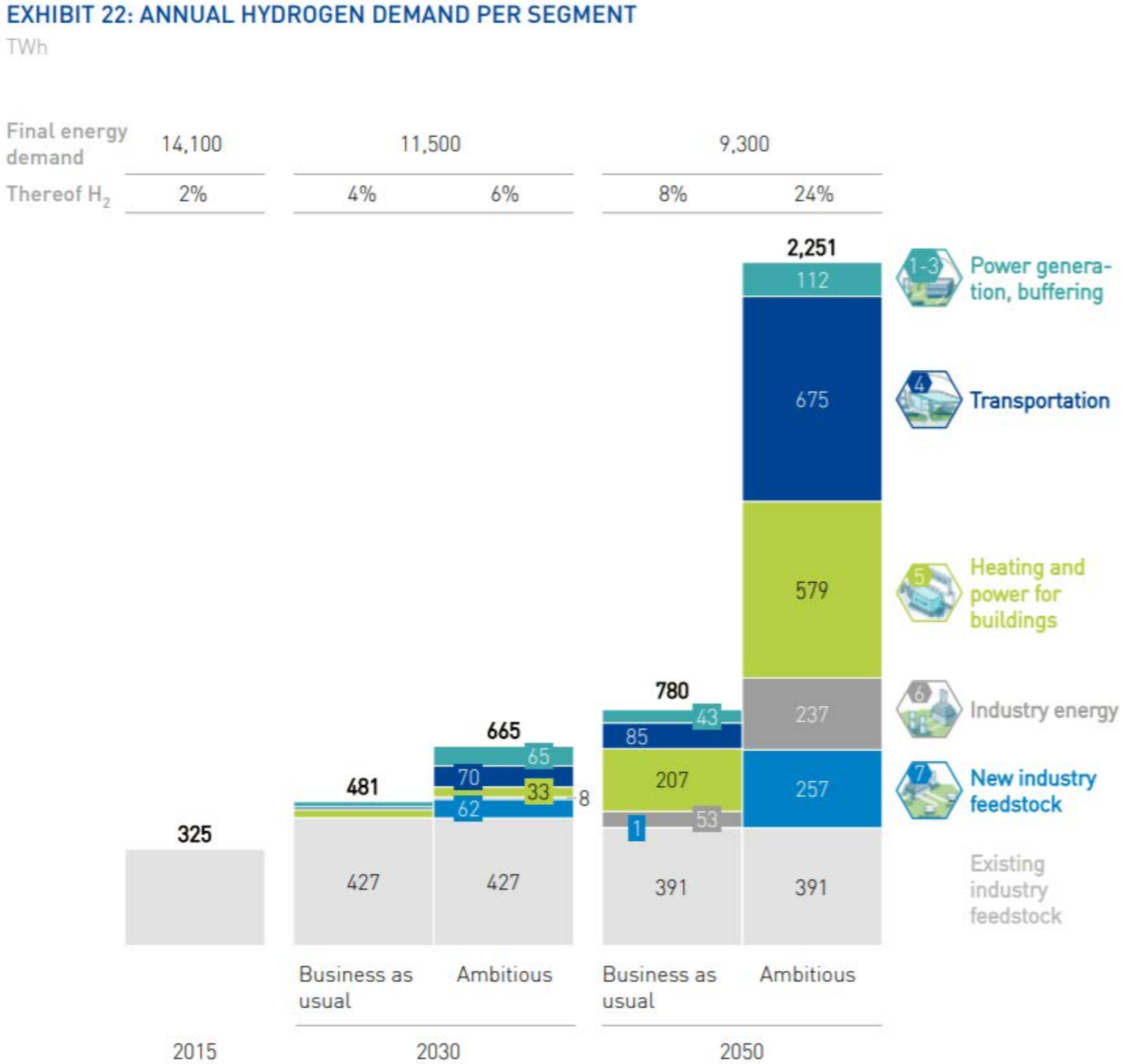


Figure 30: Estimated future volume of hydrogen in the European energy mix (in TWh). Source: Hydrogen Roadmap for Europe[72].

As can be seen from the Figure 30, the ambitious scenario outlines a European hydrogen demand of 665 TWh corresponding to 55 000 tons H_2/day in 2030, and 2571 TWh corresponding to 185 000 tons H_2/day in 2050[72]. Even in a business as usual scenario, the hydrogen demand is expected to double from 2020 to 2050 to 780 TWh, translating to 40 000 and 65 000 tonnes H_2/day in 2030 and 2050, respectively. For comparison, the Norwegian natural gas export is currently in the range of 1200 TWh, which is predominantly delivered to Europe covering 25-30 % of the European natural gas demand.

Given the European energy and climate strategies, the question is how much hydrogen will be produced internally in Europe, based on renewable energy sources, and how much hydrogen is it realistic to assume will be imported from other countries, including Norway.

[72] Hydrogen Roadmap for Europe, p.49. Calculated based on lower heating value (LHV) for hydrogen (33.3 kWh/kg), https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf.

In light of the growing curtailment of renewable energy in Europe, it is expected that hydrogen production will become an integral part of the European energy system, thereby increasing the utilization of renewable energy. Preparations for this is evident, as illustrated by the recent announcement of a joint plan[73] between BP and the German utility company RWE on installation of 100 MW electrolyser-based (green) hydrogen and a 130 km distribution network to be completed in 2022, to provide chemical and refinery clients with hydrogen. Similarly, Shell is partner in the SINTEF-coordinated Refhyne-project (https://refhyne.eu/) as described in Section 4.5.3, in which grid-based hydrogen is supplied to a refinery in Germany.

As can be seen from Figure 30, transportation is foreseen to consume a significant amount of hydrogen in 2050. For some modes of transportation, such as for small vehicles not requiring long driving ranges and fast charging times, battery will be the better choice of energy storage. For trucks, buses ships, trains, large vehicles however, hydrogen is, due to its higher energy density, the most promising zero-emission option for decarbonising the transportation sector since it can provide enough energy for long ranges and high payloads. Today, about 120 hydrogen stations are operated in Europe and several initiatives are announced or planned until 2025.

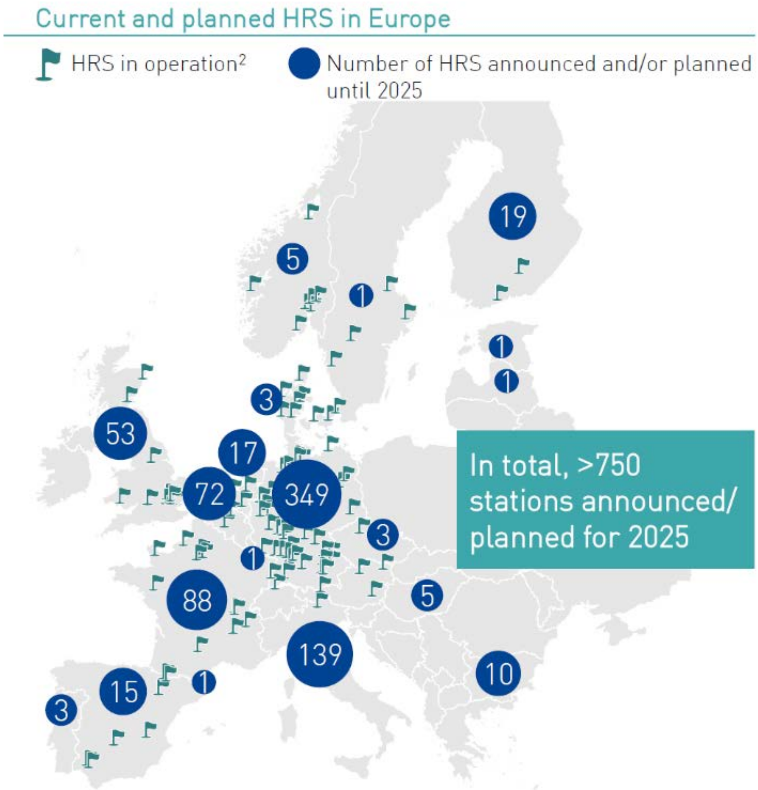


Figure 31. Current and planned Hydrogen Refuelling Stations (HRSs) in Europe in 2018. Source: Hydrogen Roadmap for Europe[74].

Very few hydrogen trucks and lorries are commercially available, although plans of large-scale deployment have been announced e.g. by Hyundai in Switzerland of about 1600 hydrogen-fuelled trucks. SINTEF is

[73] https://www.rechargenews.com/transition/bp-and-rwe-plan-germany-s-first-green-hydrogen-grid/2-1-775808
[74] Hydrogen Roadmap for Europe, p46, https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

closely involved with ASKO in the development and testing of 4 hydrogen-fuelled Scania-trucks. The first 27 tons delivery truck from Scania was launched January 20th 2020, and 3 more will soon be in operation. The Nicola Tre is now being developed in the US and Norwegian companies like Felleskjøpet are on the reservation list. Nicola has engaged in a close cooperation with Iveco for realizing their market ambitions in Europe.

Several leading actors in the maritime sector have started the race towards the best zero-emission solutions for a variety of ship segments:

- ***Car ferries*** (Fiskarstrand Yard, Norled/Statens Vegvesen)
- ***Cruise ships/Kystruten***, (Viking Cruises/Havyard)
- ***High speed passenger boats*** are also discussed as these are associated with high carbon footprint for each person km. In this segment, batteries are not delivering enough power output over long distances. Hydrogen propulsion is the only alternative and at least 5 different initiatives are under development. In addition is possibilities linked to aquaculture receiving increasing attention the latest years.

Hydrogen is also being adopted as fuel for trains. Train producer Alstom[75] has put in operation the world first passenger train operating on hydrogen in Germany. The hydrogen train has a range of approximately 1000 km. The Government of the U.K. has signed a deal with hydrogen train manufacturer Alstom S.A., which comprises replacement of 100 diesel engine vehicles with hydrogen trains, by 2022[76].

The Norwegian Parliament has decided to facilitate for testing of such trains also in Norway[77]. A SINTEF report from 2015[78] triggered this decision. In this report, SINTEF evaluated alternatives to conventional electrification with over-head lines (OHL) for freight trains and found that battery/hydrogen/hybrid solutions are the most cost efficient solutions. The most relevant rail service for these alternative zero-emission solutions is Nordlandsbanen with its length of 730 km. SINTEF has, moreover, concluded that implementation of hydrogen powered freight trains is foreseen to take place around 2025. The rational is that freight trains require 10 times more propulsion power (5 MW) compared to passenger trains, and, hence, there is still a need for fuel cell technology development and upscaling before commercialisation.

[75] https://www.alstom.com/press-releases-news/2020/3/alstoms-hydrogen-train-coradia-ilint-completes-successful-tests
[76] https://www.transparencymarketresearch.com/hydrogen-trains-market.html
[77] https://stortinget.no/nn/Saker-og-publikasjonar/Saker/Sak/?p=73545
[78] https://www.banenor.no/contentassets/24510efa7bb04f799e9b57961b3e4b9d/alternative-driftsformer-kunnskapsgrunnlag-sintef.pdf

4.5 Energy storage

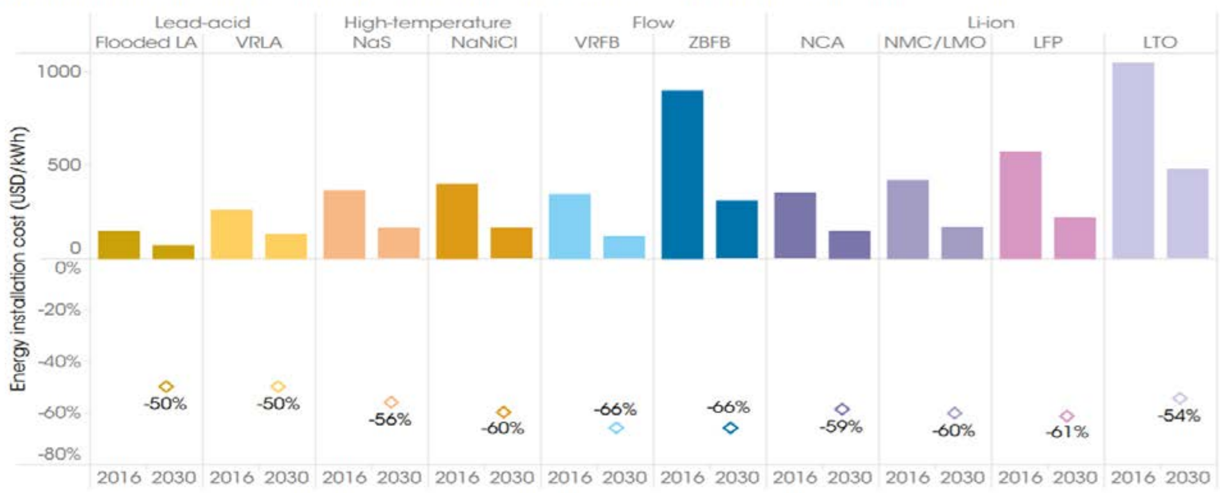
Large scale energy storage will become an integral part of the future energy system, given the intermittency of the renewable energy sources which will be massively implemented. There are many ways of storing energy. As this report focuses on energy export from Norway to Europe, we will limit the energy storage description to batteries and hydrogen, given that the potential for e.g., pumped hydro is very limited in Europe.

4.5.1 Batteries for energy storage towards 2030

Battery costs have decreased substantially in the last couple of decades. Although large decreases in costs have already been observed for battery storage, it is uncertain how the costs will develop in the future. Future developments in costs depend on several parameters that are specific for each battery chemistry, electro design (thickness, porosity), packaging (cylindrical, prismatic, pouch) and capacities. For lithium- ion batteries, 60% of the price of the battery results from raw material costs, mainly nickel and cobalt[4].

Given that materials cost constitutes a large part of the battery cost, no revolutionary price reductions can be expected. There are possibilities for the batteries to store more energy and the energy density for lithium-ion batteries has increased about 2.5 times over the last couple of decades through iterative materials improvements and improvements in manufacturing. It is however, challenging to make new materials for the same- or less cost. High- voltage cathode materials are trending. A higher content of Ni or Li in the cathodes is expected to provide increased battery current, but this also requires that other components are further developed, such as binding materials and electrolytes. During the last decade much focus has been towards development of cheaper and better (lithium) batteries for automotive use. Pack prices below $100/kWh before 2030 have been projected by e.g. Bloomberg New Energy Finances[5]. For stationary and other heavy-duty applications, the costs have been higher. The 2017 study on battery storage from the International Renewable Energy Agency (2017 IRENA study)[6] presents cost status from 2016 and outlook towards 2030. Through those years, an average decrease of around 50-60% is seen for a range of technologies. However, the 2030 costs remain well above $100/kWh for all relevant battery technologies, see figure below.

Figure ES6: Battery electricity storage system installed energy cost reduction potential, 2016-2030



Note: LA = lead-acid; VRLA = valve-regulated lead-acid; NaS = sodium sulphur; NaNiCl = sodium nickel chloride; VRFB = vanadium redox flow battery; ZBFB = zinc bromine flow battery; NCA = nickel cobalt aluminium; NMC/LMO = nickel manganese cobalt oxide/lithium manganese oxide; LFP = lithium iron phosphate; LTO = lithium titanate.

Figure 32: Energy installation costs central estimate for battery technologies, 2016 and 2030. Source: Irena report[79], page 18.

In addition to cost reductions, technology improvements were also reviewed in the IRENA study. Figure 56 shows projected increase in efficiencies for the same battery technologies, plotted with the decrease in energy installation costs. Most of these are estimated to improve their efficiency with around 10%. Cycle life is another important parameter. Although not represented here by a figure, the IRENA study expects cycle life for the same technologies to improve by between 50 to 100% from 2016 to 2030.

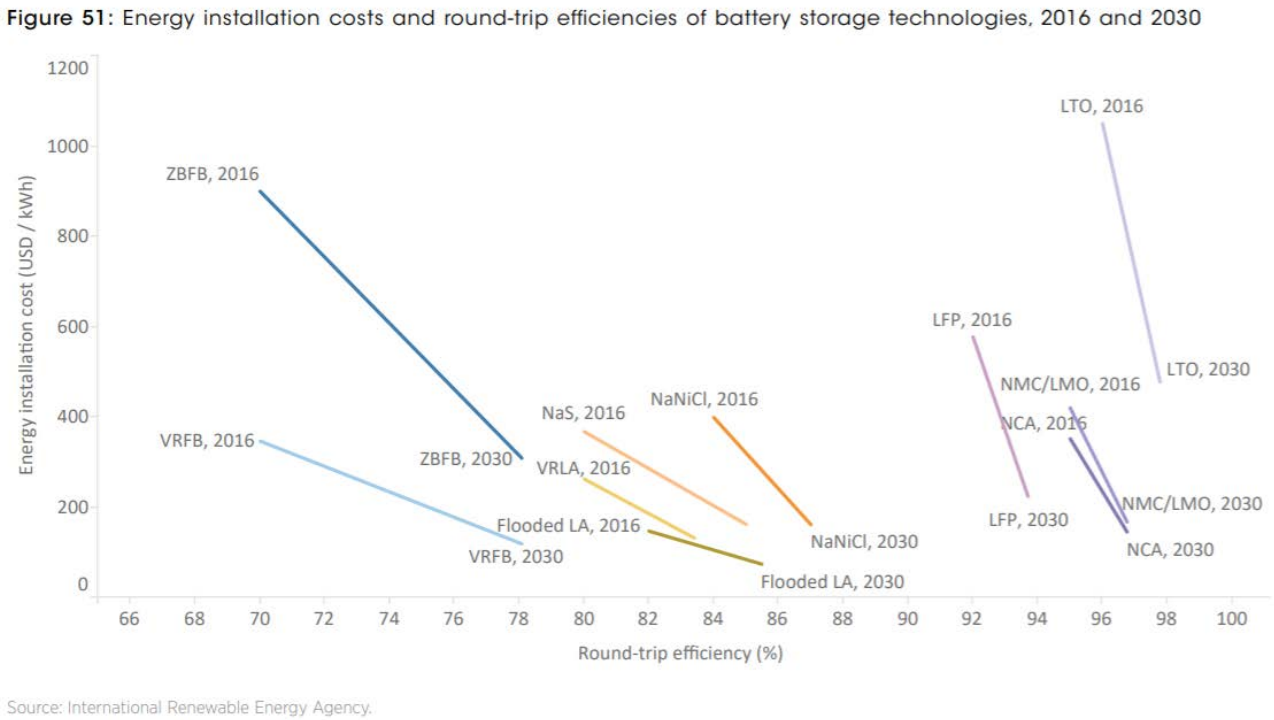


Figure 33: Energy installation costs and round-trip efficiencies estimate for battery technologies, 2016 and 2030. Source: Irena report[80], page 102.

4.5.2 Hydrogen and hydrogen carriers for energy storage towards 2030

Hydrogen is one of the options for storing energy from renewables, especially for storing large quantities of electricity over days, weeks or even months and seasons. Compared to battery-based energy storage, the overall efficiency is lower in a hydrogen storage system. There are losses in the fuel cell re-electrification, which must be added to electrolysis losses, summing up to about 60-70%. However, in addition to the energy storage function, hydrogen and hydrogen-based fuels can transport energy from renewable sources over long distances. Thus, hydrogen also offers the prospect of being a commodity that can be traded and used in different (industrial) sectors and applications. Nevertheless, the below text focusses on hydrogen as an energy storage medium.

The applicability of hydrogen as a flexible energy storage medium is to a high degree dependent on the:

[79] IRENA (2017), Electricity Storage and Renewables: Costs and Markets to 2030, page 18, https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

[80] IRENA (2017), Electricity Storage and Renewables: Costs and Markets to 2030, https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

- *amount of energy to be stored (kWh, MWh, GWh),*
- *geographic location, distance between production and end use,*
- *energy storage period (seconds, hours, days, weeks, months) and the*
- *intended final use of the stored energy (mobility, industry, heat, electricity).*

Moreover, alternative hydrogen carriers (only ammonia mentioned above) may be utilized, and hence their characteristic properties (e.g. conversion efficiency, energy density, cost) are of crucial importance.

Compressed hydrogen (CH2)
Electrolysers typically produce hydrogen at a relatively low pressure, from atmospheric up to around 60 bars. Low pressure storage solutions can be realised by using cheap steel tanks (up to 200 bars) or at even lower cost by welded steel tubes (typically 70 bars). Steel tanks are very durable and reliable, in addition to be a mature, off-the-shelf technology: they can be assumed to cost about €100/kg of stored hydrogen. This figure is however extrapolated for 200 bar tanks, and larger batteries for lower pressures may be even cheaper.

If compressed to higher pressures, hydrogen will typically be stored in composite storage tanks, e.g. from Hexagon or UMOE. Containerised tank solutions exist for pressures of 200, 350, 500 and 700 bars. A 20-foot container from Hexagon can store 320 kg of hydrogen at 250 bars. A 45-foot container from UMEO can store up to 825 kg at 350 bars. Operating costs depends on the compression work, meaning that low storage pressure normally leads to lower operating costs and visa versus. High pressure containers, being made from carbon fibre requires higher investments than steel containers.

Figure 34. Examples on different storage solutions for compressed hydrogen, Source: Siemens[81].

Salt caverns are also a possible option for large scale and long-term hydrogen storage. They are currently used for natural gas storage and provide significant economies of scale, high efficiency (the quantity of hydrogen injected divided by the quantity that can be extracted), low operational costs and low land costs. These characteristics mean that they are likely to be the lowest-cost option for hydrogen storage even though

[81] Claudia V. Massei (CEO), Siemens, Producing Green Hydrogen – An Insight from Siemens, Muscat, May 2nd 2018. https://www.ibesalliance.org/fileadmin/content/images/Oman_Solar_Forum/04_Producing_green_hydrogen_Siemens.pdf

hydrogen has low energy density compared to natural gas. Caglayan et al.[82], recently concluded that *"For the underground storage of chemical energy carriers such as hydrogen, salt caverns offer the most promising option owing to their low investment cost, high sealing potential…"*. Currently, the European Commission has launched a call for proposals[83], asking for *Cyclic testing of renewable hydrogen storage in a small salt cavern*.

Liquid hydrogen (LH2)

Hydrogen must be cooled to -253ºC (20ºK) to be converted to a liquid at atmospheric pressure. At 20 ºK it has a storage density of 71 kg / m3, which is significantly higher than that achieved with compression at ambient temperatures. The liquefaction process requires a significant amount of energy, e.g. some existing plants use from 12.0 kWh/kg (Linde Ingolstadt-plant) to 10.3 kWh/kg (Linde Leuna-plant). Liquid hydrogen has been produced in large volumes since the late 1950s and is commonly considered to be advantageous for transport of large amounts of hydrogen and for long distances. Currently, liquid hydrogen is gaining interest as energy carrier for export of renewable energy over long distances. For example, the pilot project in Japan where hydrogen will be shipped from Australia for the 2021 Olympics in Tokyo.

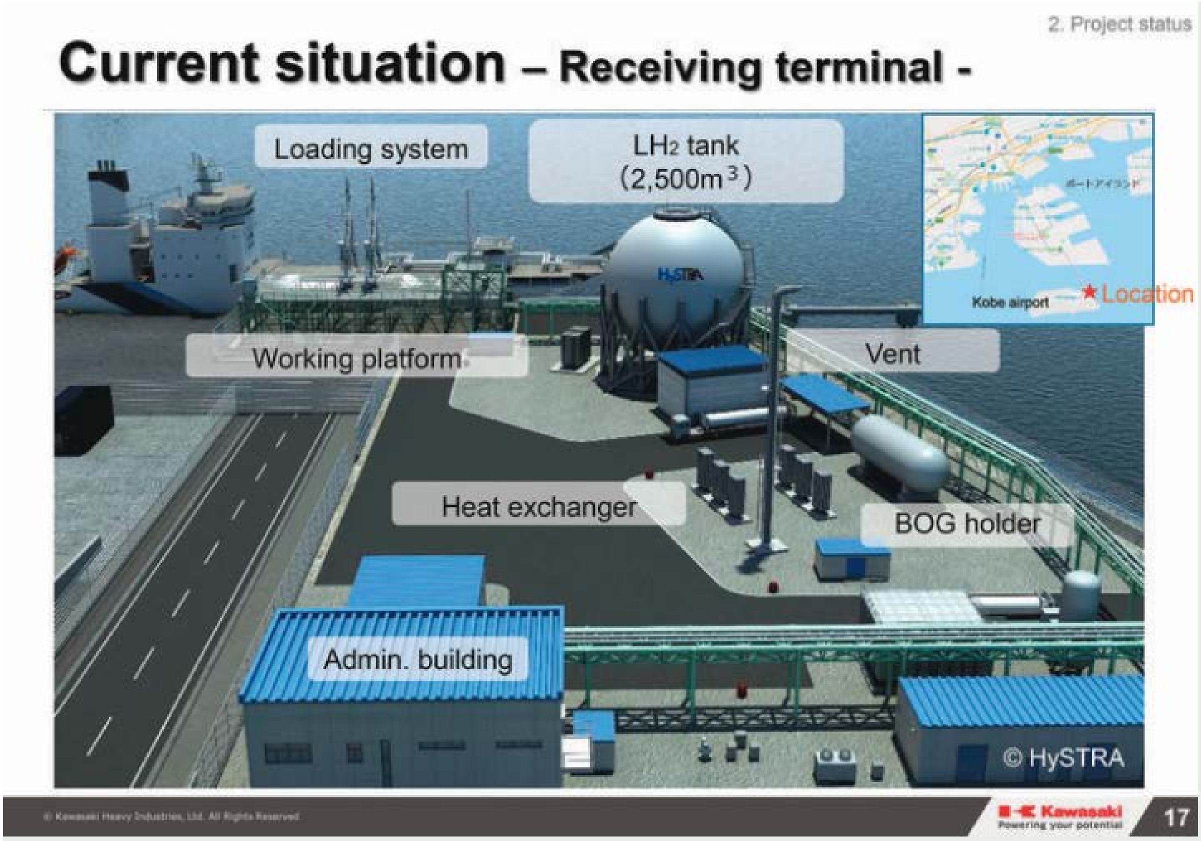


Figure 35. Liquefied hydrogen receiving terminal in Kobe, Japan, now being completed. Source: Arena Ocean Highway Cluster[84].

Ammonia (NH3)

[82] D.Caglayan et al., https://www.preprints.org/manuscript/201910.0187/v1

[83] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/fch-02-7-2020

[84] Arena Ocean Highway Cluster, Kobe March 2020. https://www.oceanhywaycluster.no/news/establishes-supply-chain-for-hydrogen-production-transportation-and-storage

Converting hydrogen to ammonia requires energy between 7% and 18% of the energy contained in the hydrogen, depending on the size and location of the system. A similar level of energy is lost when ammonia is reconverted back to high-purity hydrogen. Nevertheless, ammonia liquefies at -33°C, a much higher temperature than in the case of hydrogen, and it contains 1.7 times more hydrogen per cubic metre than liquefied hydrogen. While ammonia already is a well-established commodity, it is a toxic chemical and this may limit its use in certain locations.
Due to the energy losses in the conversion processes, the use of ammonia as energy storage in a re-electrification concept is likely not an economically viable alternative to e.g. compressed hydrogen storage.

4.5.3 Some relevant SINTEF activities

Wind power is typically available in remote location. At the Raggovidda wind farm in Varanger, a significant amount of wind resources is not being exploited due to weak grid conditions. During the EU Haeolus[85] project (coordinated by SINTEF) a 2,5 MW PEM electrolyser is being installed and demonstrated at the wind farm for hydrogen production. The wind farm has a production capacity of 45 MW, but the overall wind potential at the Varanger peninsula is estimated at 2 GW. The grid capacity is currently at 95 MW and to be increased to 145 MW, but concessions are already given for 320 MW wind power at Raggovidda and Hamnefjell wind parks. The stranded wind from such areas, where the number of full load hours is 50 % higher (4300 hours) than the average in Norway (34 %), the cost of electricity is lower and thereby providing for an attractive hydrogen production cost.

In a policy note prepared for Statkraft[86], SINTEF initially investigated the possibility of hydrogen produced from wind resources in Varanger could be the main source of zero-emission energy supply on Svalbard. It was concluded that compressed hydrogen or hydrogen bound in ammonia transported by ship to Svalbard is cost competitive with some of the low emission alternatives previously announced as the future energy supply on Svalbard.

The newly established Low Emission Research Centre[87] (SINTEF/NTNU) aims to develop new technologies and concepts for offshore energy systems, energy efficiency and integration with renewable power production technologies for application on the Norwegian Continental Shelf. With carbon-free fuels, such as hydrogen and/or hydrogen-nitrogen (N_2)-ammonia (NH_3) blends, gas turbines have the potential to achieve zero-emissions power and heat generation, through modifications of the combustion system. By applying fuel cells, chemical fuels such as natural gas or renewables (e.g. hydrogen/ammonia) to electricity through an electrochemical process. SOFC and PEMFC hold the most utility for offshore application.

[85] http://www.haeolus.eu/
[86] https://explained.statkraft.no/artikler/2018/energilosning-foreslar-fornybart-pa-svalbard/
[87] https://www.sintef.no/projectweb/lowemission/

4.6 Projects of common interest on CO_2 transport

Through its Projects of Common Interest (PCI) instrument, the European Commission funds initiatives within certain topics that have significant benefits for at least two member states in the EU. Several PCIs on CO_2 transport infrastructure exist, giving an indication of which transport routes might be available in Europe in the future. In this section, a brief description of relevant PCIs is given.

CO_2 SAPLING

The CO_2 SAPLING PCI covers the transportation infrastructure component of the Acorn full chain CCS project. It will use existing North Sea gas pipelines that are no longer required for petroleum use to transport and store CO_2 in the North Sea Basin. The St. Fergus terminal in Scotland will be the focal point of the infrastructure network, and initialisation of the project will be carried out here. Connections between the UK, Netherlands and Norway will be established through ship transport. An overview is given in Figure 36.

Figure 36: An overview of the CO_2 SAPLING PCI[88].

PORTHOS

The PORTHOS project[89] concept is based on a collective pipeline of approximately 30 km that runs through the port area in Rotterdam, The Netherlands. CO_2 from various industries in the area is collected in the pipeline. A slipstream of the CO_2 will be used for greenhouse forming in the province of South Holland, but the majority will be compressed and transported to a storage site in the North Sea, around 25 km from the coast. It is expected that it will be possible to store between 2 and 5 Mt CO_2/y by 2030.

CO_2 TransPorts

This project considers three main European ports: Rotterdam, Antwerp and the North Sea Port in Ghent. It will provide an "open access" CO_2 transportation service for capture sites at these ports[90], and serve as a platform for coordination between the port authorities. The project will be carried out in three stages. In Phase 1, focus will be on the development of CO_2 transport and storage infrastructure in Rotterdam, starting

[88] https://pale-blu.com/co2-sapling/. Visited 07.11.2019
[89] https://www.rotterdamccus.nl/en/
[90] https://ec.europa.eu/info/sites/info/files/detailed_information_regarding_the_candidate_projects_in_co2_network_0.pdf

in 2023. Phase 2 will build a pipeline network that connects the Antwerp and North Sea Port to Rotterdam and will start in 2026. From 2030, phase 3 will consider further expanding the CO_2 transport infrastructure beyond the 10 Mt/y that is considered in phase 1 and 2.

Ervia Cork CCUS
This full-chain project[91] considers the capture of CO_2 from a refinery and two gas-fired power plants in Ireland. It is envisaged that the country's well-developed natural gas pipeline network can be applied in a decarbonised future. Storage in depleted gas fields off Ireland's coast is considered, e.g. the Kinsale Head gas field 56 km from the mainland. If storage at this site is not viable, storage sites connected to other CCS projects can be used.

ATHOS
This project considers the development of a large-scale, open-access interoperable high-volume CO_2 transportation infrastructure from mainland Europe and Ireland to CO_2 storage locations in the Dutch section of the North Sea[90]. It is expected that the customers will mainly be large emitters from the Noordzekanaalgebied (NZKG) area.

Northern Lights
Northern Lights covers the transport and storage part of the Norwegian full-scale CCS project. Captured CO_2 from two sites will be transported by ship to a hub on the west coast of Norway, and subsequently transported via pipeline for permanent reservoir storage in the North Sea. The PCI includes eight different European countries. The storage location is "open source" and has a larger capacity than what is required by the Norwegian sources, meaning that third parties also can connect to the storage location in the future.

4.7 Status of CO_2 capture technologies

The production of low emission hydrogen from natural gas requires the implementation of CO_2 capture and storage (CCS). Therefore, the development of CO_2 capture technologies is highly relevant for scenarios for clean energy export from Norway to Europe.

In Bui et al. (2018), a comprehensive overview of the status of and envisaged way forward for CCS is provided. Globally, there are 17 large-scale CCS projects in operation today. Over 50% of these facilities are located in the USA. Two capture technologies are identified as commercial (i.e. TRL 9); post-combustion capture with amine solvents at power plants and pre-combustion processing of natural gas. Six capture technologies are at "Demonstration" level (TRL 7); polymeric membranes in natural gas industry, pre-combustion capture in integrated gasification combined cycle (IGCC) plants, oxy-combustion at coal power plants, post-combustion capture with adsorption, bio-energy with CCS (BECCS) in industry and direct air capture. Additionally, four capture technologies were found to be at TRL 6, i.e. pilot plant scale. This includes polymeric membranes at power plants, post-combustion biphasic solvents, chemical looping combustion (CLC) and calcium carbonate looping.

The high cost of CCS is often referred to as a main barrier for implementation. However, cost reductions are expected in the future. The first CCS projects will be more expensive than later ones, because investments in non-existing infrastructure for transport and storage of CO_2 must be made. Subsequent projects can utilize this infrastructure, and therefore achieve a lower cost. Estimates made by the CCS cost reduction task force (DECC, 2013) in the UK foresee that costs for CCS in the UK would be around £161/MWh for first mover projects. Costs could approach £100/MWh by the early 2020s and significantly below soon after.

[91] https://www.ervia.ie/business-development/carbon-capture-storage/

In a recent IEAGHG report (IEAGHG, 2019), an assessment of emerging CO_2 capture technologies for the *power sector* was given. Traditionally, 30 wt% MEA has been used as the benchmark technology for CO_2 capture, with a CO_2 avoided cost of 55.0 and 79.3 $/t CO_2 for an ultra-supercritical coal fired power plant and a natural gas combined cycle power plant, respectively. The report proposes a new benchmark solvent (40 wt% PZ/AMP blend) with CO_2 avoidance costs of 42.8 and 67.1 $/t CO_2.

In addition, the IEAGHG report provides predicted changes to levelized cost of electricity (LCOE) for a wide range of capture technologies. Electrochemical separation, i.e. CO_2 capture using fuel cells, was identified as the only technology with an anticipated reduction of LCOE greater than 30% compared to a standard CO_2 capture technology. The following post-combustion capture technologies were attributed a LCOE reduction potential of 10-30%: water-lean absorbents, precipitating solvents, membrane contactors, hybrid processes, pressure and temperature swing adsorption (and combinations of these), Ca looping and cooling and liquefaction.

5 Other market factors

5.1 Competition by renewables from the South: The Mediterranean Solar Plan and the Gulf Cooperation Council

Europe does not only depend on self-produced energy and imports from Norway, but also uses energy produced by other neighbouring countries in the East and increasingly also in the South. Norway therefore faces competition by other regions supplying energy to Europe. Relations between Europe and these countries are regulated through the European Neighbourhood Policy[92]. While energy trade is not explicitly mentioned in the core areas (good governance, democracy, rule of law and human rights; economic development for stabilisation; the security dimension and migration and mobility), it directly relates to 'economic development for stabilization', because of two reasons: First, oil and gas producing countries will be negatively affected in a future with cleaner energy and flanking measures need to be developed early. Second, especially the countries the MENA (Middle East and North Africa) region have vast supplies of solar energy, that can be exported to Europe, creating a source of income and supporting economic diversification. Clean energy imports from the South will support the European clean energy transition and, if large enough, cheap solar energy will compete with clean energy imports from Norway.

Morocco has a direct power link to Europe[93] and one of the world's largest solar power stations in Ouarzazate, funded by the European Investment Bank[94] within the Mediterranean Solar Plan project[95]. This project is co-financed by the EU's Neighbourhood Investment Facility in the context of the European Neighbourhood policy. Morocco is expected to become a net exporter of clean energy in the next decade.

Economic diversification and progress toward the Sustainability Development Goals (SDGs) are the main reasons for the Gulf Cooperation Council[96] to invest in and support the deployment of solar technologies for electricity and heat (cooling) energy. Prices of electricity generation from PV are on average lower than from fossil fuels and concentrated solar power (CSP) prices start becoming competitive. The deployment of wind technology has started, but is not yet large scale. The countries realized that in the clean energy transition,

[92] https://ec.europa.eu/neighbourhood-enlargement/neighbourhood/european-neighbourhood-policy_en
[93] https://www.ree.es/sites/default/files/downloadable/remo.pdf
[94] https://www.euneighbours.eu/en/south/stay-informed/news/morocco-european-investment-bank-funds-one-biggest-solar-power-complexes
[95] https://www.eib.org/en/publications/mediterranean-solar-plan-project-preparation-initiative.htm
[96] https://www.irena.org/publications/2019/Jan/Renewable-Energy-Market-Analysis-GCC-2019

their dependence on fossil fuels incomes induce a risk, and renewable energy technology deployment and maintenance provide high quality job generation opportunities.

5.2 Competition in the gas market: Russia and the USA

Following the Energy Unions diversification strategy, Europe has and will continue to import gas from other countries than Europe

Based on preliminary 2018 data, Russian gas exports to Europe had increased by nearly 30 per cent since 2014 (Pirani, 2018). Since then Russian gas exports have been curtailed and new pipelines threatened by a series of EU political and parliamentary initiatives and energy and competition proceedings, but these have not been sufficient to counteract the market forces which have drawn increasing Russian volumes into Europe (Yafimava, 2018). Gazprom projects that they could have a market share of 40 per cent or more by the 2030s (compared with 34 per cent in 2017) (Henderson & Sharples, 2018).

In the last few years, import of LNG from the USA to the EU has drastically increased. Following the meeting between U.S. President Donald Trump and former President of the EU Commission Jean-Claude Juncker in July 2018, the import has increased by 593%[97]. The trend is shown in Figure 37. The U.S. is increasing its gas production and expanding its LNG export infrastructure. Simultaneously, the domestic gas production in the EU is rapidly decreasing, giving a larger dependence on imports. The infrastructure for LNG import in the EU has available capacity (the utilisation rate until November 2019 was around 50%) and additional terminals are under development. Since 2018, more than 8 billion cubic meters per year has been contracted by European and US companies, implying that the import of U.S. LNG can continue to increase.

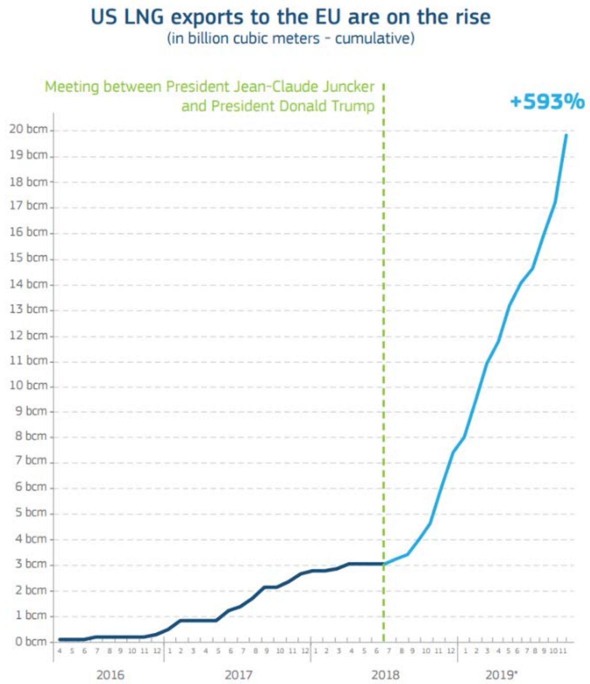


Figure 37: Cumulative LNG export from the U.S. to the EU from 2016 to November 2019. Source: European Commission

[97] https://ec.europa.eu/energy/sites/ener/files/eu-us_lng_trade_folder.pdf visited 04.02.2020

5.3 New markets: Data centres and data transmission networks

In 2018, the global demand for electricity by data centres was about 260TWh, about 1% of global electricity demand[98]. While from 2015 to 2021 both internet traffic and data centre workloads are expected to increase by factors five and three, respectively, the energy use of data centres remains approximately constant. This is due to significant energy efficiency increases. An example is mobile telecommunication technologies, where 4G has the potential to be 50 times more energy efficient than 2G. However, given the expected increase in ICT services and use, if only moderate efficiency improvements are reached, energy demand can increase 15-fold, to an approximated 8% share of global electricity demand in 2030[99]. In addition, data centres have cooling needs, such that the Nordic countries have excellent prerequisites to host such centres. Facebook for example has centres in Sweden and Denmark[100]. According to Innovasjon Norge[101], the number of data centres in Norway is currently increasing significantly, with 12 being reported to be under construction in March 2020. Currently, 8 centres are in operation.

Energy use by data centres in Norway would not count as exports of energy directly as the energy is consumed within Norway. But, the export of ICT services is directly enabled by the abundance of cheap clean energy, so that the potential is significant. In addition, the excess heat could be used in the proximity of the data centres if those are built in locations with heat demand, e.g. larger residential areas such as towns or cities.

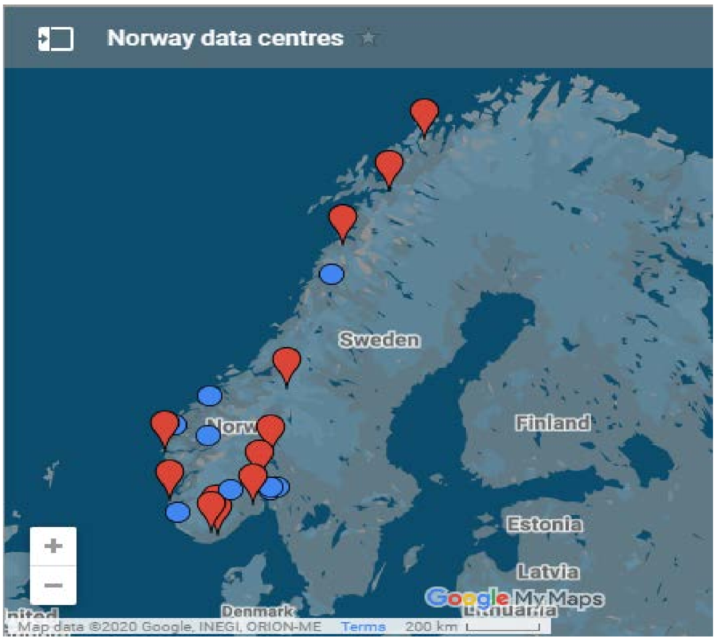


Figure 38: Data Center sites in Norway in operation (blue) and under construction (red). Source: Innovasjon Norge

[98] https://www.iea.org/reports/tracking-buildings/data-centres-and-data-transmission-networks & https://www.iea.org/reports/world-energy-outlook-2019/electricity
[99] https://www.nature.com/articles/d41586-018-06610-y
[100] https://www.theverge.com/2016/9/29/13103982/facebook-arctic-data-center-sweden-photos & https://www.facebook.com/OdenseDataCenter/posts/facebooks-newest-nordic-renewable-energy-solutionwe-are-excited-to-announce-that/1618163611638859/
[101] https://www.innovasjonnorge.no/en/start-page/invest-in-norway/industries/green-it/data-centre-sites/

6 Discussion: using this information for generating scenarios for the main project[102]

"*The energy world is marked by a series of deep disparities. The gap between the promise of energy for all and the fact that almost one billion people still do not have access to electricity. The gap between the latest scientific evidence highlighting the need for evermore rapid cuts in global greenhouse gas emissions and the data showing that energy related emissions hit another historic high in 2018. The gap between expectations of fast, renewables-driven energy transitions and the reality of today's energy systems in which reliance on fossil fuels remains stubbornly high. And the gap between the calm in well supplied oil markets and the lingering unease over geopolitical tensions and uncertainties.*"

IEA WEO (2019, p.23)

Forecasting energy demand involves a lot of uncertainties. However, the large trends of population decline, continuous improvements in energy efficiency and relatively low economic growth result in the unanimous projection of declining energy demand in Europe over the next decades. Expectations about the energy mix vary substantially depending on climate ambitions, but are relatively equal across different projection efforts. While there is still a multitude of different theories and models when it comes to economic growth, it seems that for energy demand projections, most rely on the efforts of a few. The developments in demand by energy carrier is generally not endogenous to the models, but can be directly traced back to the exogenous policy assumptions. This is in the very nature of the scenario set-ups, where different policy options are modelled to achieve certain climate targets. The IEA technology perspective scenarios take a slightly different approach building upon what is technically feasible and come to much lower emission reductions than for example integrated assessment models.

While all scenarios reviewed here are available for the entire EU and differentiate between broad economic sectors and energy carriers, they do not acknowledge country differences. These differences become important, especially when the big trends outlined in these scenarios will be used together with the detailed energy systems models with high geographical and time resolution (see WP 2 report). The demand side of energy system models becomes ever more advanced, including for example price reactions. Differentiating price development is important to determine substitution effects between different energy carriers, but also need to be linked to the broader economic and structural development. Substitution effects between energy carriers and between energy and other production inputs may differ greatly across economic sectors. Costs for renewables and, thus, related energy prices continue to decrease, reinforcing uptake of renewable energy, which in turn might lead to energy prices decreases (through learning effects). This effect was, for example, clearly visible during the early stages of deployment of solar PV in Germany (Wiebe & Lutz, 2016). In addition, energy policies such as environmental taxes may determine innovative behaviour (Porter & van der Linde, 1995a) (Porter & van der Linde, 1995b). For Norway, however, a closer link to Europe and more ambitious climate policies around the world would increase electricity prices (NVE, 2019).

The importance of the structure of the economy, and, thus, structural change, for determining energy demand calls for whole-economy models with high industry resolution, such as models based on input-output tables (McCarthy, et al., 2018). Since these models are based on very different data, units for modelling (monetary versus physical), sector classification (broad economic sectors versus individual energy technologies), time periods (annual versus hourly), and geographical scales, linking them to energy systems models is challenging. Rather, the information that can be obtained from these models should serve as boundary conditions, determining bandwidth for possible development pathways.

One way to do so, is to include a variety of parameters as exogenous uncertainties into the scenario set-up, such as raw material prices development and expected temperature in addition to technology, population, and

[102] We would like to thank the participants of the Clean Export Workshop on March 4, 2020, for their input and comments.

GDP trends. The latter should be specified at a more detailed sectoral level. This results in a magnitude of industry specific development paths combined with different expectations about energy efficiency improvements, the use of new energy technologies such as hydrogen or CCS and other technological changes. Both the countries energy mix and GDP development can then be determined bottom-up (as the sum over industries). This in turn would also determine labour income, thus influencing household demand for energy services, electricity, heat and transport. To ensure consistency between changes in demand and production, these changes should be taken as such, but implemented in an input-output based model that consistently links final and intermediate demand, both domestic and international trade, to sectoral production. The modelling of investments into production capacities and infrastructure is very rough in most economy-wide models. We need to ensure that both investments in the energy transport infrastructure as well as investments in production capacities for the new technologies and investments in the use of new technologies are well reflected.

Uncertainties in economic and technology development need to be integrated into the modelling. Data for the uncertainty parameters can be informed by the scenarios following the concepts of decision making under deep uncertainty as e.g. used in the XLRM approach (Lempert, et al., 2003) (Kalra, et al., 2014), by selecting best/worst cases for robust optimization, or generated randomly using for example Monte Carlo simulations.

7 Conclusions

To fulfil the Paris Agreement, global greenhouse gas (GHG) emissions need to peak now (Figueres, et al., 2017) and be reduced to net-zero emissions the latest by 2050. In addition to increasing energy efficiency and other measures to lower the energy demand, a shift from fossil energy sources without emissions abatement is unavoidable. The demand for clean electricity will increase due to increased electrification of the heat and transport sector. Hydrogen can, as an energy carrier, enable decarbonization and increased deployment of renewable energy through sector coupling of transport, industry, buildings, as well as the power sector.

This transition affects Norway in two contrary ways: First, the Norwegian economy has been and still is relying on the export of fossil energy, currently contributing to more than 50 % of Norwegian goods exports[103] (see Figure 1). The largest markets are the European countries, with the EU importing around 90% of Norway's exports of oil and gas over the last decade. Hence, the EU's medium[104] and long-term[105] plans for the reduction in the use of fossil fuels could lead to a substantial reduction in Norway's export of fossil fuels, which will affect the Norwegian economy. Second, Norway can provide Europe with clean energy required for the long-term plans of the EU as illustrated on the title page of this report. This includes hydropower, which can also be used for balancing an increased incorporation of intermittent power sources in Europe and relatively large, untapped wind resources in Norway (Skar, et al., 2018). Furthermore, Norway has the potential to produce hydrogen with CCS from the abundant natural gas resources under the Norwegian continental shelf and through electrolysers utilizing stranded renewable energy sources. Hydrogen can furthermore be exported in the form of ammonia. Hence, the energy transition offers both challenges and opportunities to Norway's role as an energy export nation.

This report has provided an overview of the main policies, instruments and uncertainties that will influence the potential for clean energy export from Norway to Europe in the coming years. It covers climate policies and regulations, economic and societal trends, energy technologies and infrastructure for energy export, as well as other factors influencing competition. The challenge for energy scenario modelling is to bring

[103] 2167 TWh primary energy in 2018, 6.5 times the total Norwegian energy supply of 319 TWh in 2018: SSB: https://www.ssb.no/energi-og-industri/statistikker/energibalanse
[104] EU 2030 climate and energy framework: https://ec.europa.eu/clima/policies/strategies/2030_en
[105] EU 2050 long-term strategy: https://ec.europa.eu/clima/policies/strategies/2050_en

together energy decision-making and everyday processes as represented in detailed energy system models with the global long-term sustainability transition and uncertain energy policies.

Projections for energy demand are changing every year, the general trend slowly changing with updated population and GDP scenarios, but the expected energy mix mostly determined by policy choices, and not depending much on price and cost development. Hydrogen and CO_2-related technologies, while mentioned, are not introduced at large scale in the existing scenarios. Energy export infrastructure can become a bottleneck, if not enough capacity is installed, even though significant gas infrastructure already exists. Political will and acceptance by the local population are factors that need to be considered here as the recent discussion about the NorthConnect HVDC cable between Norway and Scotland has shown. In addition, linking infrastructure costs to energy production costs is necessary to give an overall picture of resulting energy prices for industry and households.

For informing short and long-term investment decisions for both energy infrastructure and energy production capacity, it is preferable to use forecasts instead of scenarios. However, scenarios help in understanding possible ways forward. They show pathways and their boundaries, thus giving bandwidths of possible and for probable developments. Investments today, will put the world on a lower or higher pathway, reinforcing current choices for the future. The problem of stranded assets is real (Mercure, et al., 2018), policy choices need to be transparent and credible (Rogge & Reichardt, 2016), to make investment decisions easier and their outcomes more reliable.

We should challenge existing scenarios, extending possible bandwidths and combinations of uncertainties as much as possible, especially with regard to the introduction of currently immature technologies (such as hydrogen or CO_2-technologies) at large scales, while considering market regulations to ensure that the scenarios are realistic. When doing all of this we need to continuously make certain to communicate modelling inputs and outcomes using comprehensive story lines.

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