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Norwegian Centre for Energy Transition Strategies

ENERGY DEMAND PROJECTIONS AND THE NTRANS TRANSITION PATHWAYS

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Summary

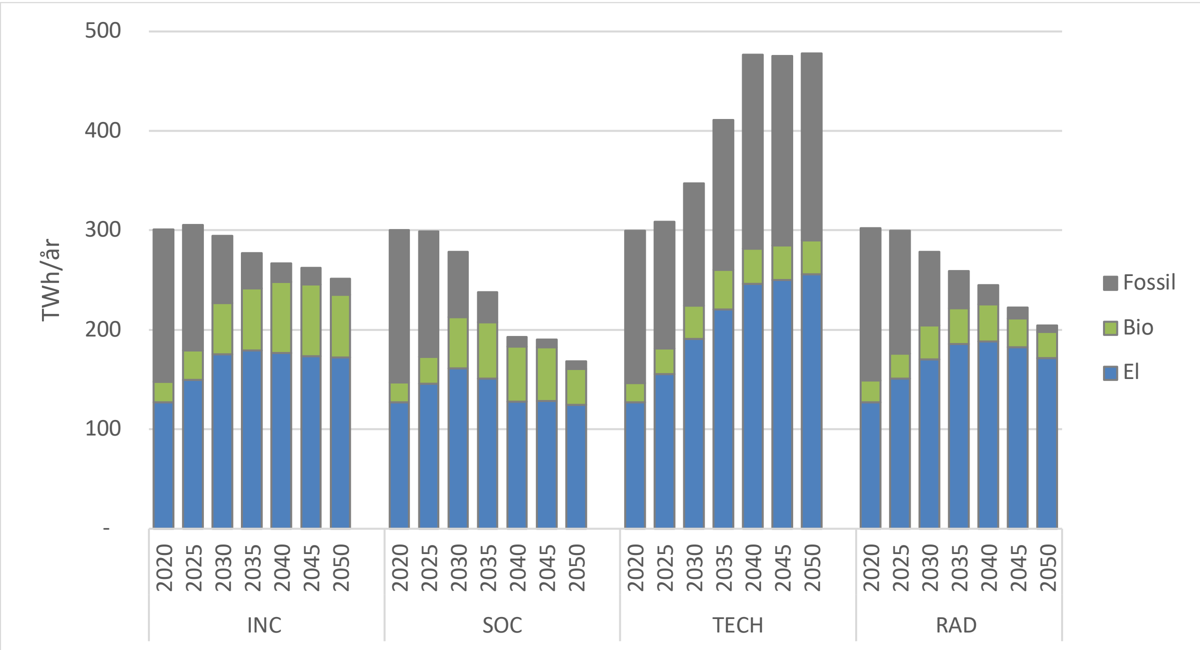
This report presents Norwegian energy demand projections towards 2050 for the end-use sectors industry, buildings, and transport. This report is a shorter version of the work conducted by Institute for Energy Technology (IFE) as a part of FME NTRANS (Norwegian Center for Energy Transition Strategies), documented in (Rosenberg et al., 2024). All assumptions behind the different demand projections of the Norwegian energy system towards 2050 can be found in the IFE-report, to ensure openness and transparency.

Different energy demand projections have been developed to capture the uncertainty of future energy service demand. The projections are aligned with the four NTRANS socio-technical scenarios (Espegren et al., 2023), but have been updated based on new knowledge and information. Moreover, this report includes a more thorough description of the future projections.

By using the energy system model IFE-TIMES-Norway, the energy use in the four NTRANS scenarios has been analysed. The report also includes results on the energy consumption of different bioenergy products, hydrogen and fossil fuels, as well as CO_2 emissions and electricity production, consumption and trade for the four scenarios.

The figure shows the total energy consumption divided by energy carriers in the four NTRANS scenarios. The consumption of electricity, bio and fossils ranges significantly between the four scenarios.

The consumption of electricity in 2050 ranges from 124 TWh in SOC (the Social change pathway), to 172 TWh in RAD (the Radical transformation pathway) and INC (the Incremental innovation pathway) and to 256 TWh in TECH (the Technological substitution pathway).



ENERGY CONSUMPTION BY ENERGY CARRIER (INCL. BLUE HYDROGEN FOR EXPORT) (TWH/YEAR)

Contents

1 Introduction and scope

The energy demand projection towards 2050 has been an IFE research activity under the framework of FME NTRANS (Norwegian Center for Energy Transition Strategies). NTRANS focuses on the role of the energy system in the decarbonization of sectors such as energy, transport, industry, and buildings, as well as our everyday lives. The energy demand projection is carried out as a user case in NTRANS. We have had useful discussions and received relevant inputs and comments from the user partners in the center during NTRANS workshops, meetings, summer gatherings and in the annual conference.

This report is an edited and shorter version of the work conducted by Institute for Energy Technology (IFE) and documented in (Rosenberg et al., 2024). All assumptions behind the different demand projections of the Norwegian energy system towards 2050 can be found in the IFE-report, to ensure openness and transparency.

In 2014, IFE developed an energy demand projection as an activity in FME CenSES (Rosenberg & Espegren, 2014). The main objective of the previous projection was to establish a reference energy demand projection that user partners and research partners in the center could use in their own analyses. As the previous demand projection is 10 years old, an updated demand projection was needed.

We have developed a base demand projection as well as alternative projections. The projections are made in accordance with the NTRANS socio-technical scenarios, and the demand development is specified in more detail to reflect the different pathways described in the scenario report (Espegren et al., 2023). The analyses' base year is 2020, and the analysed horizon is 2050. Our work has aimed to establish a systematic, transparent, and open approach to the energy demand development for Norway that can be used and further developed by the NTRANS partners. Our focus has been on establishing a new energy demand projection where the assumptions are presented open, and in detail.

We have explored the energy demand development in the NTRANS socio-technical transition pathways and how the sectors energy, transport, industry, and buildings can develop under different technological and societal change. These projections give insight in how the future energy demand can look like in the different low carbon transition pathways. It is a challenging task to anticipate how much energy, and which energy carriers, we will use in the future, thus this new demand projection can be used as a basis for new studies, e.g. when studying options for additional climate measures, or when including land use as a part of future analysis.

We have included a comparison of demand projections for Norway made by other organisations and actors. A review of the different demand projections shows that different actors have different purposes and use different assumptions, and that there is great uncertainty related to future energy demand.

Our aim is that governmental organizations, energy companies, policy makers and other stakeholders in the energy transition can use these demand projections as a common basis when discussing energy strategy, investment options and policy instruments in the low carbon transition.

2 Analyzing framework

2.1 Methodology

The methodology is based on the work done in 2014 in FME CenSES (Rosenberg & Espegren, 2014). In the first step, the energy service demands of residential, service, industry (including offshore), and transportation are calculated. We have used various approaches to calculate future demand for energy services across sectors, and the energy service demand vary depending on the sector-specific futures described in the four NTRANS scenarios.

In the second step, the energy system model IFE-TIMES-Norway (Haaskjold et al., 2024) is used to analyse the use of energy carriers in the four scenarios. All assumptions behind the different energy demand projections and the analysis of the energy system towards 2050 can be found in the IFE-report (Rosenberg et al., 2024).

FIGURE *1* presents a principal sketch of the modelling structure. Present and future ***energy service demand*** is calculated outside of the energy system model and used as an important input. In contrast, ***energy use*** by energy carriers, end-use sectors, and technologies are examples of model results.

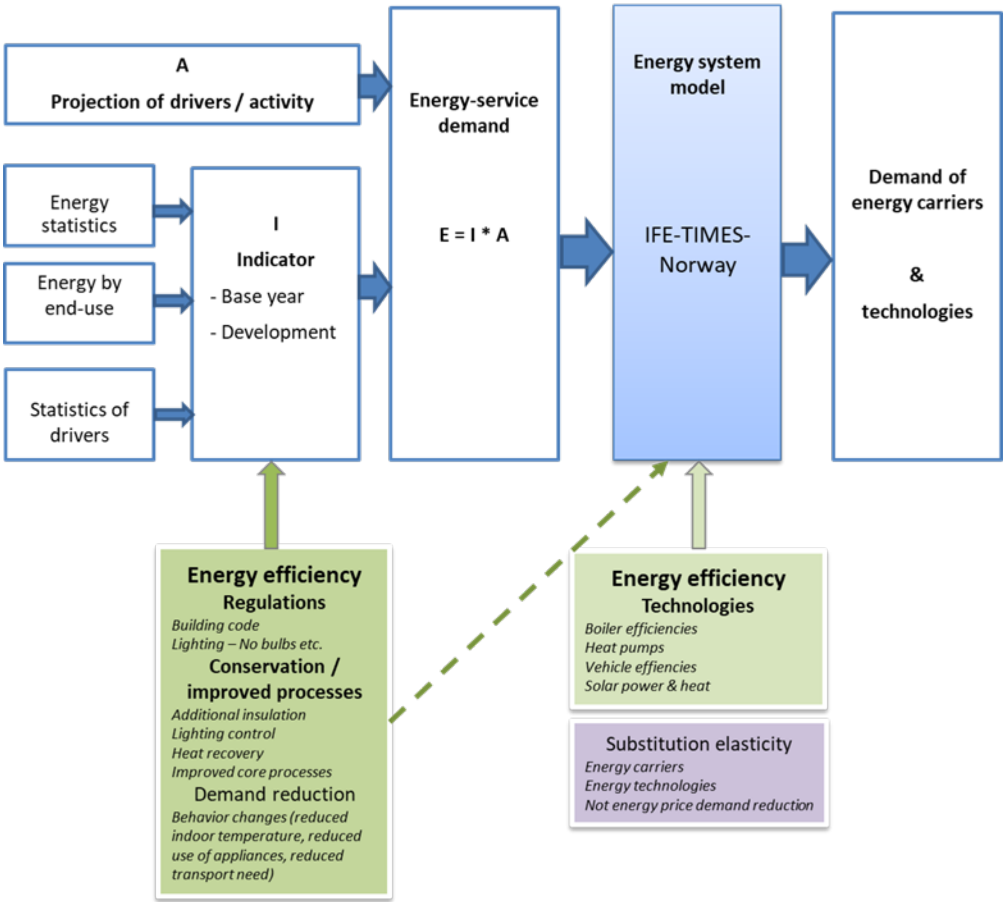


FIGURE 1: PRINCIPAL METHODOLOGY SKETCH (SOLID-DRAWN ARROWS ARE INCLUDED IN IFE-TIMES-NORWAY, DOTTED LINES SHOW POSSIBLE APPLICATIONS NOT INCLUDED IN THE PRESENT MODEL)

2.2 NTRANS scenario definition

Four energy transition pathways have been developed under the framework of FME NTRANS (Espegren et al., 2023). These socio-technical pathways are based on the degree of disruption to the existing socio-technical regime and its central actors and institutions. We distinguish varying degrees of depth of change in two dimensions: socio-institutional/system architectural (societal) and technological dimensions. We consider combinations of low and high changes, which result in four pathway types: incremental innovation, technological substitution, social change, and radical transformation.

The Incremental innovation pathway (INC) involves very limited discontinuity and changes in society and technology. The Technological substitution pathway (TECH) involves deploying new core technologies to fit incumbent actors' existing system architecture and capabilities as much as possible. The Social change pathway (SOC) involves major societal change associated with new system functionality and service characteristics with less change in sub-system core technologies. The Radical transformation pathway (RAD) comes with the highest degree of discontinuity. It reflects a transition pattern where society with its institutions are transformed to fit the properties of novel core and architectural technologies.

These socio-technical pathways are quantified in four scenarios and used in energy system analysis. The energy demand projections vary between the four scenarios, due to the different future development of society and technology. Societal change mainly impacts demand and central/local energy production. Scenarios with ***low*** societal change (TECH & INC) have a higher economic growth compared with scenarios with ***high*** societal change (SOC & RAD).

The future activity varies between the scenarios, with SOC having the lowest future demand, INC and RAD having a medium activity level, while TECH has the highest activity/demand level. The scenarios with ***high*** societal change focus on local solutions and well-being. A brief overview of how the quantification of costs, capacities, potentials and hurdle rate vary in the four scenarios are included in Figure 2.

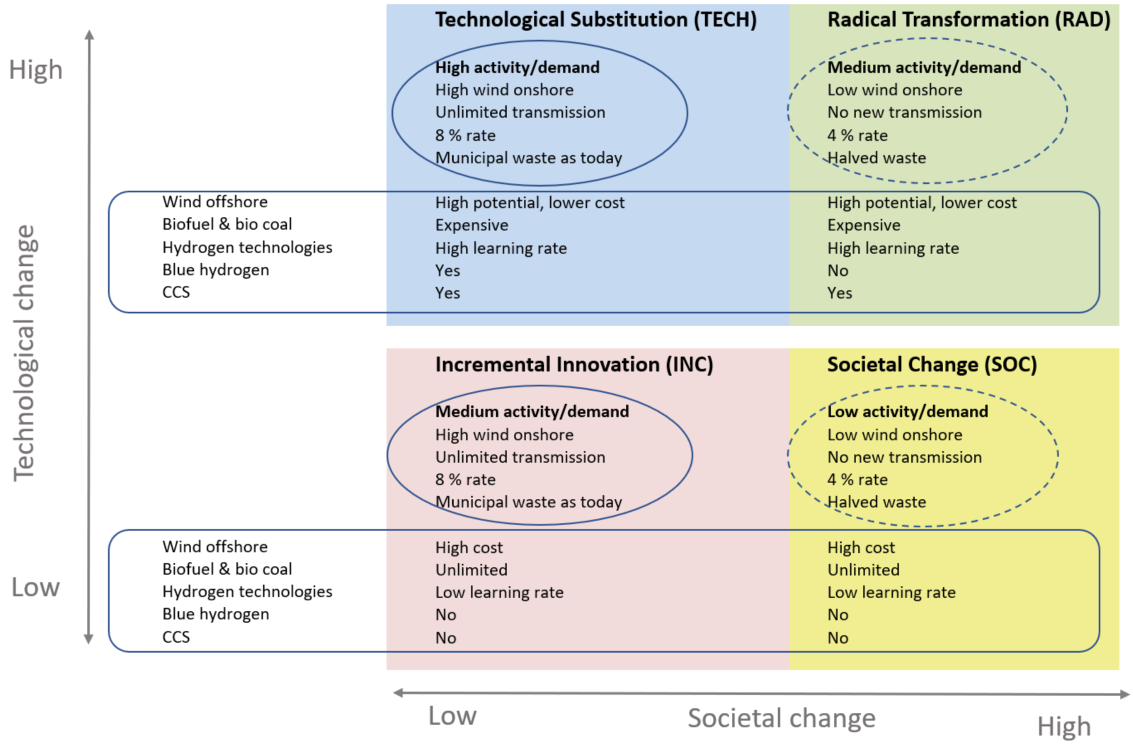


FIGURE 2: OVERVIEW OF QUANTIFICATION OF THE FOUR NTRANS SCENARIOS FOR USE IN ENERGY SYSTEM ANALYSIS

3 Projections of energy service demand

The most resource-demanding part of the work done is the development of new projections of energy service demand of the end-use sectors residential and commercial buildings, industry and transportation. To facilitate the reading of this report, only a summary is presented here. Readers interested in the background are encouraged to further reading of the detailed description in (Rosenberg et al., 2024). In addition, some details of the energy service demand projections are included in appendix A2 - A5. The projections are based on statistics, population projections, assumptions of future development and knowledge of energy use of different end-use demands, and all this information makes the description rather tedious to read, if the interest is mainly on the resulting use of different energy carriers, technologies used or CO_2 emissions.

The Norwegian population will increase from 5.368 mill. in 2020 to 6.034 mill. in 2050 according to the medium scenario in (Statistics Norway, 2022). In combination with different other assumptions (see Table 3), this gives an increased building area from 2020 to 2050 of 7% in single-family houses, of 42% in apartments and of 12% in commercial/non-residential buildings. The energy service demand is divided by end-use and is an important premise for analyses of future energy demand. It relies on several assumptions, since the statistics and knowledge are of higher uncertainty than e.g. building areas. More energy efficient new buildings, renovation of old ones as well as a higher share of apartments, contribute to a decrease in energy use. Our calculations give a decrease from 2020 to 2050 in energy service demand of 1.7% in dwellings and of 3% in commercial buildings. This base projection is used in NTRANS scenarios TECH and INC, while a lower energy service demand is calculated for RAD and SOC.

The methodology of demand projections of Norwegian industry is based on a bottom-up definition of plants, sub-sectors and regions of the present manufacturing industry and supplemented by knowledge and assumptions of new establishments. The future energy demand of the industry sector is largely uncertain but has a significant impact on the Norwegian power balance due to the large power demand and high ambitions of future activities. Our base assumption for the industry demand projection is that most existing plants continue operating at the same level as today and this projection is used in INC and RAD. A high activity projection is used in TECH, and a low activity projection is used in SOC. The energy demand of oil and gas extraction towards 2050 develops according to the planned decommissioning and new fields that have started or plan to start production after 2021. In 2050, the extraction activity is assumed to be about 70% of the level of today (Sokkeldirektoratet, 2024). The activity of onshore manufacturing industry from 2020 to 2050 increases by 27% in our base projection, doubles in the high projection and is reduced by 21% in the low projection.

For the transport sector, the demand projections carried out by the Institute of Transport Economics (TØI) in the context of the National Transport Plan (NTP) 2025-2036 is used as the main source of information. In addition to the NTP demand projections, an alternative demand - LOW alternative - is considered, which follows a case with low national growth in population and lower transport demand levels by 2050. Personal transport demand by car is expected to see the highest growth above the total average (around a 35% increase in 2060 relative to 2020). Road freight is estimated to have the highest growth by 2060, increasing by about 83% relative to 2020 levels. By 2060, rail and maritime freight transport are projected to increase by 42% and 38%, respectively, relative to 2020 levels.

The energy ***service*** demand projection for buildings, industry (only the electricity specific demand for industry, see analysis results for an absolute development) and transportation is presented in Table 1.

As demand for road transport is given in vehicle-km/year while all other demands are given in TWh/year it is not possible to summarize.

Table 1: Energy service demand in 2020, 2030 and 2050 in each of the NTRANS scenarios and in Base)

Sector	Buildings	Industry (el. specific)	Transport (Road)	Transport (Non-road)
Unit	TWh/year	El TWh/year	1000 million vehicle-km/year	TWh/year
		2020		
Base	83.0	54	44.8	26.7
		2030		
Base	82.8	63	51.5	28.5
INC	82.8	63	51.5	28.5
TECH	82.8	71	51.5	28.5
RAD	74.9	63	51.5	27.8
SOC	74.9	56	51.5	27.8
		2050		
Base	81.6	67	56.9	31.8
INC	81.6	67	56.9	31.8
TECH	81.6	93	56.9	31.8
RAD	55.4	67	45.8	25.0
SOC	55.4	43	45.8	25.0

4 Analysis assumptions

Most of the assumptions used in the analyses presented in this report are as documented in (Haaskjold et al., 2024). The project specific assumptions are presented below, together with some basic assumptions that are repeated here, to facilitate the understanding of the analyses (as presented in (Rosenberg et al., 2024).

CO_2

The Norwegian government published pathways for carbon taxes to be used in socioeconomic analyses in 2024 (Ministry of Finance, 2023). The main pathway increases linearly up to 2410 NOK/t CO_2 in 2030 and then is kept constant at this level until 2050. In addition to the main pathway, a low and a high tax pathway was also included. The medium tax pathway wasn't sufficient to obtain a low carbon society in our analysis and thus an adjusted medium pathway is used in the analyses presented here, where the trend until 2030 is prolonged until 2035, and thereafter kept constant, see Figure 3. The high CO_2 tax pathway is used in sensitivity analyses to illustrate the impact of higher CO_2 costs.

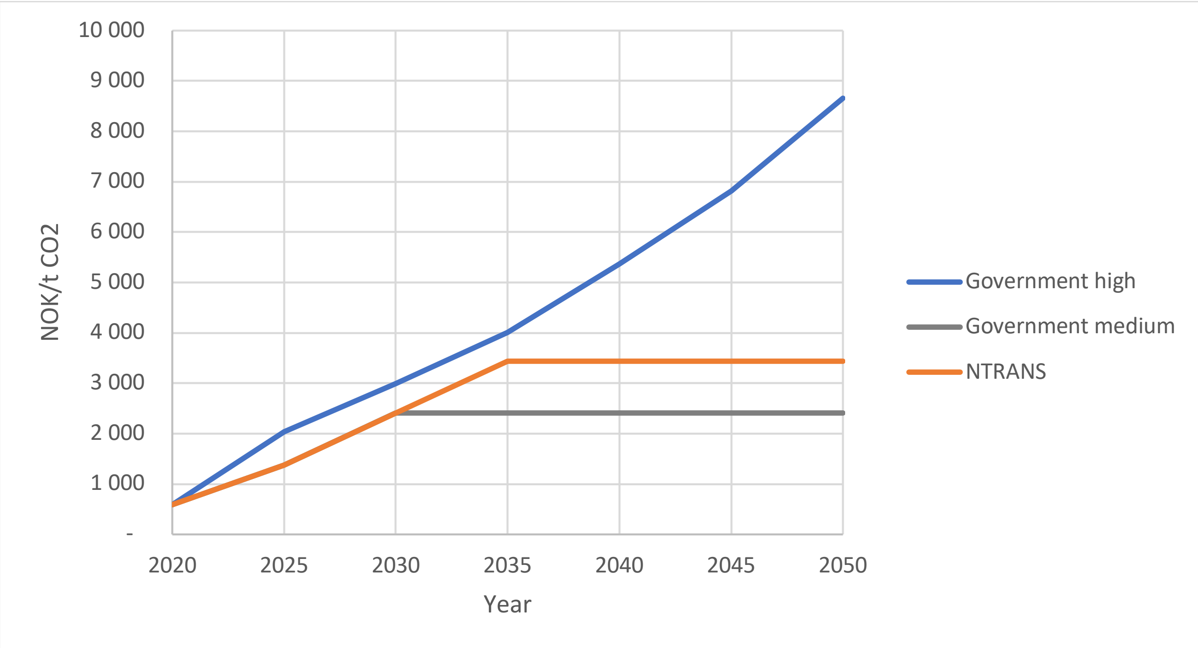


FIGURE 3: CO_2 TAXES IN THIS STUDY (NTRANS) AND THE MEDIUM AND HIGH PATHWAYS OF THE GOVERNMENT (NOK/T CO_2) (MINISTRY OF FINANCE, 2023)

Bio energy

Bio energy can be one of the solutions for a low-carbon economy, but it is also a limited resource. In TECH and RAD the total use of bioenergy-based energy carriers is limited to the annual sustainable bio energy resources in Norway. In INC and SOC, we assume that unlimited volumes of biofuel, biogas and bio coal is available and can be imported, see (Espegren et al., 2023) for more details.

Hurdle rate

A high degree of behaviour changes and citizen involvement is expected in SOC and RAD. This is modelled as a willingness to accept lower return on investment and thus a socio-economic rate of 4% is used for all investments. The more economic behaviour in TECH and INC is considered as a need for higher return on investments and a rate of 8% is applied for end-use investments in buildings, transportation, stationary batteries, electrolysers and building applied PV.

Power generation

In the SOC and RAD scenarios, new onshore wind power is restricted to already applied concessions, as well as reinvestments in existing plants. The total potential if reinvestments in all existing plants are made is 5 GW, corresponding to 15 TWh production. New potential for offshore wind is driven by the degree of technology change, with INC and SOC having limited potential of 12 GW by 2050. In these two scenarios, high cost of new development is assumed. Contrarily, TECH and RAD assume a high expansion potential for offshore wind by 2050 of up to 50 GW and 38 GW respectively, with lower cost of investment due to high technology learning. The expansion potential is based on the Norwegian target of 30 GW by 2040. In terms of new transmission grid development, INC and TECH assume high transnational interactions to support the green transition in Europe and allow for new value creation in Norway through increased exports.

Electricity trade

IFE-TIMES-Norway needs exogenous input of electricity prices for countries with transmission capacity to Norway. Electricity trade prices are typically project specific as these highly depend on the remaining assumptions of the study. In this study, two different price scenario files are used (High is used in INC and SOC and Medium in TECH and RAD). They are based on a bi-directional linking with the power marked model EMPIRE (Haaskjold & Pedrero, 2023; Haaskjold et al., 2024).

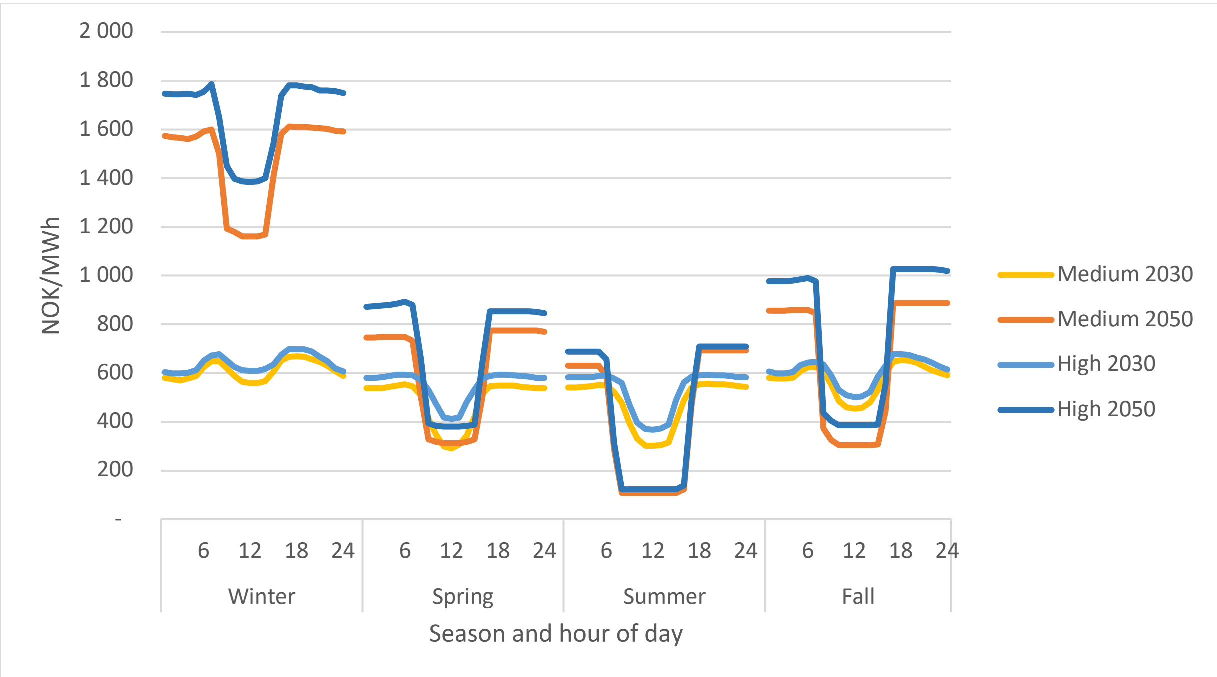


FIGURE 4 ELECTRICITY PRICES FOR EXPORT TO GERMANY IN THE TWO PRICE SCENARIOS IN 2030 AND IN 2050 (HAASKJOLD ET AL., 2024)

5 Energy system analysis

The energy service demand is input to the energy system model IFE-TIMES-Norway. This model is described in detail in (Haaskjold et al., 2024). This chapter presents the corresponding energy system analysis aligned with the NTRANS-scenarios.

First, the energy consumption (total and divided by sector) is presented. Then, data for total use of different energy carriers (electricity, bioenergy, hydrogen, and ammonia) are presented. This is followed by results of electricity generation and trade. The model result on long-term marginal Norwegian electricity prices is discussed in this chapter. Finally, the CO_2 emissions and use of CCS and DACCS is presented.

5.1 Energy consumption and use of end-use technologies

5.1.1 Sum of end-use sectors

In total, the end-use sectors buildings, onshore industry, and transport decrease the use from 320 TWh in 2020 to 250 TWh in 2050 in INC, 170 TWh in SOC, 190 TWh in RAD, while it increases to 400 TWh in TECH, see Figure 5. The figure does not include the consumption of electricity to produce hydrogen or ammonia nor the use of biomass to produce biofuels, but only the energy content of the energy carrier used in each sector, and it don't include energy use offshore.

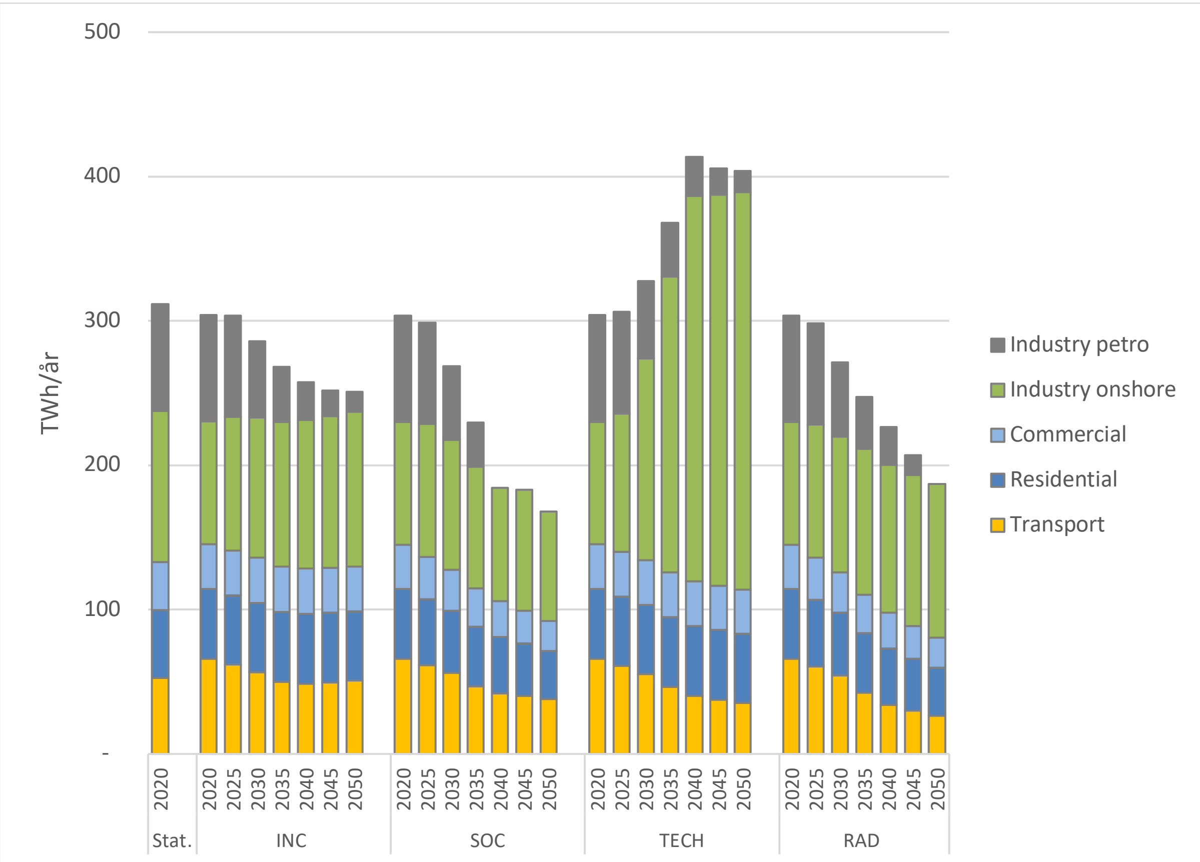


FIGURE 5: USE OF ENERGY IN ONSHORE INDUSTRY, PETROLEUM INDUSTRY, COMMERCIAL BUILDINGS AND RESIDENTIAL HOUSES AND IN TRANSPORT (TWH/YEAR)

5.1.2 Residential

The energy consumption in the residential sector remains constant from 2020 to 2050 in INC and TECH and is reduced from 48 TWh in 2020 to 33 TWh in 2050 in SOC and RAD (32% reduction), see Figure 6. Electricity is the main energy carrier in all years towards 2050, followed by biomass (mainly wood) and a small share of district heating (3-5 TWh/year).

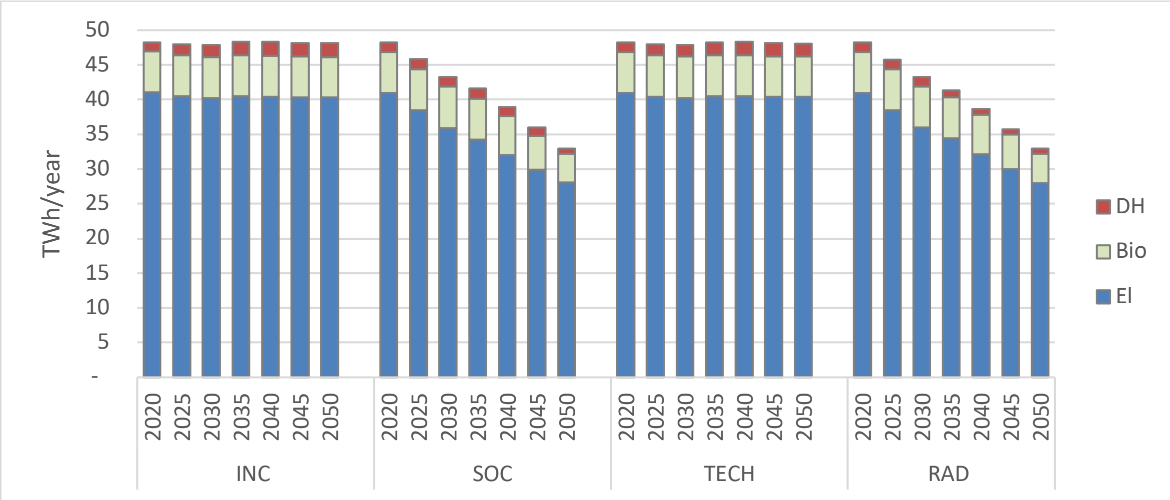


Figure 6: Energy consumption by carrier in residential houses (TWh/year); DH = District heating, Bio = bio energy, El = Electricity

The most used heating technology in all four scenarios is direct electric heating, but in SOC and RAD it is halved from 2020 to 2050, see Figure 7. Use of wood plays an important role in all scenarios. Different types of heat pumps have a share of about 25% in all the analysed years and scenarios. Use of district heat increases most in INC and TECH.

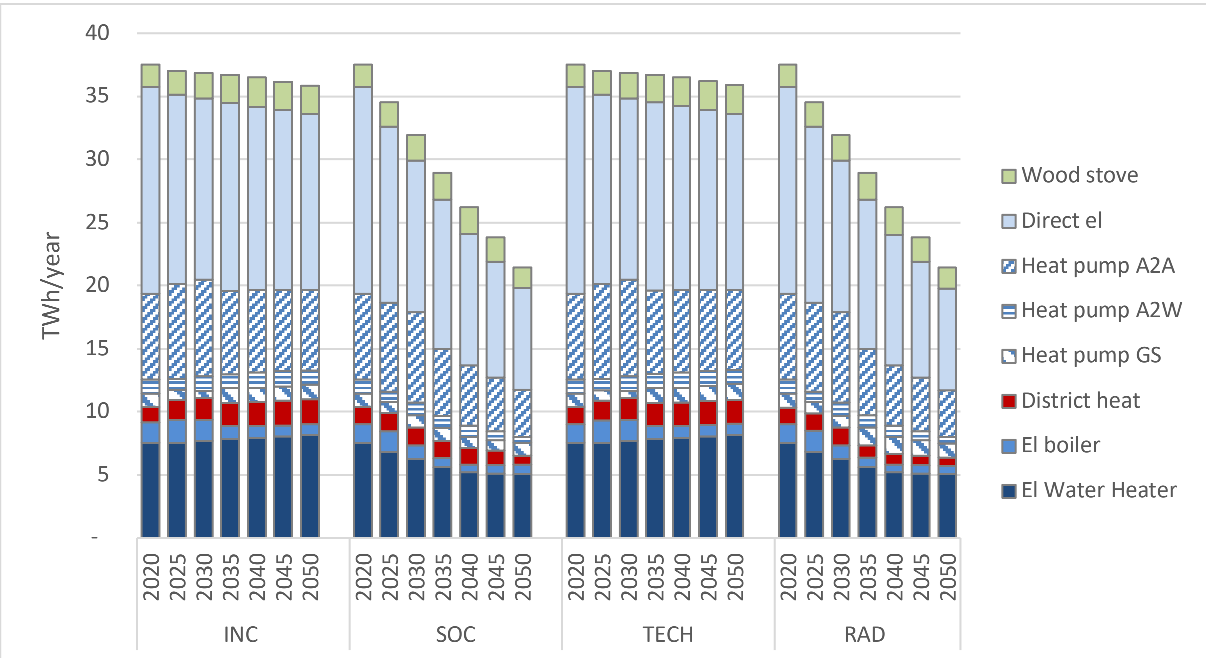


Figure 7: Heating technologies (delivered energy for space heating and water heater) in residential houses (TWh/year)

5.1.3 Service

Energy consumption in commercial buildings is about 31 TWh in 2020 and remains at this in INC and TECH for all years until 2050, while in SOC and RAD, the energy consumption decreases to 21 TWh (32% reduction), see Figure 8. In all years and scenarios, the energy carrier dominating in commercial buildings is electricity, but it decreases from 27 TWh in 2020 to 25 TWh in 2050 in INC and TECH and to 17.5 TWh in SOC and RAD.

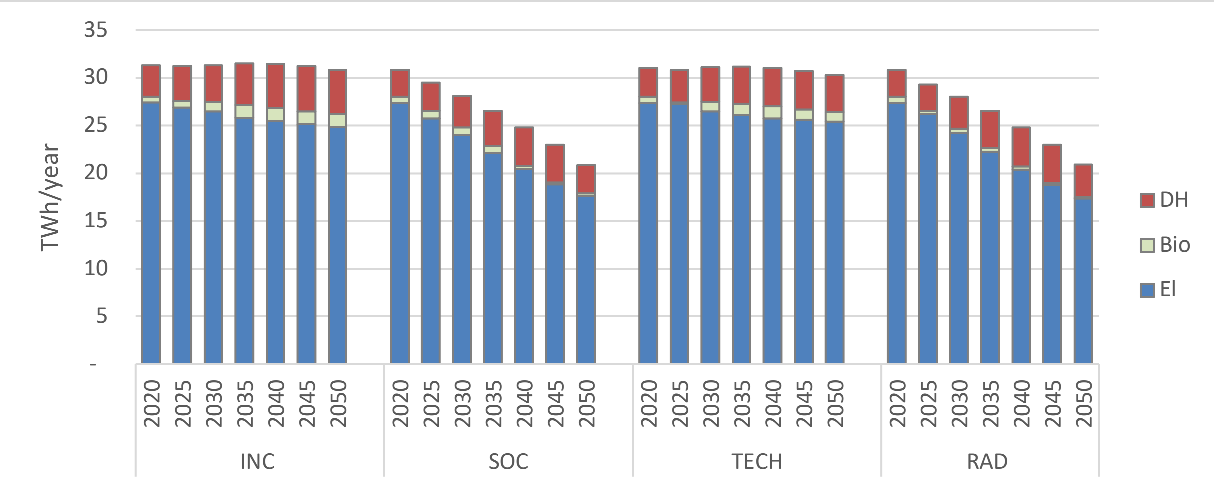


FIGURE 8: ENERGY CONSUMPTION BY CARRIER IN COMMERCIAL BUILDINGS (TWH/YEAR); DH = DISTRICT HEATING, BIO = BIO ENERGY, EL = ELECTRICITY

When it comes to heating technology used, electric heating (boilers, direct electricity, and heat pumps) is reduced in all scenarios, while the use of district heating increases. Biomass use is highest in INC and TECH but only reaches a maximum of 1.2 TWh, and it is small in SOC and RAD, less than 0.2 TWh in 2050.

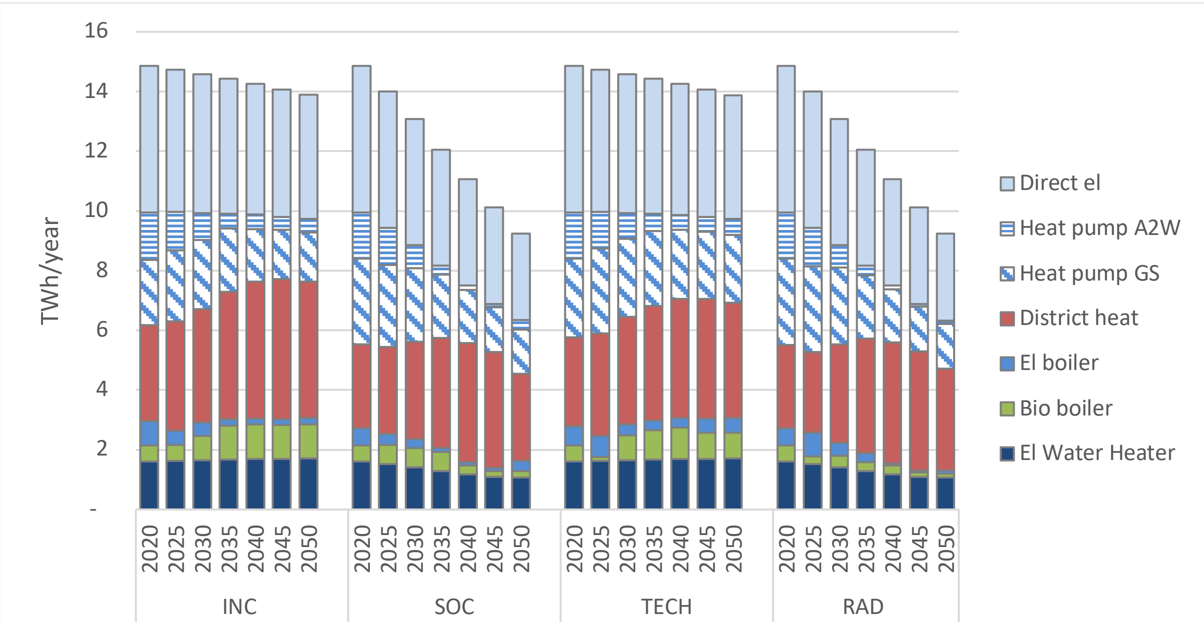


FIGURE 9: HEATING TECHNOLOGIES (DELIVERED ENERGY FOR SPACE HEATING AND WATER HEATER) IN COMMERCIAL BUILDINGS PER YEAR AND SCENARIO (TWH/YEAR)

5.1.4 Industry

In TECH, the large export of hydrogen is an exogenous input to the analyses, and this results in a much higher energy consumption in TECH than in the other scenarios, see Figure 10. Use of gas for electricity production for oil and gas extraction is also included in Figure 11, and this is mostly replaced by electricity from 2030-2035.

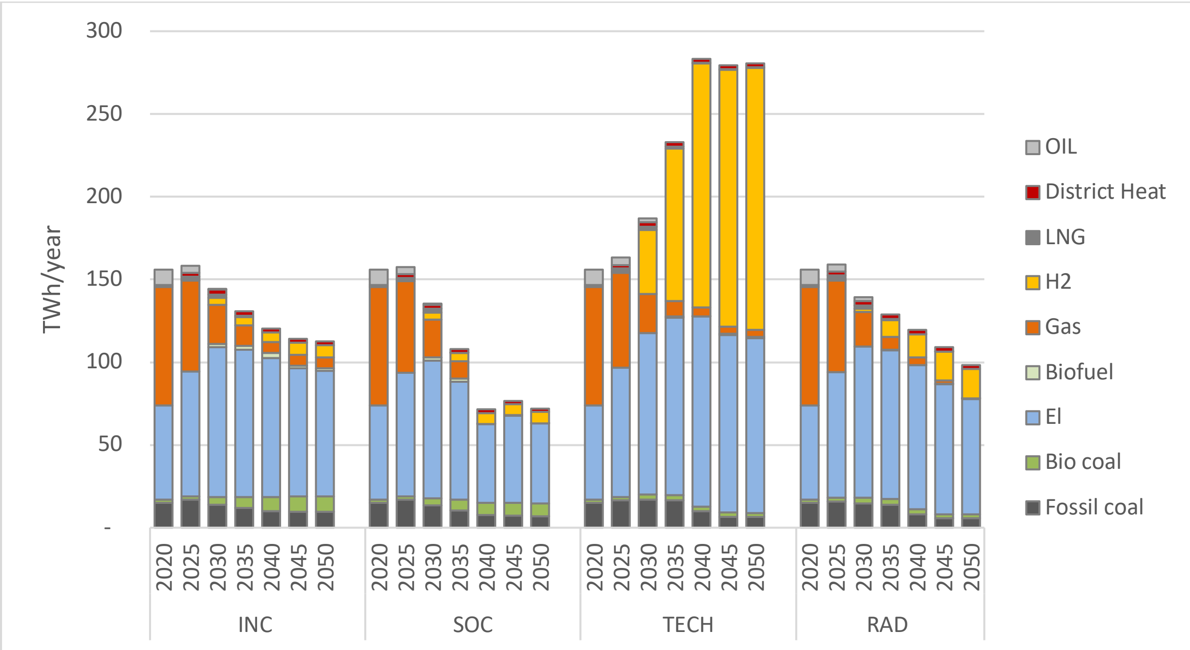


FIGURE 10: ENERGY CONSUMPTION PER CARRIER IN INDUSTRY, INCL. H_2 EXPORT AND GAS IN OIL AND GAS EXTRACTION, PER YEAR AND SCENARIO (TWH/YEAR)

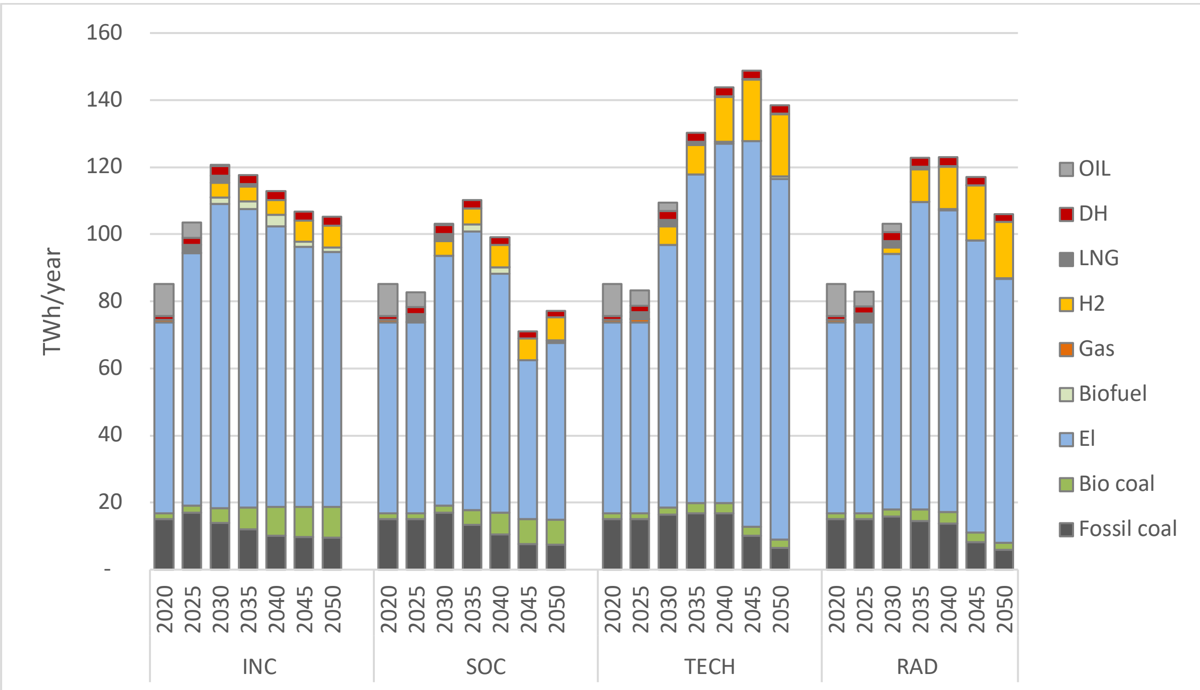


FIGURE 11: ENERGY CONSUMPTION PER CARRIER IN INDUSTRY EXCL. H2 EXPORT AND GAS IN OIL AND GAS EXTRACTION, PER YEAR AND SCENARIO (TWH/YEAR)

Figure 12 presents the energy consumption for manufacturing of aluminum, other metals, chemicals, and non-metallic minerals. In the aluminum industry, alternative energy use in aluminum is limited to two new processes in TECH. Electricity consumption will increase from 20 TWh in 2020 to about 25 TWh in INC and RAD and 33 TWh in TECH in 2050, while the consumption in SOC will be only 17 TWh in 2050.

Manufacturing of other metals than aluminum can, to a greater extent, be replaced using bio coal or hydrogen. In INC and SOC, bio coal is the main alternative, while TECH and RAD will use about 8-10 TWh of hydrogen in 2050. The electricity consumed for hydrogen production is not included in this electricity consumption but comes in addition.

Chemical manufacturing is constant in INC, TECH, and RAD, while it is less than half in SOC. In TECH, RAD and SOC, all-natural gas use is replaced by hydrogen, but some remain in INC.

Non-metallic minerals increase the use of biomass in all scenarios. In TECH and RAD, electrification also occurs, resulting in increased electricity consumption from about 1 TWh in 2020 to almost 3 TWh in 2050.

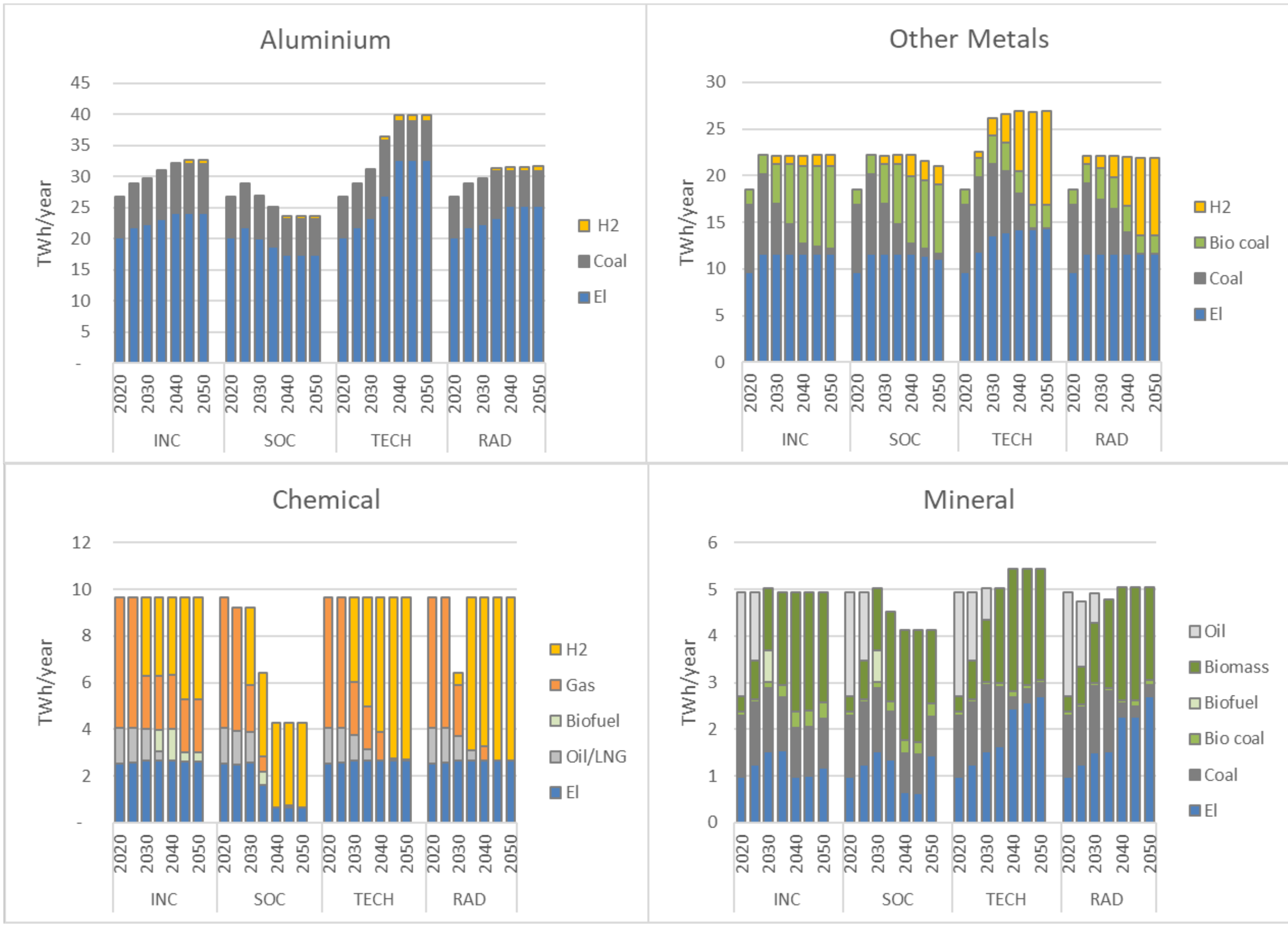


FIGURE 12: ENERGY CONSUMPTION PER INDUSTRY SUB-SECTOR PER SCENARIO AND YEAR (TWH/YEAR)

Petroleum activities decline in all scenarios. In SOC, there is no activity from 2040 and onwards, and in RAD, this sector will be closed down by 2050. In INC and TECH, about 1/3 of the present activity remains in 2050. The use of gas for power generation is largely replaced by electricity from the onshore grid, as shown in Figure 13.

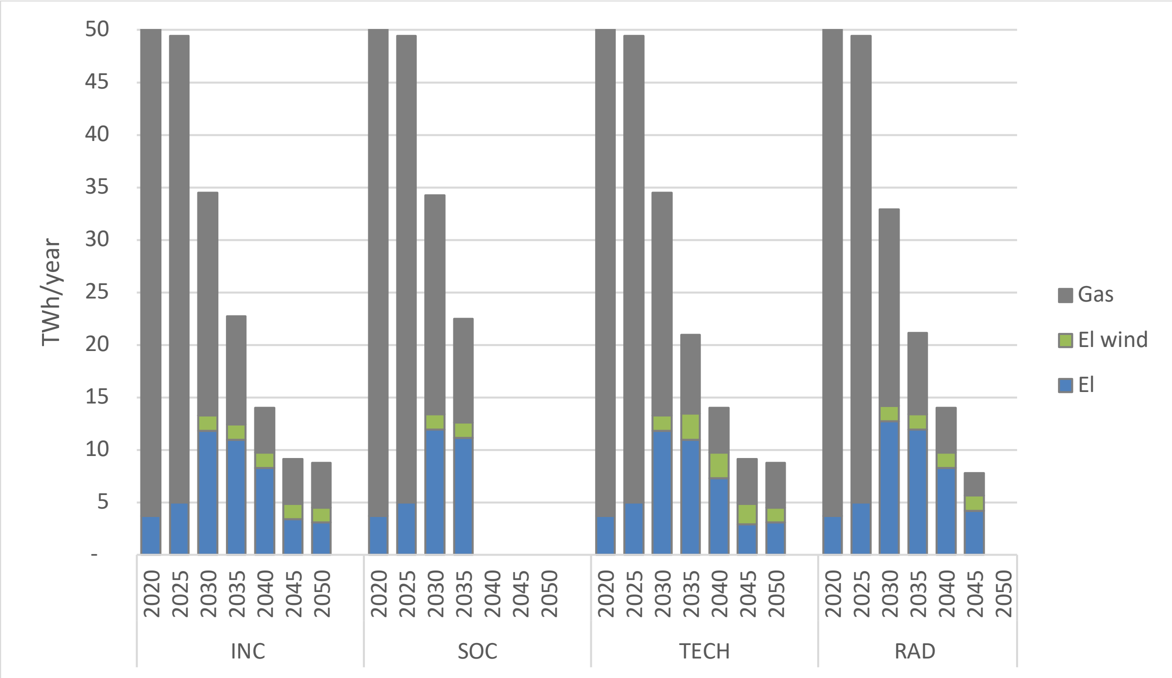


FIGURE 13: ENERGY CONSUMPTION FOR PETROLEUM ACTIVITIES OFFSHORE AND ONSHORE PER SCENARIO AND YEAR (TWH/YEAR)

5.1.5 Transport

In the transport sector, about 86% of the fuel consumption is covered by fossil fuels in 2020. In 2050 all will be replaced by electricity and biofuels in INC and SOC. In TECH and RAD, a small amount of fossil fuels will remain in 2050, as seen in Figure 14. Biofuels will dominate energy use in 2050 in INC and SOC, with shares of 60% and 53%, respectively. The electricity use is high in all scenarios, varying from 16 TWh in SOC in 2050 to 21 TWh in TECH.

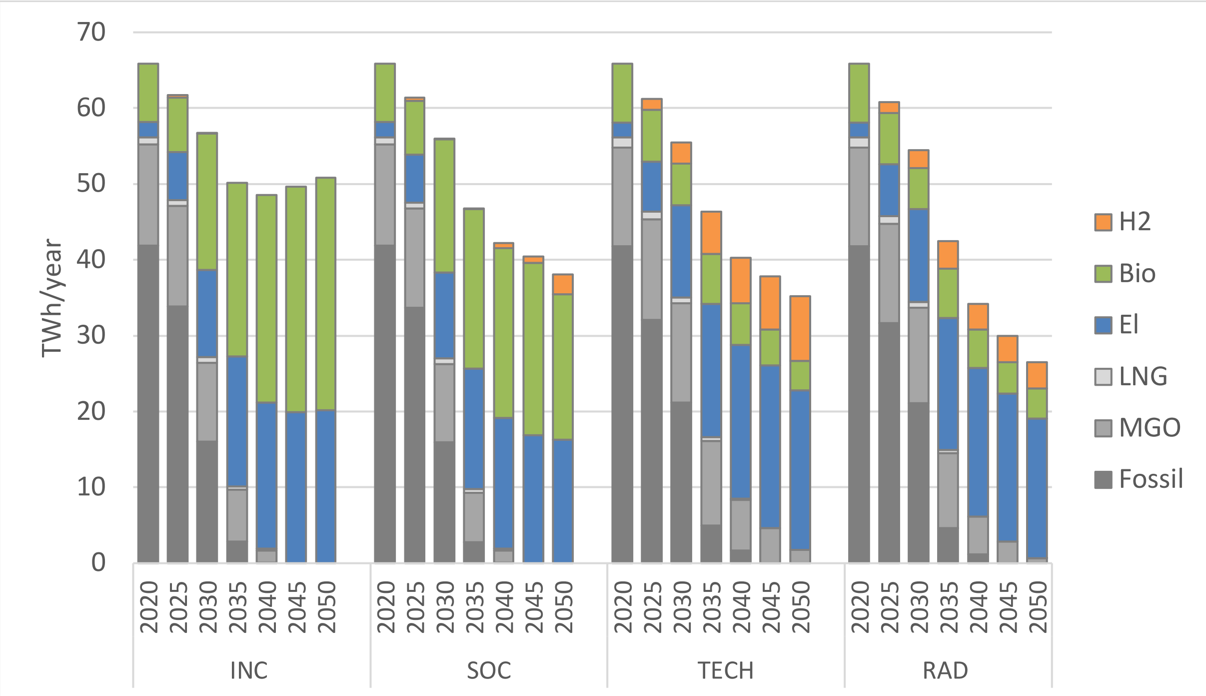


FIGURE 14: ENERGY CONSUMPTION BY CARRIER OF ALL TRANSPORT (TWH/YEAR)

Figure 15 presents the energy consumption in road transport. No fossil fuels are used from 2045 in any of the four scenarios. In 2040 the fossil fuels are phased out in both INC and SOC, while some fossil fuels remain in TECH and RAD. In RAD, all road transport will be battery-electric by 2050, but since the use of battery-electric trucks is somewhat limited in the other scenarios, biofuels or hydrogen will be used in addition. The total energy use is highly reduced in all scenarios due to more efficient vehicles.

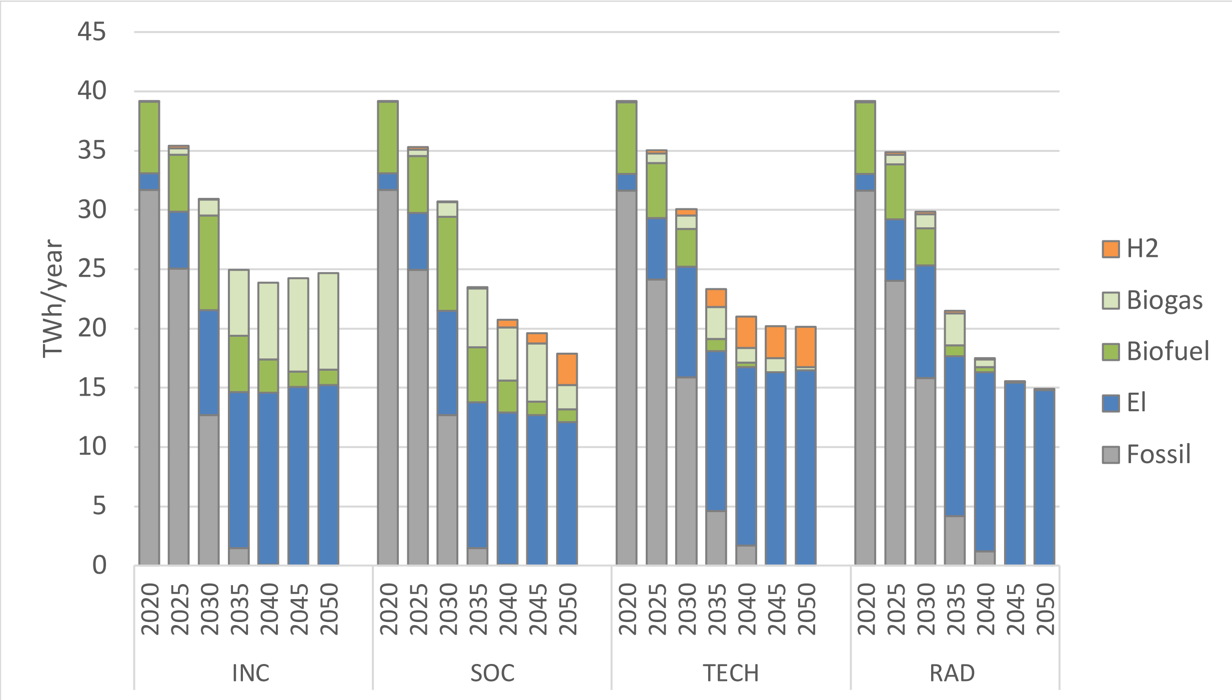


FIGURE 15: ENERGY USE IN ROAD TRANSPORT (TWH/YEAR)

The energy use in sea transport is presented in Figure 16. In INC and SOC, all sea transport will be decarbonised by 2045, and instead, biofuels and electricity will be used. The limited availability of biofuels in TECH and RAD results in some remaining use of MGO in 2050, which covers about 10% and 5% shares, respectively, for TECH and RAD. Nonetheless, most fossil fuels are replaced by ammonia, electricity, and biofuels.

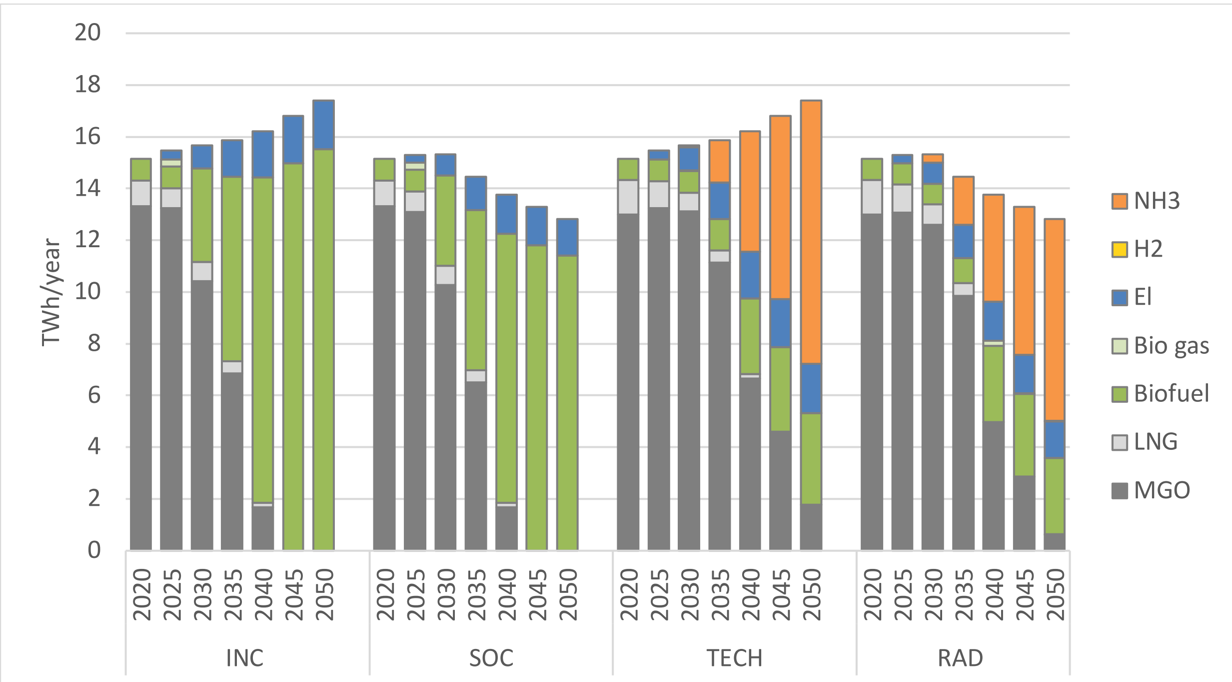


FIGURE 16: ENERGY USE IN SEA TRANSPORT (TWH/YEAR)

5.2 Energy use by energy carrier

5.2.1 Total energy consumption

Figure 17 presents the total energy consumption by energy carrier, including the energy content of exported blue hydrogen in TECH. Fossil fuel use will be very little in 2050 in all scenarios but TECH due to the gas used for hydrogen production in TECH. Electricity consumption is increasing in INC, RAD, and TECH and decreasing in SOC. The use of bioenergy increases in all scenarios.

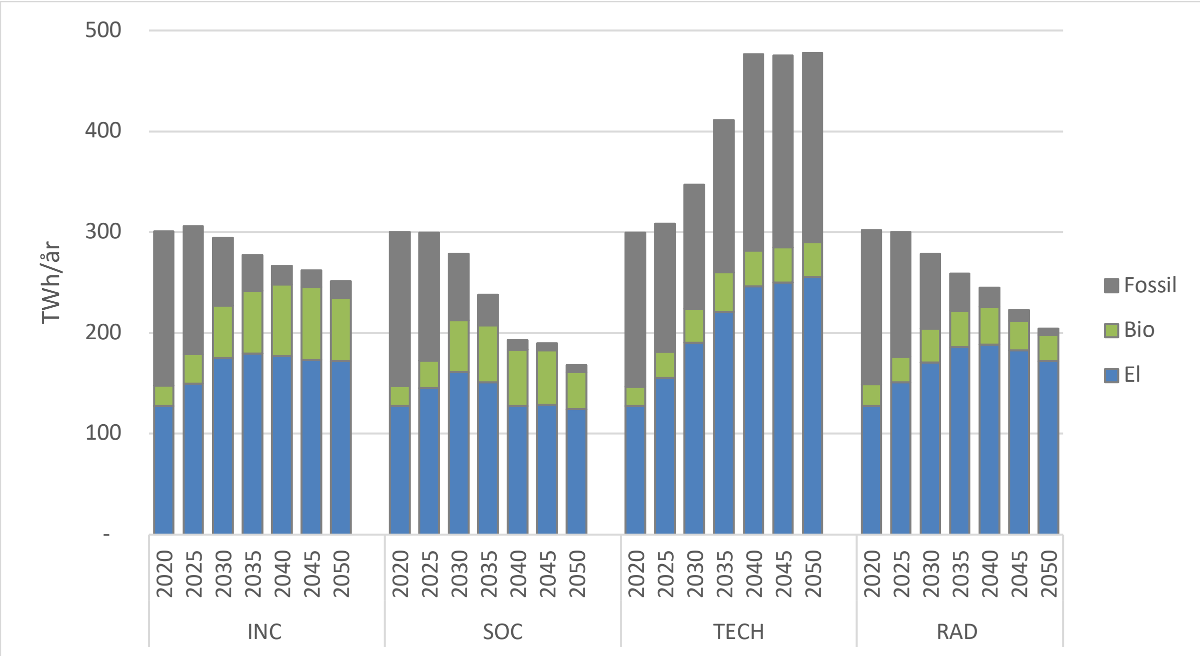


FIGURE 17: ENERGY CONSUMPTION BY ENERGY CARRIER (INCL. BLUE HYDROGEN FOR EXPORT) (TWH/YEAR)

5.2.2 Electricity

Electricity consumption, excluding grid losses, increases in INC, RAD, and TECH and decreases slightly in SOC (see Figure 18).

Electricity consumption in buildings is relatively constant in INC and TECH, while it reduces considerably in SOC and RAD.

Electricity consumption in manufacturing industries is almost constant in SOC, but if electricity for hydrogen production for industrial processes is added, the consumption increases by about 10 TWh. Electricity consumption in the other scenarios increases considerably. Petroleum-related industries (including electrification of oil and gas extraction) show an increase from 2020 to 2030 and then a decrease to zero in SOC and RAD in 2050 and to about 10 TWh in TECH and INC.

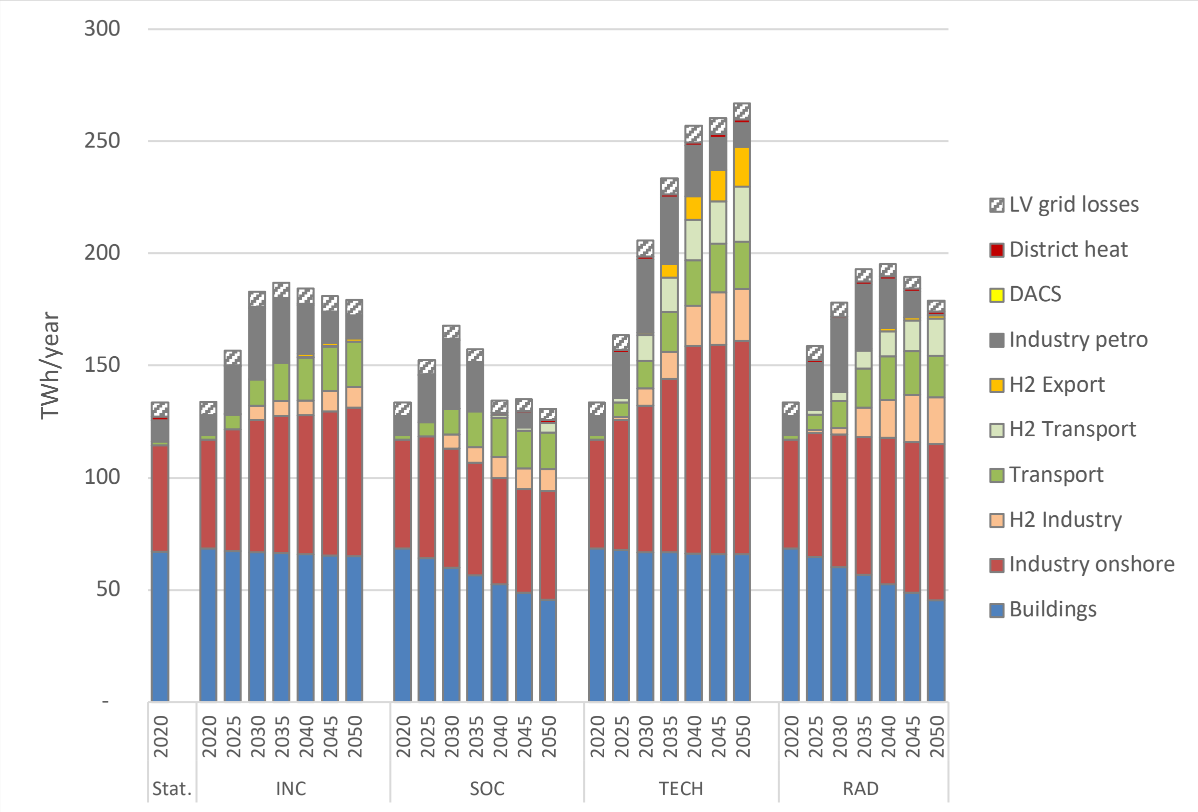


FIGURE 18: ELECTRICITY CONSUMPTION BY SECTOR AND SCENARIO FROM 2020 TO 2050 (TWH/YEAR)

The electricity consumption per industrial sub-sector is presented in Table 2.

TABLE 2: ELECTRICITY CONSUMPTION PER INDUSTRIAL SUB-SECTOR IN 2050 (TWH/YEAR)

Sub-sector	2050	2050	2050	2050
	High	**Medium**	**Medium**	**Low**
	TECH	**RAD**	**INC**	**SOC**
ALUminum	33	25	24	17
METals, other	27	22	13	14
CHEMical	10	10	7	5
MINerals, non-metallic	3	3	1	1
WOOD	4	4	4	3
OTHER	6	7	6	6
PETRO (onshore and offshore)	10	-	10	-
BATtery manufacturing	9	6	6	-
DATA centres	16	4	4	2
NEW, other new plants	18	1	1	-
AGRiculture	13	3	3	3
CONstruction	4	4	4	4
Sum	**153**	**89**	**83**	**55**

5.2.3 Hydrogen and ammonia

Figure 19 presents the use of hydrogen and ammonia. The export of hydrogen dominates the figure, as it is assumed to be 130 TWh of blue hydrogen and 10 TWh of green hydrogen in 2050. Only 1 TWh of hydrogen is expected to be exported in INC and RAD, and none will be exported in SOC. Figure 20 presents the use of hydrogen and ammonia without exported volume.

Most of the hydrogen is produced by central alkaline electrolyzers. A small amount is produced by local alkaline electrolyzers and in INC, some production by central PEM electrolyzers is observed.

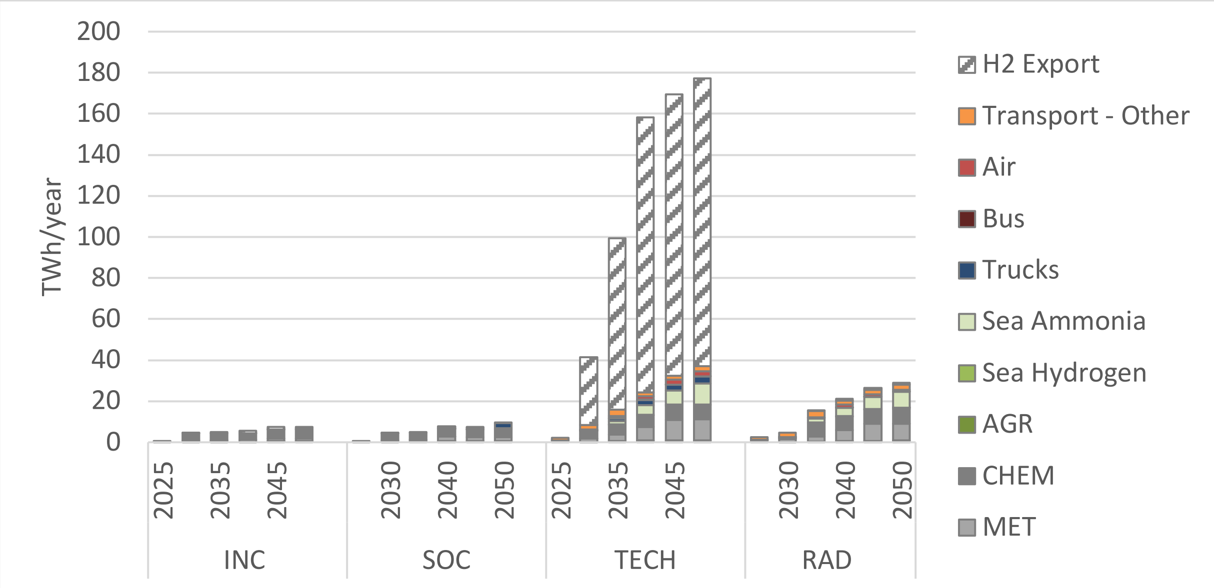


FIGURE 19: USE OF HYDROGEN AND AMMONIA INCLUDING EXPORT OF HYDROGEN IN 2025-2050 PER END-USE AND SCENARIO (TWH HYDROGEN/YEAR)

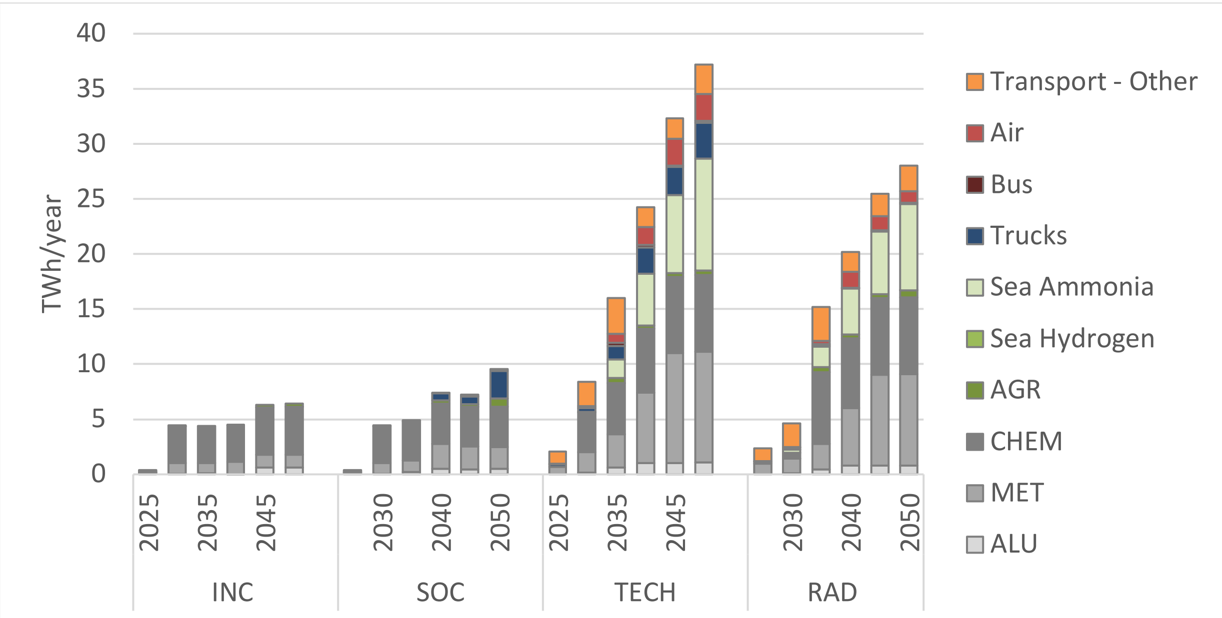


FIGURE 20: USE OF HYDROGEN AND AMMONIA EXCLUDING EXPORT OF HYDROGEN IN 2025-2050 PER END-USE AND SCENARIO (TWH HYDROGEN/YEAR)

5.2.4 Bio energy

Bio energy can be used for different purposes such as biofuel and biogas for transport or heating, bio coal in industrial processes, and biomass as raw materials in wood industries or e.g. chips for heat production in boilers. The Norwegian biomass resources are estimated to be 46 TWh/year and in TECH and RAD, these resources represent the maximum use of bio energy for all purposes. In INC and SOC, unlimited imports of bio energy products are possible. Figure 21 shows the domestic resources (black line) compared to how this is used for production of different bio energy products in the four scenarios. The figure shows the biomass needed for production of e.g. biofuel or bio coal, while the imported products are the energy content of each product, not the biomass needed for production of them.

The Norwegian resources are fully used in TECH and most of it is also used in RAD. No Norwegian resources are used for biofuel production in INC and SOC, but all is imported with the assumptions used in our analyses.

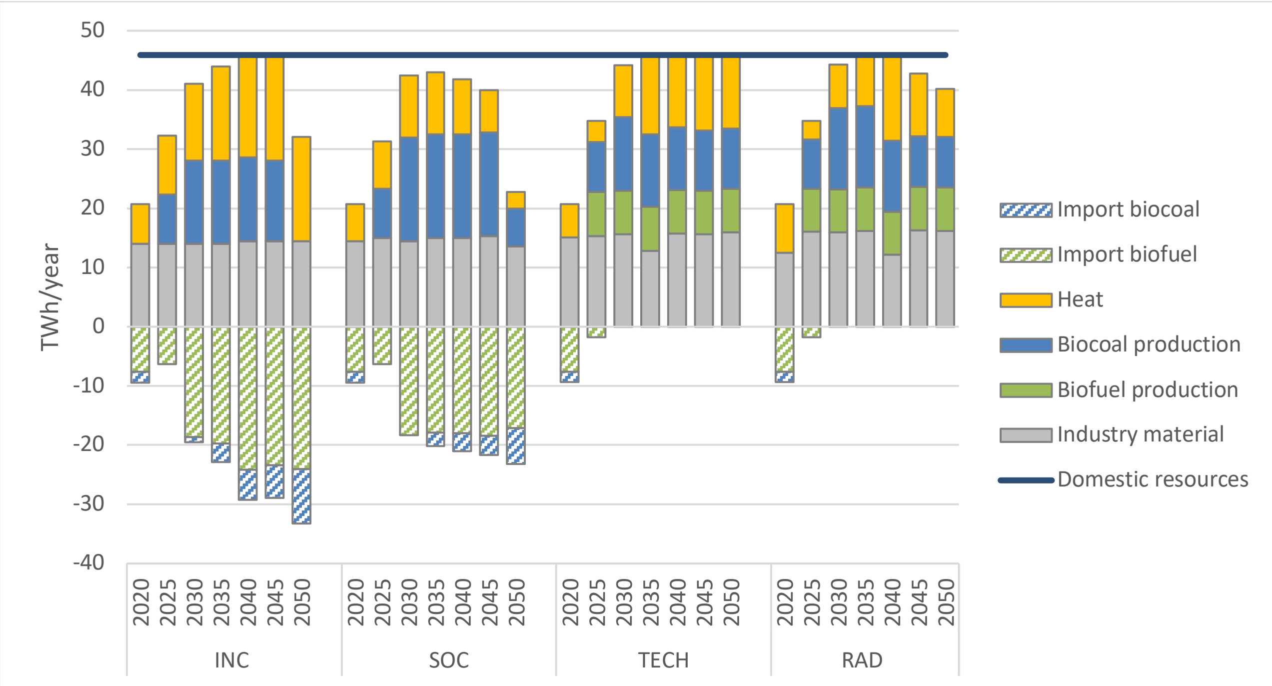


FIGURE 21: USE OF BIO ENERGY RESOURCES FOR PRODUCTION OF BIOFUEL, BIO COAL AND IN BIO BOILERS AND STOVES, AS WELL AS IMPORT OF BIOFUEL AND BIO COAL AND TOTAL DOMESTIC RESOURCES OF SOLID BIO ENERGY (TWH/YEAR)

Biofuel can be used both for transport and heating, but most of it is used for transport in all years and scenarios. In 2020, most of the biofuel is used in road transport, but from 2030 and forward, sea transport is a big consumer in INC and SOC. Air transport also becomes an important use of biofuel from 2030.

Biogas will be important in INC and SOC from 2030 forward, when no ICE vehicles can be sold anymore. It has a minor place in TECH and RAD, especially in 2035, before battery and hydrogen trucks take over. Buses use a high share of biogas in INC, and partly in the other scenarios, particularly around 2030-35. The use of biogas for sea transport is minimal, and only observed in 2025 in INC and SOC.

5.3 Electricity system

5.3.1 Generation

Figure 22 presents the electricity generation in all four scenarios. The highest production is for TECH since this is the scenario with the highest demand, high technology learning, and few limitations on new expansion options.

INC has the second-highest electricity generation, with 90 TWh more production in 2050 compared to 2020. Wind power is an important part of the increase, with almost 50 TWh of onshore wind and 30 TWh of offshore wind power in 2050.

Offshore wind power is considerable in RAD, with almost 50 TWh in 2050, but due to scenario assumptions, onshore wind is limited to 15 TWh. The total increase in power production in RAD from 2020 to 2050 is 79 TWh. SOC results in the lowest increase in electricity production with only 28 TWh more in 2050 compared to 2020.

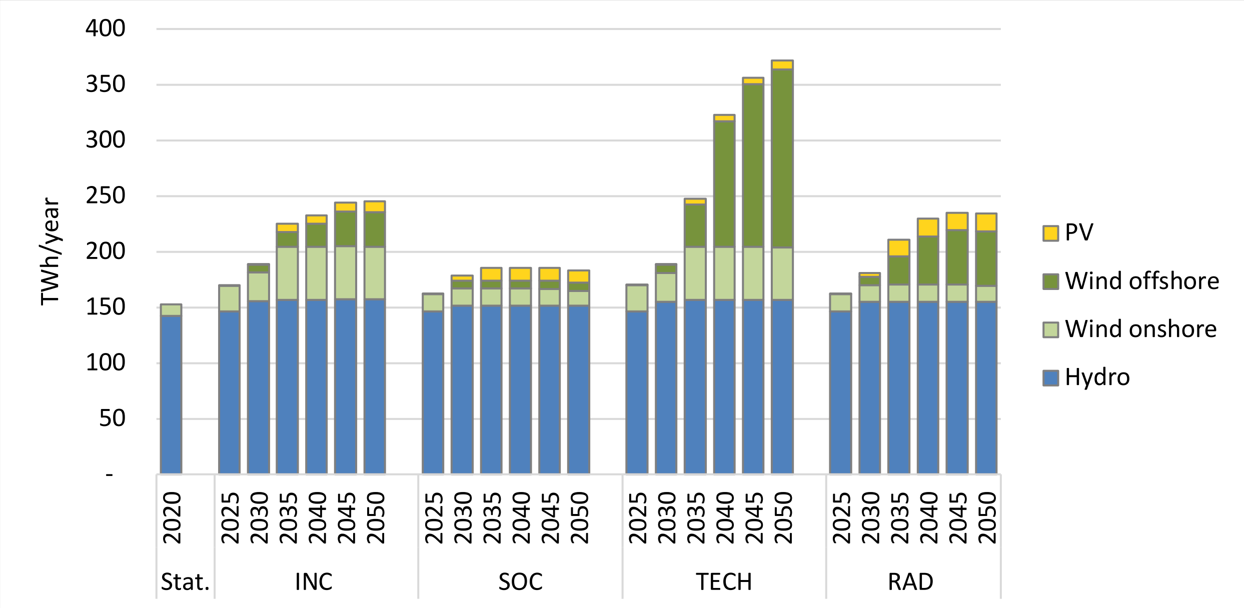


FIGURE 22: ELECTRICITY GENERATION BY TECHNOLOGY AND SCENARIO FROM 2020 TO 2050 (TWH/YEAR)

5.3.2 Trade and transmission capacity

The net electricity export to Europe depends on electricity generation and domestic electricity demand, as well as the restrictions enforced on expanding new transmission cables. Figure 23 shows the net electricity trade (annual export minus annual import) for each scenario and analysed year. The most challenging year in all scenarios is 2030, with about balance in export in INC and SOC and with more import than export in TECH and RAD. Towards 2050 all scenarios result in a considerable net export, more than 40 TWh per year. In SOC, no new transmission cables are allowed. Hence, even though energy demand is low, the net export volumes are restricted to that of today's transmission capacity.

The trading of offshore wind capacity significantly impacts the overall net values. While SOC and RAD only allow for radial connections to Norway, INC and TECH can gain from hybrid cables, making offshore wind a more profitable solution.

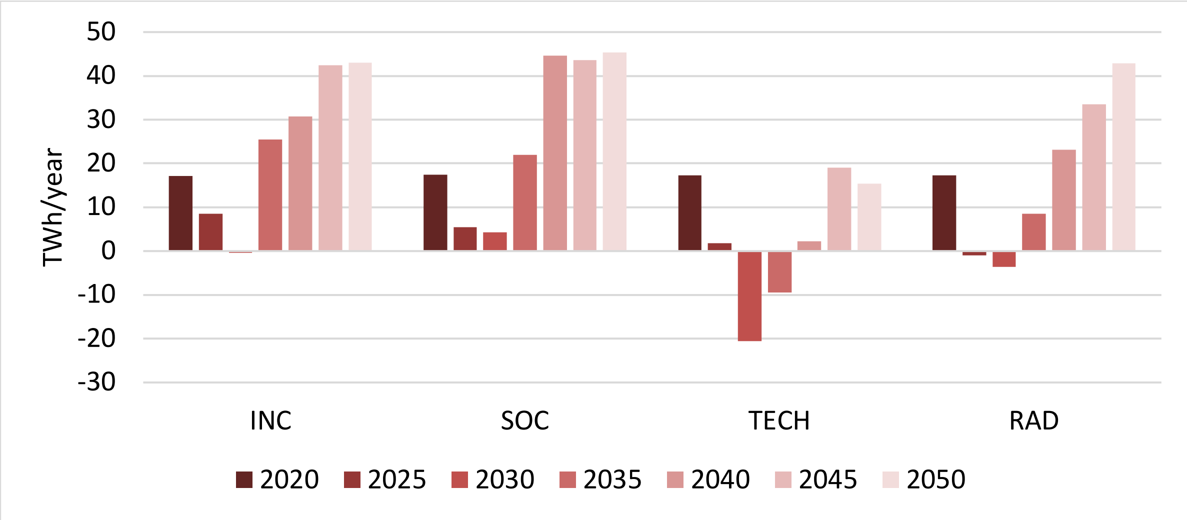


FIGURE 23: NET ELECTRICITY EXPORT TO EUROPE BY SCENARIO FROM 2020 TO 2050 (TWH/YEAR)

5.3.3 Electricity prices

The marginal electricity prices in the five spot price regions are quite similar, and Figure 24 presents an example of the prices per scenario and hour for region NO1 in 2050. The profiles are more constant during the hours and seasons in 2030 and gradually become more volatile.

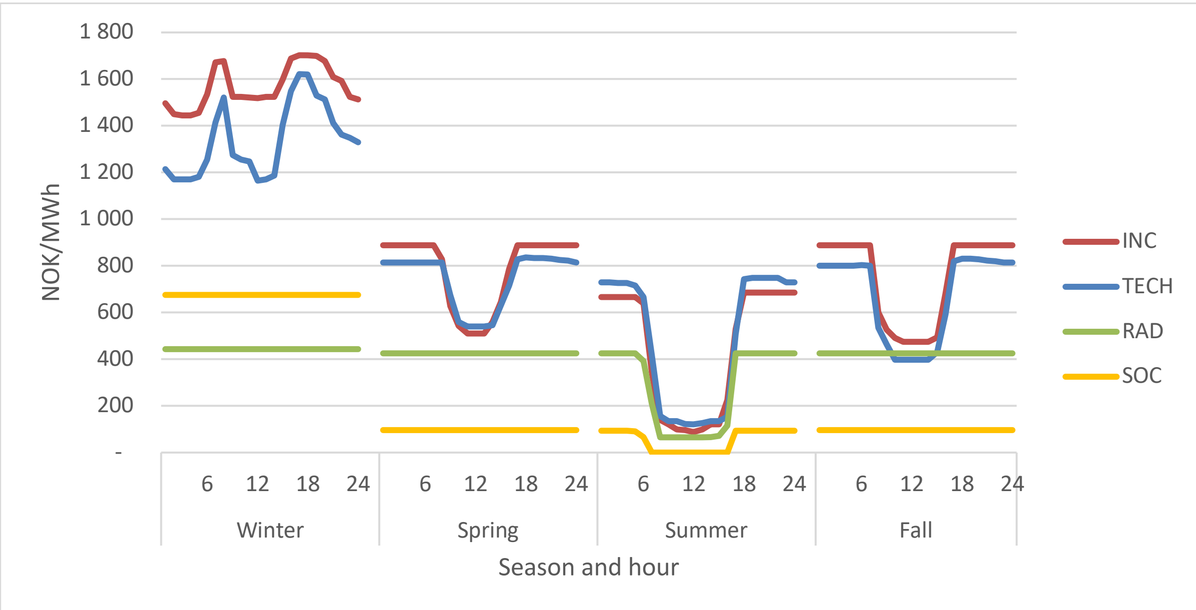


FIGURE 24: MARGINAL ELECTRICITY PRICE IN 2050 IN NO1 PER SEASON, HOUR AND SCENARIO (NOK/MWH)

The marginal electricity prices in SOC increase from 2030 to 2035, but then the marginal prices decrease every period and is as low as 100 NOK/MWh in 2050 in spring and fall and zero prices are reached during day-hours in the summer. These very low prices result in more use of electricity for heating. The reason for these low marginal prices is locked in power, due to the limitations of new transmission capacities and the rather low energy demand.

5.4 CO_2 emissions and capture technologies

5.4.1 Emissions

IFE-TIMES-Norway covers CO_2 emissions of 38.9 mill tons in 2020. This is about 2 mill. ton CO_2 less than the total CO_2 emissions in the emission account (41.2 mill tons in 2020) (Statistics Norway, 2023b). The difference can be explained by that some emissions are excluded such as the non-energy related CO_2 emissions, flaring and other process emissions of petroleum activities, and emissions from Svalbard.

The CO_2 emissions divided by industry and different transport modes are presented in Figure 25. INC has the lowest reduction, while RAD has no CO_2 emissions in 2050. TECH has additional emissions due to large export volumes of blue hydrogen, and therefore, the emissions excluding emissions from blue hydrogen production are also presented.

The emissions from road transport are decreasing rather fast, with trucks being the most challenging mode to decarbonize. Sea transport needs longer to reduce emissions if unlimited biofuels are unavailable as in TECH and RAD. It is not fully decarbonized in TECH, even in 2050.

Some emissions remain in the industry in all scenarios in 2050, and in RAD, this is almost fully compensated by the use of general DACCS. However, with the resulting electricity prices in TECH, using DACCS is not a cost-efficient solution to reduce emissions.

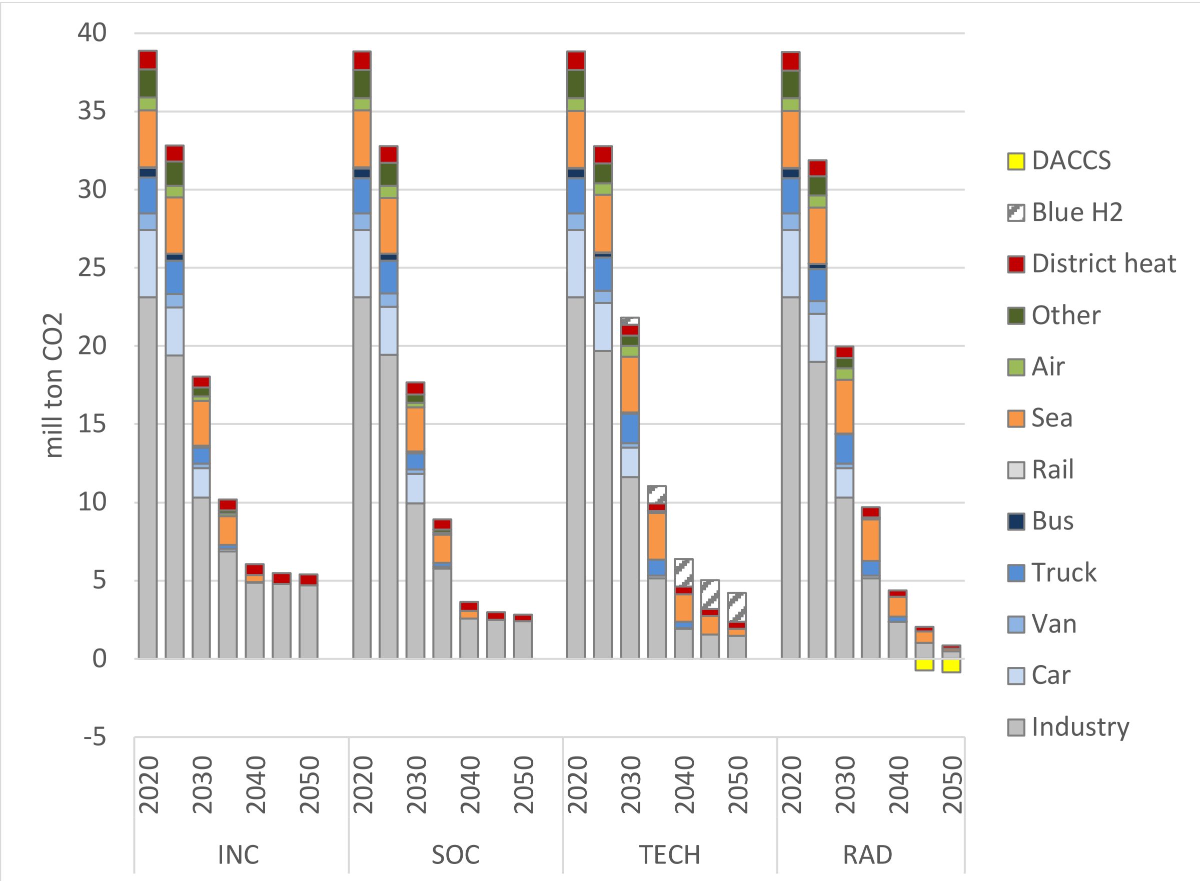


FIGURE 25: CO_2 EMISSIONS BY END-USE AND SCENARIO (MILLION TONS OF CO_2/YEAR)

5.4.2 CCS and DACCS

In all four scenarios, the ongoing CCS plans at one cement plant and one district heating plant are assumed to be implemented. In line with the scenario description, INC and SOC do not offer additional investment possibilities. In TECH and RAD, most heavy industries and all district heating plants can invest in more CCS and DACCS.

Figure 26 shows CO_2 captured, excluding blue hydrogen production. If the production of blue hydrogen used for exports is included, an additional 35 mill ton CO_2/year will be captured from 2040 and onward.

CCS is used in aluminium production in all years when available in TECH and RAD. In the production of other metals and chemicals, CCS is used from 2035 to 2040 before the processes using coal and gas are replaced by hydrogen.

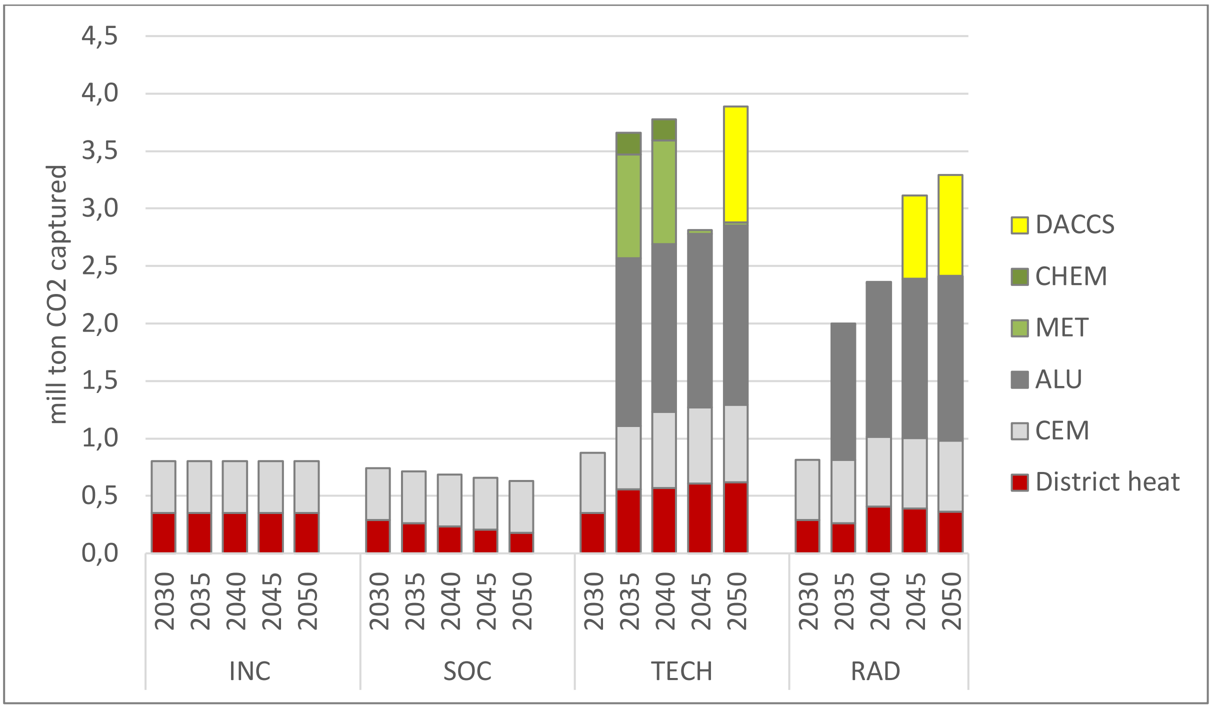


FIGURE 26: USE OF CCS AND DACCS EXCLUDING PRODUCTION OF BLUE HYDROGEN (MILL T CO_2/YEAR)

The net CO_2 emissions from industry by sub-sector and the use of CCS and DACCS are presented in Figure 27. In INC, the net emission from industry is 4.7 mill. t CO_2 and CCS can only be used in one cement plant. Due to lower production in SOC compared to INC, the net emissions will be 2.4 mill in 2050. With the possibility of investing in both CCS and DACCS and higher technology learning in industrial low carbon technologies, the emissions in TECH and RAD are lower. The use of CCS in industry is 2.9 mill. t CO_2 in TECH in 2050 and 2.4 mill. t CO_2 in RAD. In addition, about 1 mill t CO_2 is captured by DACCS in RAD and TECH in 2050.

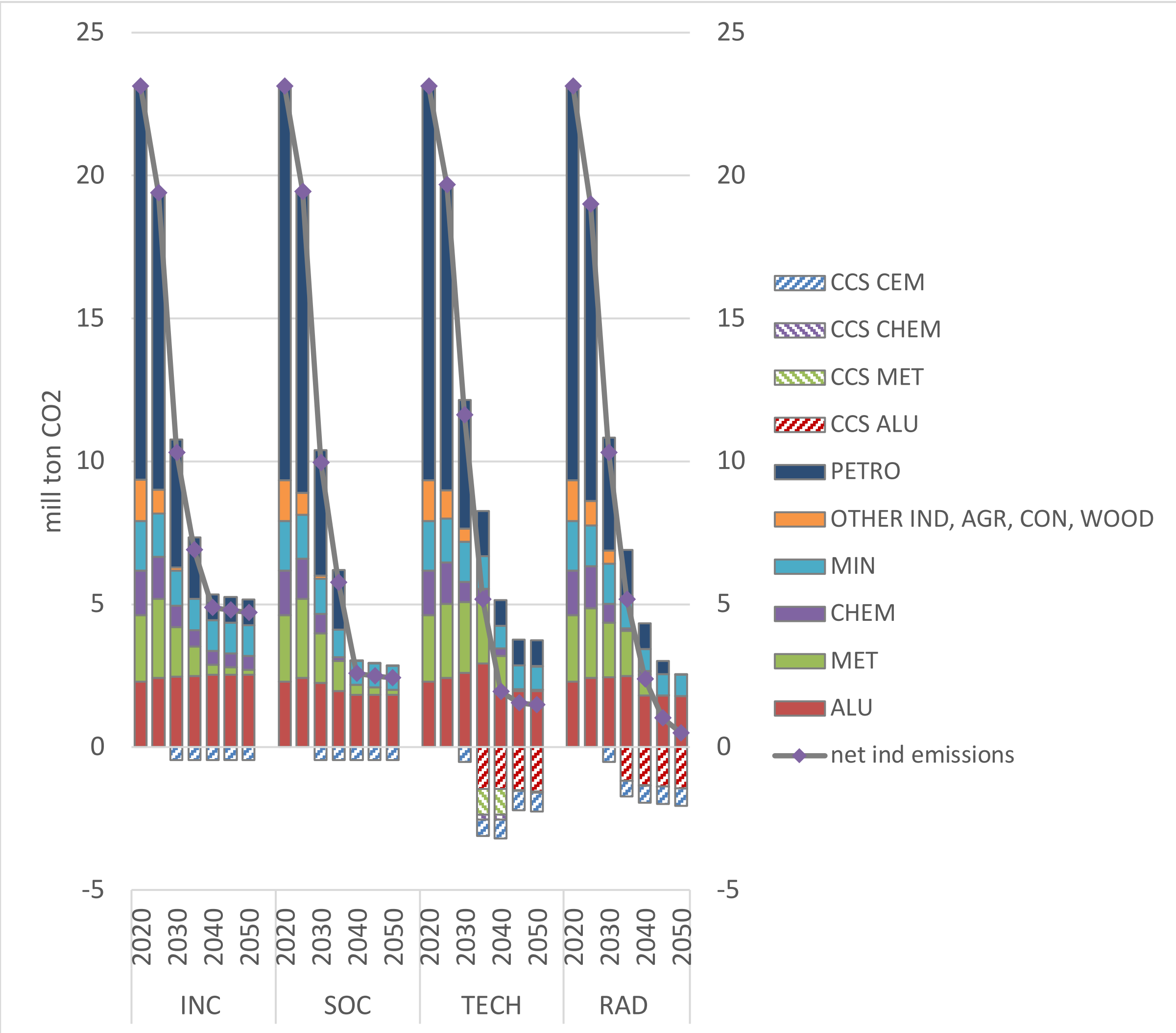


FIGURE 27: CO_2 EMISSIONS AND CAPTURED CO_2 IN INDUSTRY EXCLUDING BLUE HYDROGEN, DISTRICT HEAT AND GENERAL DACCS (MILL T CO_2/YEAR)

The sensitivity to the cost of CO_2 emissions is studied with analyses of the four scenarios, and the results show that both the use of CCS and DACCS increases when the cost of emitting CO_2 increases.

6 Comparison

There is a great uncertainty related to future energy demand. Over the last few years, different Norwegian actors have made different projections for future Norwegian energy use. These analyses can have different purposes and use different underlying assumptions. It can be challenging to compare different forecasts as the different studies have different scopes for their work. Some projections cover the total energy demand, including the consumption of all types of energy carriers, whereas most projections cover the electricity demand only. It is also challenging to access the underlying assumptions used for the projections, as they are not open and accessible. Also, the various actors have different starting points and purposes for their analyses of future demand, which can impact the projection.

In our comparison we have included the electricity demand projections from the following actors: Prosess21, Statnett, NVE, Statkraft and DNV. The projections we have examined were updated in 2023, except for Prosess21, which was made in 2020. The projections analyze demand development towards 2050, except for NVE, which has a final year of 2040. The electricity demand projections show that all foresee an increase in future electricity demand, and some a significant increase.

This section compares the future electricity demand towards 2050 from these reports with the resulting electricity demand of this report for the four NTRANS scenarios.

The electricity demand from the four NTRANS transition pathways (as well as for the Statkraft scenarios) results from an energy system optimization model, while other projections use different methodologies to project future electricity demand, such as development in GDP and population or development in activity level.

The energy demand in NTRANS-INC follows a rather conservative development, with medium growth in the industrial sector. This scenario is embedded in approved national policies, and considers international policies which can impact national development, such as the Net Zero Initiative in the EU and the Inflation Reduction Act in the US.

The five projections NTRANS-TECH, Statkraft Net Zero, NVE, Statnett high and Prosess21 gives the highest growth in future electricity demand. The NTRANS-TECH and Statkraft Net Zero have highest increase of almost 100 % (96 % and 98 %) from the reference level, while Prosess21 has an increase of 61 % from today's level (216 TWh in 2050), see Figure 28.

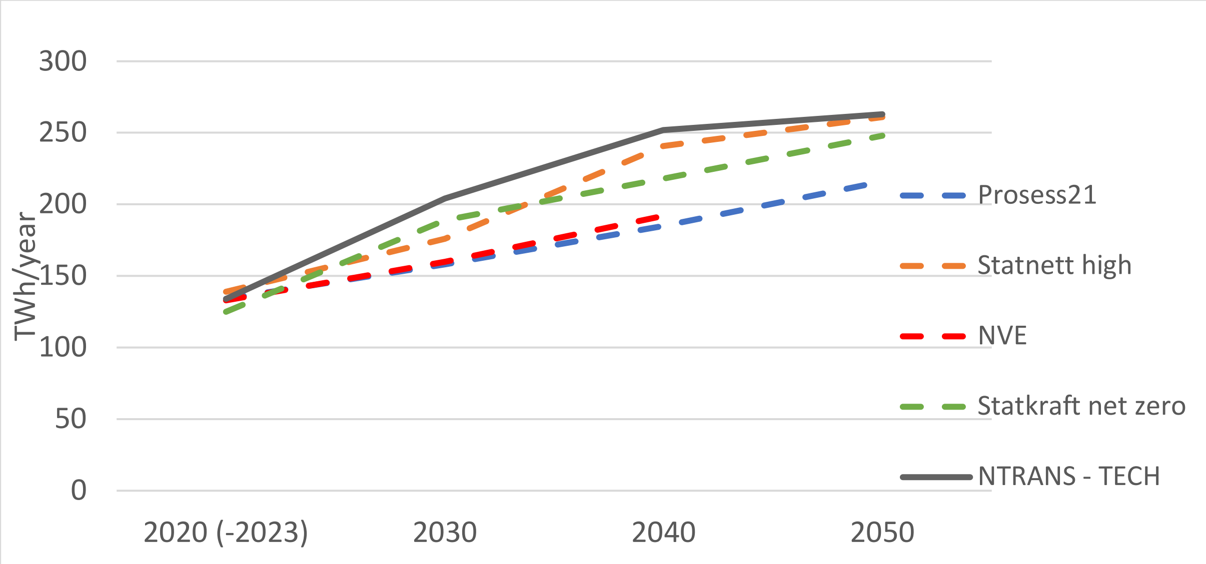


FIGURE 28: HIGH ELECTRICITY DEMAND PROJECTIONS 2020-2050, TWH/YEAR

On the other end of the scale are the NTRANS-RAD, NTRANS-SOC, NTRANS-INC, DNV, Statkraft low and Statnett low. These projections result in the lowest electricity demand in 2050, see Figure 29. NTRANS-SOC gives the lowest electricity demand in 2050. It decreases with 4 % from today's level (129 TWh in 2050). While Statnett's and Statkraft's low scenario has an approx. increase of 40 % from today's level.

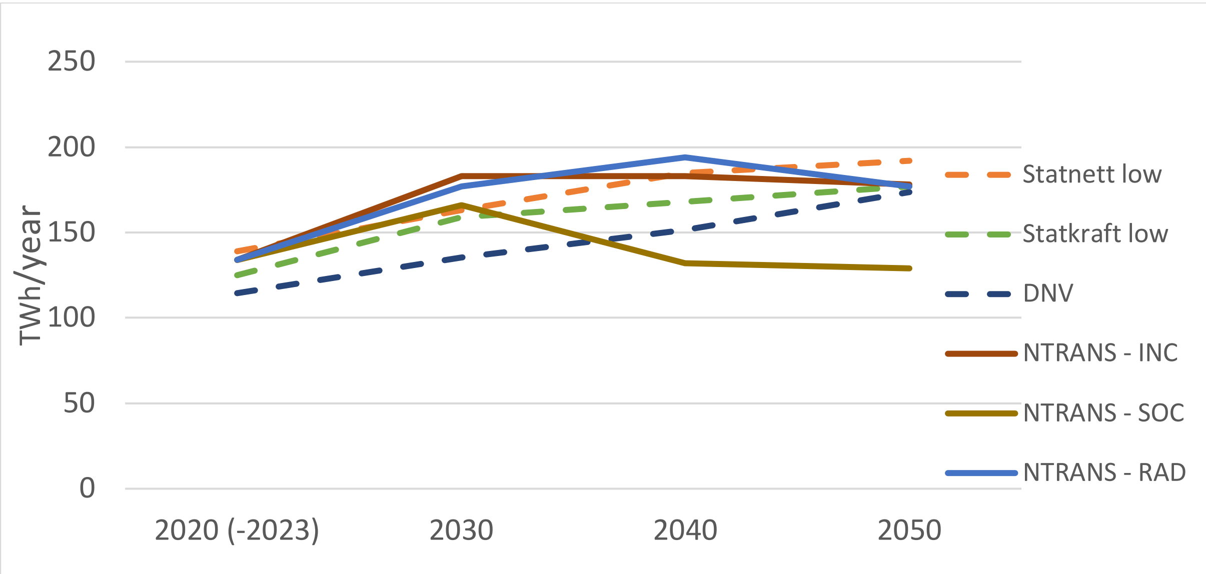


FIGURE 29: LOW ELECTRICITY DEMAND PROJECTIONS 2020-2050, TWH/YEAR

The huge range in the projections represents the uncertainty in future demand for energy. The projections vary from 263 TWh electricity demand in 2050 (the highest is in NTRANS-TECH) to 129 TWh in 2050 (the lowest is in NTRANS-SOC). The uncertainty is related to development of Norwegian industry, the degree of social change, the degree and speed of decarbonization, and phase out of fossil fuels as well as the dependency of imported bio energy.

The insights from the demand projections developed in NTRANS, show that different sustainable transition pathways in terms of changes in society and technology are possible. We do not assume that any of the four projections are “likely” to happen exactly in the form as they are described here.

The transition of the Norwegian energy system can unfold in different ways – and have different consequences, and in this work, we have studied how the energy demand can develop in the different NTRANS scenarios, which combine varying degree of technological and societal change. We have used the four different developments in energy demand and analysed the NTRANS scenarios to see how important parameters such as electricity consumption, power production, use of fuels and CO2 emission can develop towards 2050.

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A1 Abbreviations

The following abbreviations have been used in this report:

AGR	Agriculture (primary sector, incl. agriculture, forest, fishing with aquaculture but excl. fishing vessels that are included in Transport)
ALU	Aluminium industry
BAT	Battery factories
CHEM	Chemical industry (excl. metallurgic)
COM	Commercial buildings
CON	Construction and building industry
CCS	Carbon Capture and Storage
DATA	Data centres
DH	District Heat
DHW	Domestic Hot Water
El spec	Electricity Specific energy service demand (appliances, lighting, motors etc.)
MET	Metal industry (production of other raw metals than aluminium)
NEW	Other new industry activities such as hydrogen, ammonia or synfuel for export
MFH	Multi-Family Houses
MIN	Mineral industry (non-metallic mineral products)
NTP	National Transportation Plan
OTHER Ind	Light/other industry (food, metal products, transport equipment, textiles etc.)
PET-ON	Petroleum industry onshore (onshore oil and gas treatment and refineries)
PETRO	Petroleum industry offshore (oil and gas extraction)
SFH	Single-Family Houses
SH	Space Heating
TEK	Building code
WOOD	Wood industry (production of pulp & paper, and sawmills)

A2 Residential sector - Energy service demand projections

An edited and shorter version of the details of the demand calculations from (Rosenberg et al., 2024) is presented below.

For buildings, two projections are developed, one low projection used in scenarios with high societal change (SOC and RAD), and one base energy service demand projection used in scenarios with low societal change (INC and TECH).

The activity used for the projections of future energy demand in the residential sector is dwelling area (m2). It is calculated as:

Activity (dwelling area) = Population * area per dwelling / persons per dwelling

The dwelling area in the base year is based on information from Statistics Norway, dwellings per building type and useful area (Statistics Norway, 2023a). The average area of single-family houses is calculated to 154 m^2 and of multi-family houses to 69 m^2. The average area of all dwellings is calculated to 130 m^2.

Future dwelling area is calculated based on development of different parameters derived on historical evolution. Most of the key statistics and assumptions are presented in Table 3. The middle alternative population growth is used in the base projection of residential energy service demand. The number of persons per dwelling is assumed to continue to decrease, from 2.12 in 2020 to 2.00 in 2033 and onward. The number of new multi-family houses of all new dwellings has increased from 32% in 2000 to 63% in 2022 (Statistics Norway, 2023c). In 2018-2022 the average share of new multi-family houses was 62%, and this share is assumed to continue until 2050. It is assumed that the average dwelling size of single-family houses will be 180 m^2/dwelling from 2023-2050, slightly higher than the average statistics of 2018-2022 (178.9 m^2/dwelling). The dwelling size of multi-family houses is assumed to be 95 m^2/dwelling, compared to 94.1 m^2/dwelling in average in 2018-2022. The annual demolition rate is assumed to be 0.7% in single-family houses (SFH) and 0.4% in apartments (MFH) in all years, based on (Sandberg et al., 2023). This results in an average lifetime of the dwellings of 143 years for SFH and 250 years for MFH. Compared to a detailed building stock model, this is a simplification since the demolition rate usually vary with the age of the building.

The renovation rate is just below 1% per year, according to (Sandberg et al., 2023), but they also show to studies that the rate of energy upgrading is only 20% of the renovation rate. We assume that 0.2% of the existing dwellings are upgraded to a level of the building code TEK10 and the energy renovation upgrading is assumed to be equal to a decrease in energy consumption by 20%.

The total dwelling area will, with these assumptions, increase to 364 mill. m^2 in 2050, divided in 294 mill. m^2 single-family houses and 69 mill. m^2 multi-family houses. The yearly growth rate is 5 times higher for multi-family houses compared to single-family houses.

The resulting development of number of households and household area is larger than the population growth. The area per dwelling and per person will also increase while the number of persons per dwelling will continue to decrease.

TABLE 3: KEY STATISTICS AND ASSUMPTIONS USED IN THE PROJECTION OF RESIDENTIAL AREAS

	Starting year	Starting value	2030	2050	Yearly growth 2020-2050
Population (mill.)	2020	5.368	5.661	6.034	0.39%
Alternative population projections:					
- Low LLL	2020	5.368	5.509	5.386	0.01%
- High HHH	2020	5.368	5.827	6.680	0.73%
Persons per household	2020	2.12	2.03	2.00	
Share of multifamily houses of new dwellings (number of dwellings)	2018-2022	62%	62%	62%	
Area per new dwelling	2018-2022				
(m^2/dwelling)		178.9	180	180	
- single family house		94.1	95	95	
- multifamily house		126.3	127.3	127.3	
- average					
Renovation rate with energy upgrading (% per year)			0.2%	0.2%	
Demolition rate (% per year)					
- single family house			0.7%	0.7%	
- multifamily house			0.4%	0.4%	
Dwelling area (mill. m^2)	2020				
- Total		321	335	360	0.38%
- Single-family houses		273	277	291	0.22%
- Multi-family houses		49	58	69	1.2%

The projection of energy service demand of households (E) is calculated as:

$$E = A * I = \text{dwelling area } (m^2) * \text{specific energy service demand } (kWh/m^2)$$

The energy service demand is divided by end-use and is an important premise for analyses of future energy demand. The input used for the present calculations are based on publications from NVE (Lien et al., 2018), Statistics Norway (Statistics Norway, 2023d) and building regulations of 2017 (Lovdata, 2017). The energy by end-use for the types of dwellings used here are mainly based on (Lien et al., 2018; Spilde et al., 2023).

Energy use per square meter is calculated and calibrated for existing dwellings, resulting in 158 kWh/m² for single-family houses (SFH) and 156 kWh/m² for multi-family houses (MFH). These totals are divided into space heating, domestic hot water (DHW), and appliances, with values for each end-use type based on recent studies.

For new dwellings, energy use aligns with building regulations, with end-use shares adjusted for a low-demand alternative.

Figure 30 and Figure 31present the residential energy service demand in the two projections from 2010 to 2050. The medium projection results in a constant demand towards 2050 despite an increase in area of 12%. In the low demand projection with more efficient buildings (both for heating and appliances), dwellings' total energy service demand is reduced to 49 TWh in 2050.

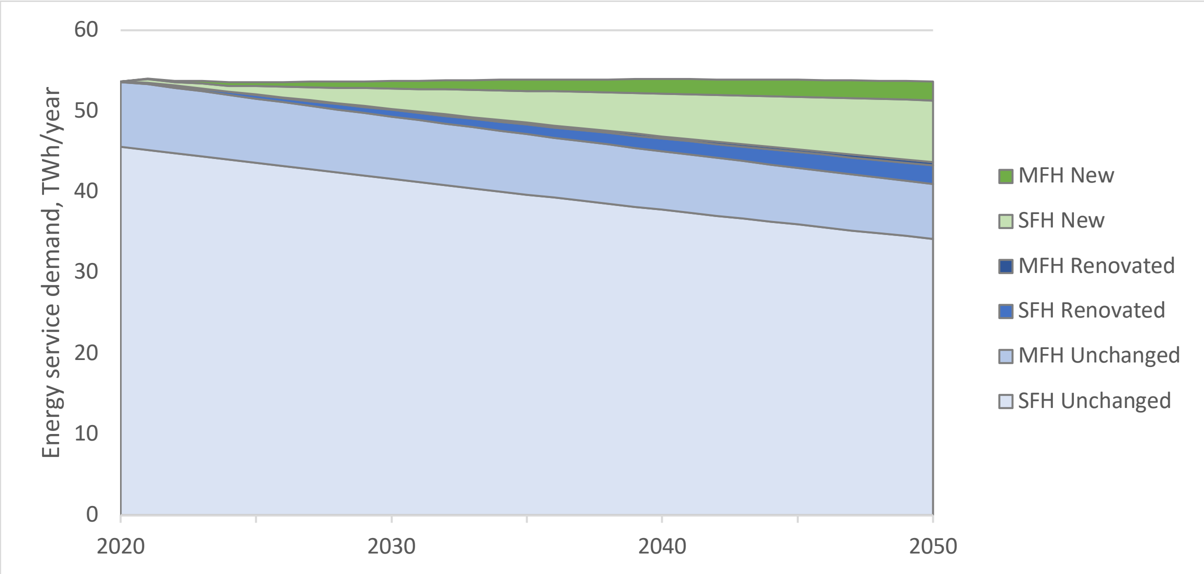

FIGURE 30: ENERGY SERVICE DEMAND BY DWELLING TYPE AND END-USE (INC AND TECH), TWH/YEAR

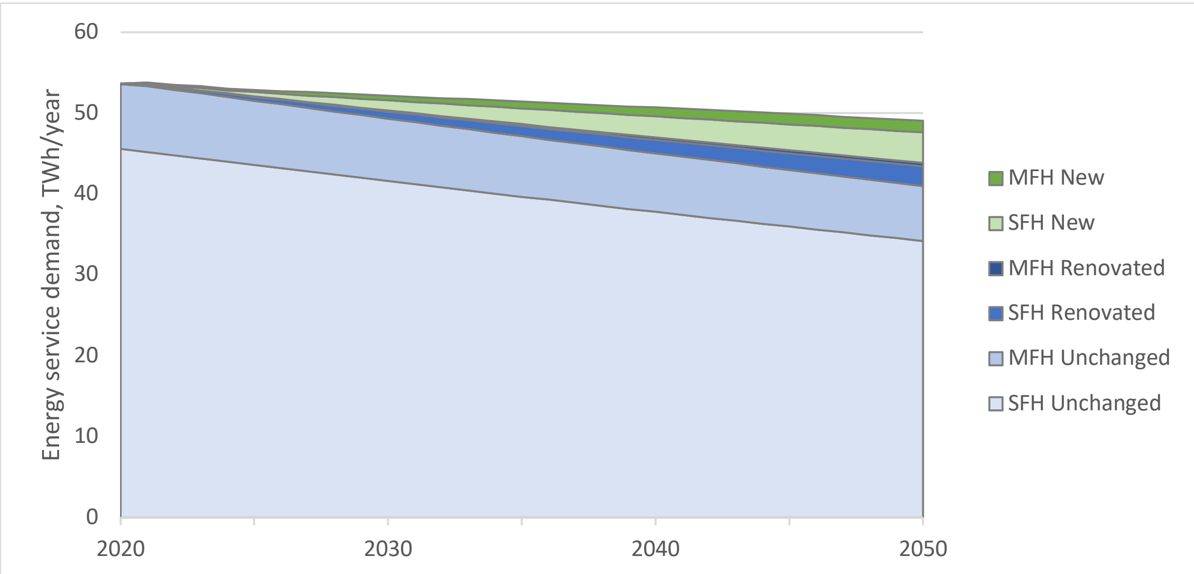

FIGURE 31: ENERGY SERVICE DEMAND BY DWELLING TYPE (SOC AND RAD), TWH/YEAR

Energy efficiency in the energy service demand projection is set as a fixed 20% reduction for renovated homes and is included in building codes for new dwellings.

The energy demand is allocated to the five regions (NO1-NO5) based on population, dwelling area, and energy degree days to distribute space heating needs. Figure 32 presents the energy service demand of dwellings in 2050 per region and end-use. The dominating region and dwelling type is single-family houses in NO1.

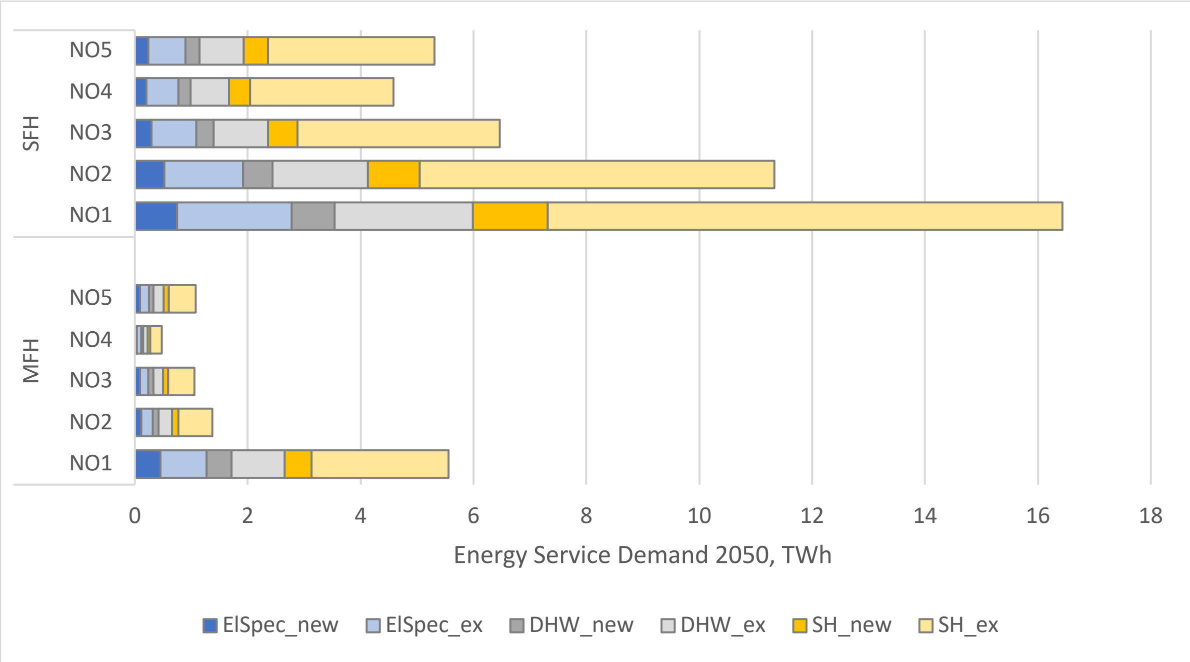

FIGURE 32: ENERGY SERVICE DEMAND IN DWELLINGS IN 2050 PER REGION AND END-USE, (INC AND TECH), TWH/YEAR

A3 Service sector - Energy service demand projections

An edited and shorter version of the details of the demand calculations from (Rosenberg et al., 2024) is presented below.

One method of projecting energy needs in the service sector (tertiary sector, commercial buildings) is by using the projection of man-hours or gross product from an economic model, often together with assumptions about efficiency factors. As a development of these parameters is not available, another methodology must be used. Population projections have a central role in many projections of both energy needs and economic development and have been chosen as the fundamental driver in our work.

The energy consumption is closely linked to the building area of different sub-sectors and is thus calculated based on existing areas in the base year and estimated increase due to population growth. The energy consumption also depends on the age of the buildings. For simplicity, all existing buildings are aggregated to one category and all buildings constructed after 2020 is another category in IFE-TIMES-Norway. Behind these aggregated categories are more detailed information of building areas, specific energy demand, demolition, and renovation rates etc.

The increased building area is calculated based on the population projections assuming a constant area per person for each building type. The total area of commercial buildings increases from 111 mill. m2 in 2020 to 124 mill. m2 in 2050. The demolition rate is assumed to be 0.5% per year (lifetime of 200 years) and the renovated buildings with energy upgrading is assumed to have an annual rate of 0.3%.

As for the residential sector, energy service demand is calculated as building area multiplied by end-use per m², divided by status for area i.e. new, renovated or unchanged.

E = A * I = building area (m2) * specific energy service demand (kWh/m2)

The energy service demand by end-use is crucial for analyzing future energy needs, but data availability is limited and uncertain. The calculations here are based on a study by NVE (Spilde, Sævold et al. 2023), which specifies energy demand for space heating, domestic hot water, ventilation, lighting, appliances, and cooling. These are aggregated into three categories: space heating, domestic hot water, and specific electricity use, applied to existing buildings.

The energy service demand for new buildings is based on the 2017 building regulations (Lovdata 2017). In scenarios with higher energy efficiency goals (SOC and RAD), it's assumed that new buildings use 25% of current space heating demand, 80% of domestic hot water demand, and 80% of electricity demand.

With this, the energy service demand will decrease slightly, from 35 TWh in 2020 to 34 TWh in 2050, %, see **Figure 33**.

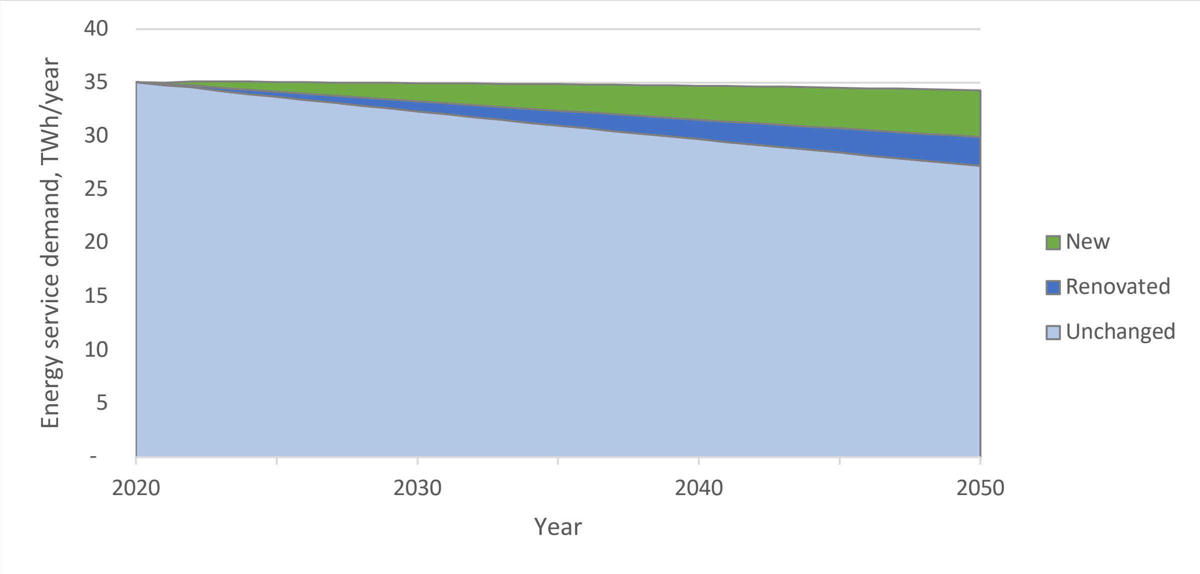

FIGURE 33: ENERGY SERVICE DEMAND 2020-2050, (INC AND TECH), TWH/YEAR

In addition to the projection for INC and TECH, a lower demand projection is defined for commercial buildings, used in SOC and RAD. This lower demand projection has an energy service demand for space heating being 25% of the building code of TEK10, 80% of domestic hot water demand and 80% of appliances and lighting. With these assumptions, the total energy service demand of commercial buildings is reduced from 35 TWh in 2020 to 33 TWh in 2050.

The energy service demand is divided into the five price regions NO1-NO5 based on population, and, in addition, the number of energy degree days is used to distribute the demand for space heating. Energy service demand for domestic hot water and specific electricity is distributed based on population. The dominating region is NO1 with the highest end-use demand is for electricity specific purposes (appliances, air conditioning, lighting etc.), see **FIGURE 34**.

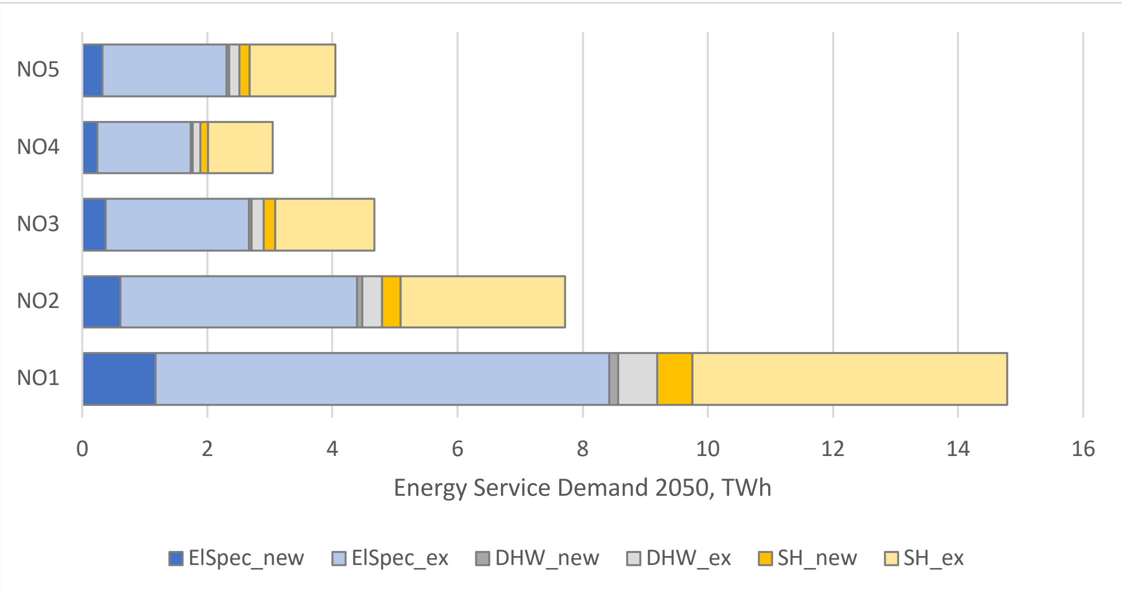

FIGURE 34: ENERGY SERVICE DEMAND PER REGION AND END-USE IN 2050, TWH (DHW = DOMESTIC HOT WATER, SH = SPACE HEATING)

A4 Industry sector - Energy service demand projections

An edited and shorter version of the details of the demand calculations from (Rosenberg et al., 2024) is presented below.

Method and structure

Future activities of the industry sector are uncertain and has a high impact on the energy system. Three projections have been developed. The projection based on existing industry and known developments is used in INC and RAD, while a projection including ambitious plans on industry growth is used in TECH, and low projection with less industrial activity than today is used in SOC.

The methodology of demand projections of Norwegian industry is based on a bottom-up definition of plants, sub-sectors and regions of the present manufacturing industry and supplemented by knowledge and assumptions of new industrial establishments. In this study, industry also includes the primary sector with agriculture, forest, and fishing (incl. fish farming) as well as the sub-sectors construction and mineral mining. In addition to manufacturing industries, the energy sector producing fuels such as oil refineries, production of fuels for export and onshore activities connected to the offshore oil and gas extraction is included. The offshore petroleum industry is represented through five regions in the model, capturing the energy demand development of 38 oil and gas fields.

The energy system model calculates total energy ***use*** and use of various energy carriers and investments in new technologies. The energy ***service*** demand is defined as a demand for energy in GWh/year. This can be translated into production volumes such as tons/year with an indicator of energy use per produced unit. One problem with the use of volumes (tons) instead of energy (GWh) as demand unit, is the inhomogeneous products of most modelled industry sub-sectors.

The industry structure is based on a bottom-up approach of individual plants of approximately the 50 biggest plants (energy use) and, in addition, some of the other large CO2 emitters, in total about 60 plants. The site data is mainly based on information from the database of (Miljødirektoratet (The Norwegian Environment Agency), 2023).

Base year demand

An overview of the largest electricity consumers and/or the plants with the highest CO2 emissions per price region is presented in Table 4. The plants' names are shortened to compromise the table and keep it a level of recognition, but a challenge is that some plants change names over time. In total, 63 individual industrial plants are included in the model.

The identified plants are used to allocate the energy consumption from the energy balance to each sub-sector and price region (Statistics Norway, 2023d). The electricity consumption of 2020 is used as the main input, with additional information on consumption from 2018 to calibrate the model base year and the energy balance of 2021-2022 to include recent developments.

The energy ***service*** demand per sub-sector and end-use used as input to IFE-TIMES-Norway is presented in Table 5.

TABLE 4: OVERVIEW OF LARGE PLANTS PER INDUSTRY SUB-SECTOR AND PER PRICE REGION IN 2020

ALUminum	METal prod.	CHEMical	MINeral prod	WOOD	PET-ON
NO1					
		Dynea Lillestrøm	Rockwool Moss	Norske Skog Saugbrugs	
		Chemring Nobel	Glava Askim	Borregaard	
		Unger fabrikker	Magnor Minerals	Hellefoss Paper	
			Gyproc	Nordic Paper	
				Hunton Gjøvik	
				Forestia Braskereidfoss	
NO2					
Hydro Karmøy	Eramet Sauda	Yara Porsgrunn	Norcem Brevik	Vafos Pulp	Gassco AS Kårstø
Alcoa Lista	Eramet Porsgrunn	INOVYN Rafnes	Elkem Carbon	Huntonit	Gasum LNG
Sør-Norge Aluminium	Glencore Nikkelverk	Ineos Rafnes			Esso Slagentangen
Speira Holmestrand	Eramet Kvinesdal	Ineos Bamble			
Hydro Vigelands Brug	Eramet Titanium & Iron				
	Fiven Lillesand				
	REC Solar Kristiansand				
NO3					
Hydro Sunndal	Elkem Thamshavn	Tjeldbergodden	Glava Stjørdal	Norske Skog Skogn	Nyhamna prosessanlegg
Hydro Høyanger	Elkem Bremanger		Hustadmarmor	MM FollaCell	
	Wacker Chemicals			Ranheim Paper & Board	
NO4					
Alcoa Mosjøen	Celsa Armeringsstål	Yara Glomfjord	Norcem Kjøpsvik		Hammerfest LNG
	Elkem Rana				
	Ferroglobe Mangan				
	Elkem Salten				
	Finnfjord				
NO5					
Hydro Årdal	Boliden Odda				Gassco AS Kollsnes
	Elkem Bjølvefossen				Mongstad raffineri
					Stureterminalen
Total number of plants					
9	17	9	9	11	8

TABLE 5: ENERGY SERVICE DEMAND PER SUB-SECTOR AND END-USE DEMAND IN 2020 (TWH/YEAR)

	ELC - non-substitutional electricity	HEAT - process, boilers, machinery	PRC - process material	Total energy service demand
	TWh/year	TWh/year	TWh/year	TWh/year
Aluminum	20.2	0.7	6.6	27.5
Other metals	9.7	0.1	8.8	18.6
Chemicals	2.5	1.5	5.6	9.6
Minerals	0.9	2.7	0.4	4.0
Wood	3.6	3.1		6.7
Petroleum onshore	6.9	12.4		19.3
Petroleum offshore	3.7			3.7
Other industry	4.9	3.4		8.3
New (data centres)	1.1			1.1
Construction	1.5	3.0		4.5
Agriculture	2.4	1.7		4.1
Total	**57.4**	**28.6**	**43.3**	**107.4**

Demand projection

The future energy demand of the industry sector is very uncertain. Still, it highly impacts the Norwegian power balance due to the large power demand and high ambitions of future activities. The industry demand projection assumes that most existing plants continue operating at the same level as today. The Norwegian industry's base demand projection includes known plans for shutdowns or investments in increased production. In alternative projections, the demand can increase or decrease, which is described in each projection. Three projections have been developed for the industry: high - used in TECH, medium - used in INC and RAD, and low activity – used in SOC. For onshore industry, the electricity ***service*** demand (electricity specific demand) for the three projections is presented in **Figure 35**.

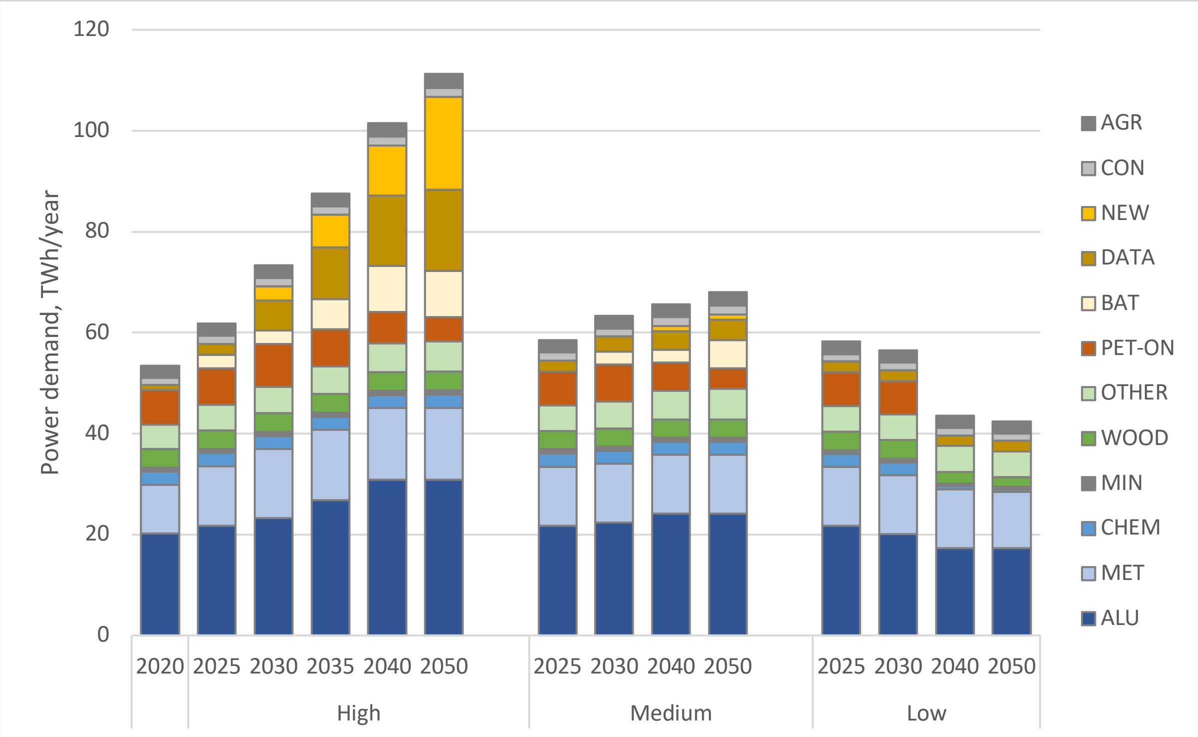

Figure 35: Power demand projection per industrial sub-sector (TWh/year)

The oil and gas sector's energy consumption for 2021 is calculated based on data for diesel and fuel consumption provided by Miljødirektoratet. The energy demand towards 2050 will develop according to the planned decommissioning and new fields that have started or are planned to start production after 2021. For energy demand related to offshore oil and gas extraction, the development for the five grouped regions is presented in *Figure 36*. The demand is included as electricity demand, in which gas consumption is converted using a rate of 0.35. Demand is further assumed to be flat throughout the year. Based on the Ministry of Energy (Klimautvalget, 2023), it is assumed that not all oil and gas sector emissions can be omitted, corresponding to 0.9 Mt remaining in 2050. Electrification of offshore from shore is included in the base year with the sites that are in operation today; Utsirahøyden, Vallhall, Troll A, Martin Linge and Goliat.

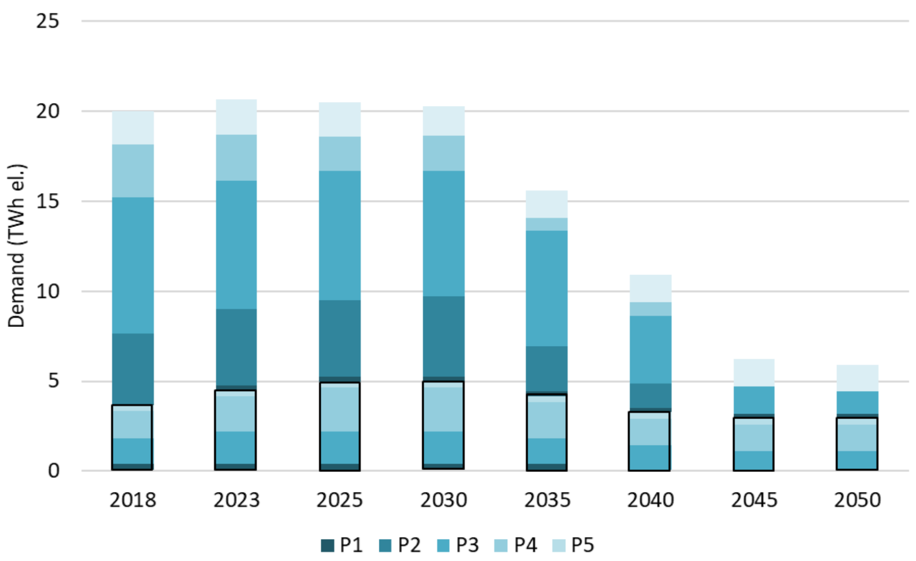

FIGURE 36: DEMAND PROJECTIONS ASSUMED IN THE BASE CASE FOR THE FIVE OFFSHORE REGIONS FROM 2018 TO 2050. ELECTRIFICATION FROM EXISTING POWER FROM SHORE IS MARKED BY THE BLACK BOX. REMAINING DEMAND CAN BE COVERED BY GAS OR NEW ELECTRIFICATION.

In short, the industry develops as follows in the three scenarios:

- Aluminium:
  - High scenario - three new production lines (50 % increase in el demand in total)
  - Medium scenario – one new production at Karmøy in 2040 and close down of one plant (20% increase in el demand in total)
  - Low scenario – no new plant and close down of two plants (14% decrease in el demand in total)
- Other metals:
  - All scenarios – planned production expansion at two plants
  - High scenario – annual increase of 1% + one new green steel plant
  - Low scenario – close down of one plant
- Chemicals:
  - Medium & High scenario – no changes
  - Low scenario – decrease, no petro-chemical industries from 2040- (Yara fertilizer production is electrified)
- Non-metallic minerals:
  - High & medium scenario – constant / small increase
  - Low scenario – close down of two plants
- Wood:
  - High scenario – one mill annual increase of 2%
  - Medium scenario – no changes
  - Low scenario – several shut-downs, decrease to about 50% power demand
- Other industry, construction, agriculture:
  - Medium & High scenario – increase by population or GDP w/decrease in energy intensity
  - Low scenario – no changes
- Oil & Gas extraction

  - Medium & High scenario – as assumed by «Sokkeldirektoratet»
  - Low scenario – no extraction from 2040
- Onshore petroleum
  - Medium & High scenario – close down of Mongstad refinery by 2050
  - Low scenario – no activity from 2040-
- Battery manufacturing:
  - High scenario - four plants
  - Medium scenario – two plants (in 2030 and 2050)
  - Low scenario – no plant
- DATA centers
  - High scenario – increase to 16 TWh in 2050
  - Medium scenario – increase to 4 TWh in 2050
  - Low scenario – increase to 2 TWh in 2050
- Other new production / hydrogen for export
  - High scenario – increase to 18 TWh electricity in 2050 (+ 100 TWh blue hydrogen)
  - Medium scenario – increase to 1 TWh electricity in 2050
  - Low scenario – no plants

A5 Transportation - Demand projections

An edited and shorter version of the details of the demand calculations from (Rosenberg et al., 2024) is presented below.

For the transport sector, the demand projections carried out by the Institute of Transport Economics (TØI) in the context of the National Transport Plan (NTP) 2025-2036 is used as the main source of information. Namely, the reports for personal transport (TØI-report 1926/2022) (Madslien & Steinsland, 2022) and freight transport (TØI-report 1918/2022) (Madslien et al., 2022) are used as basis, which include estimates from the BIG and NGM models, respectively. These transport demand projections have 2020 as start year and projected estimates for 2030 and 2060 for different transport segments, as well as the relative value change between these years. To fit the model inputs in IFE-TIMES-Norway, additional estimates for 2050 are calculated by scaling the transport demand values for 2030 with the relative change in the 2030-2060 period.

The NTP demand projections are used in INC and TEC, while an alternative lower demand projection which follows a case with low national population growth and lower transport demand levels by 2050 is used in SOC and RAD.

For road transport, the demands are provided in vehicle-km for the different road transport types. In contrast to this, the demands from the other transport segments are included in the model as energy service demands (specified in GWh per year). More specifically, these demand estimates included historical values from the national energy balance from Statistics Norway (Statistics Norway, 2023d) for domestic aviation, domestic navigation (further divided into maritime passenger and freight transport), fishing, railway, and other vehicle uses for non-transport purposes. The respective energy demands for 2020 were projected towards 2030 and 2050 using the projected demand increases from the NTP reports as scaling factors.

The passenger transport demand projections have been aggregated to correspond to the five electricity spot market areas. The results of this aggregation are presented in Figure 37 for the estimates derived from the NTP 2025-2036 projections, which shows that an increase in transport demands from personal passenger cars is expected across all areas. In NO1 and NO2 an increase of over 25% is expected by 2050 relative to the demands in 2020. Similarly, the demands in NO3 and NO5 are expected to increase by about 22-23% in 2050 relative to the values in 2020. Meanwhile, a more modest increase of only about 9% is expected in NO4, for the same periods.

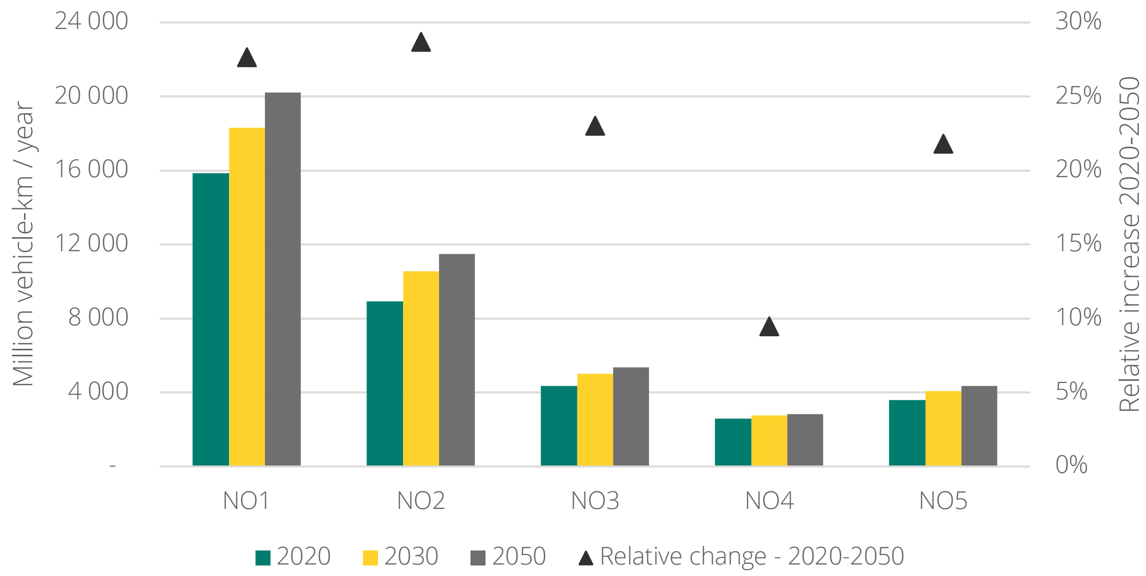

FIGURE 37: TRANSPORT DEMAND DEVELOPMENT IN INC AND TECH BY SPOT MARKET AREA AND RELATIVE CHANGE IN TRANSPORT DEMAND (2020-2050) FOR PERSONAL PASSENGER VEHICLES (CARS).

The transport demands for heavy freight also see upward trends from 2020 to 2050, based on the NTP 2025-2036 projections. As seen in Figure 38, NO3 and NO4 are the regions with larger expected increases in freight transport demands by 2050 relative to the 2020 values. These demands are further divided into three truck classes, and the overall developments, and relative changes from 2020 to 2050 follow the same trends.

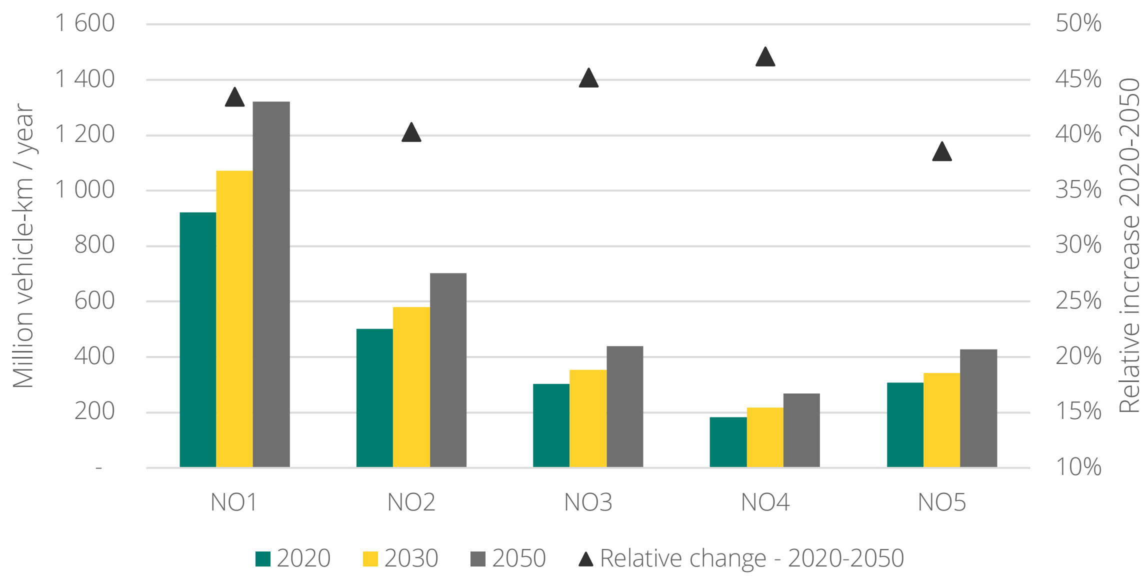

FIGURE 38: TRANSPORT DEMAND DEVELOPMENT IN INC AND TECH BY SPOT MARKET AREA AND RELATIVE CHANGE (2020-2050) FOR HEAVY ROAD FREIGHT TRANSPORT.

The demand in the other transport segments, namely in domestic aviation, domestic sea transport, rail, and other non-road vehicle uses are modelled in terms of energy use. The corresponding energy demand in these transport segments was estimated using as basis the growth projections from the NTP 2025-2036 data, the energy balances from Statistics Norway, and regional and segment splits. The resulting projections showing the energy demand for these segments are presented in Figure 39.

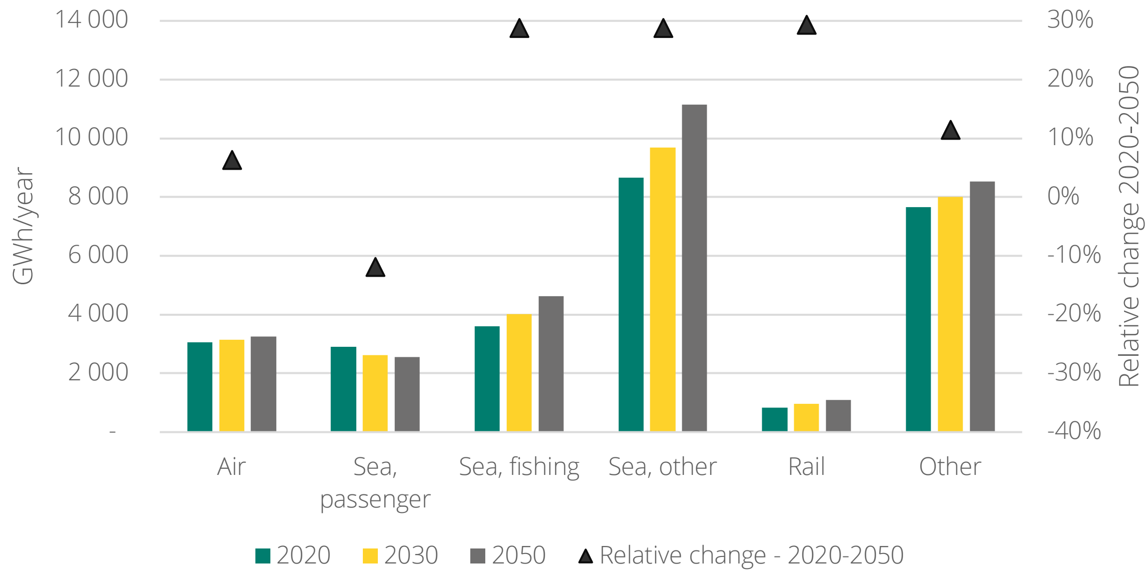

FIGURE 39: ENERGY DEMAND DEVELOPMENTS IN INC AND TECH AND RELATIVE CHANGE VALUES (2020-2050) FOR TRANSPORT SERVICES IN AIR, SEA, RAIL AND OTHER TRANSPORT SEGMENTS.

In the LOW alternative (used in SOC and RAD), it is assumed that the same per capita transport demands as in the NTP 2025-2036 projections are kept, with correspondingly lower population values. This assumption results in an increasing trend in transport demands by 2030, corresponding to the recent NTP projection. In 2050, it is assumed that the transport demand decreases, reaching the same per capita transport demands levels as 2020. Transport demand growth rises until 2030, and then falls to similar levels as in 2020, thus diverging from the NTP projection from 2030 onwards.

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