Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ENERGY EFFICIENCY, DISTRICT HEATING AND HEAT PUMPS FOR REDUCED POWER CONSUMPTION

Potential scenarios for Norwegian building mass towards 2050

ZEN REPORT No. 47 – 2023

Hanne Kauko, Benjamín Manrique Delgado, Stian Backe, Igor Sartori | SINTEF

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Preface

Acknowledgements

This report has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, AFRY, Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Nord-Trøndelag Elektrisitetsverk - Energi, Smart Grid Services Cluster, Statkraft Varme, Energy Norway and Norsk Fjernvarme.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, an NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Norwegian Summary

Energieffektivisering, fjernvarme og varmepumper for redusert kraftbehov

Det norske kraftsystemet står overfor enorme utfordringer i overgangen til et fossilfritt samfunn. Den pågående elektrifiseringen av transport og industri, sammen med etablering av ny kraftintensiv industri, krever rask og omfattende økning i både produksjon av fornybar elektrisitet og transmisjonskapasitet. Denne økningen kunne delvis unngås gjennom energieffektivisering sammen med økt bruk av varmepumper og alternative energibærere til oppvarming. Redusert energibruk i bygninger og mer utbredt bruk av fjern- og nærvarme har et stort potensial for å redusere strømbehovet i Norge, og samtidig bidra til økt energisystemfleksibilitet, i perioder når nettet er høyest belastet.

Ved å kombinere ambisiøse energieffektiviseringstiltak med økt bruk av fjernvarme i urbane områder og varmepumper i distriktene kan energibruken til bygninger og spesielt etterspørselen til elektrisitet reduseres betydelig.

Vi har i denne studien kvantifisert potensialet for økt bruk av fjernvarme og varmepumper for å redusere strømbehovet i Norge. Det fremtidige energibehovet til den norske bygningsmassen, delt i tre ulike grupper i forhold til beboertetthet, ble først modellert i ulike scenarier i forhold til energieffektivitet og bruk av vannbåren oppvarming. Resultatet ble deretter brukt i en energisystemmodell for å ta hensyn til ulike energikilder og fleksibiliteten som er tilgjengelig i produksjon av fjernvarme.

Studien viser at økt bruk av fjernvarme reduserer det totale strømforbruket, og da spesielt topplastbehovet. Sammenlignet med 2020-nivået, vil fortsettelse med dagens praksis føre til en økning på +3 % i total etterspørsel for elektrisitet på grunn av bygninger alene innen 2030, og +7 % innen 2050. Den tilsvarende økningen i topplastbehov er +2 % innen 2030 og +5 % innen 2050. Gjennom maksimal bruk av fjernvarme vil det totale elektrisitetsbehovet forbli på 2020-nivå, mens toppeffektbehovet kan reduseres med -1 % innen 2030 og -5 % innen 2050.

En betydelig reduksjon i både det totale strømbehovet og topplastbehovet oppnås først når maksimal bruk av fjernvarme kombineres med ambisiøs energieffektivisering og maksimal bruk av varmepumper i distriktene. I et slikt scenario er det mulig å oppnå en reduksjon på -12 % i det totale strømbehovet innen 2030 og -26 % innen 2050 sammenlignet med 2020-nivået. Toppeffektbehovet kan reduseres med -17 % innen 2030 og -35 % innen 2050.

Resultatene er av største betydning for alle interessenter som er involvert i utviklingen av energisystemet i Norge, på lokalt og nasjonalt nivå. Kuldeperioder om vinteren, og ineffektiv bruk av strøm til oppvarming, er drivkraften for investeringer i kraftsystemet. Massiv utvidelse av kraftproduksjon og overføringskapasitet kan delvis unngås med sterkt fokus på energieffektivisering i bygg sammen med økt bruk av fjernvarme for oppvarming i tettbygde strøk, og varmepumper i rurale områder. Dette kan redusere de totale systemkostnadene for energiproduksjon og spare naturen for unødvendige ytterligere inngrep.

Summary

Energy efficiency, district heating and heat pumps for reduced power consumption

The Norwegian power system is facing enormous challenges in the transition to a fossil-free society. The on-going electrification of transport and industry, together with establishment of new power-intensive industries, calls for rapid and extensive increase in both production of renewable electricity and the transmission grid capacity. This increase could partly be avoided through energy efficiency measures, heat pump adoption, and the use of alternative energy carriers for heating. Reduced energy delivered to buildings together with increased use of district heating have a great potential to reduce Norwegian electricity demand, and at the same time contribute to increased energy system flexibility when the grid is under the highest load.

Combining ambitious energy efficiency measures with maximal use of district heating in urban areas and heat pumps in rural areas can reduce the energy use and particular the demand for electricity significantly.

The aim of this study was to quantify the potential for increased use of district heating and heat pumps on reducing buildings' future electricity demand in Norway. The future energy demand of the Norwegian building stock, divided into three different groups with regards to population density, was first modelled in different scenarios with respect to energy efficiency and potential access to district heating network. The outcome was then applied in an energy system model to account for different energy sources and the flexibility available in the production of district heating.

The study shows that increased use of district heating reduces buildings' electricity consumption, and in particular the buildings' peak power demand. Comparing to 2020 level, continuing with business-as-usual will lead to 3% increase in buildings' electricity demand by 2030, and +7% by 2050. The corresponding increase in buildings' peak power demand is +2% by 2030 and +5% by 2050. Maximizing the use of district heating without ambitious energy efficiency standards will allow the buildings' electricity demand to remain at the 2020 level, while buildings' peak power demand could be reduced with -1% by 2030 and -5% by 2050.

A net reduction in both total electricity and peak power demand in buildings is achieved only when maximal use of district heating is combined with ambitious energy efficiency standards and maximising the use of heat pumps in rural areas where district heating is not feasible. This scenario allowed a reduction of -12% in buildings' electricity demand by 2030 and -26% by 2050, compared to 2020 levels. The buildings' peak power demand could be reduced with -17% by 2030 and -35% by 2050.

The results are of utmost importance for all stakeholders involved in the development of the energy system in Norway, at local and national level. Cold periods in the winter, and the inefficient use of electricity for heating, are the driving force for investments in the power system. Massive extension in the power production and transmission capacity can be partially avoided with strong emphasis on buildings' energy efficiency, together with the use of district heating in urban areas and heat pumps in rural areas. This can reduce the total system costs for energy production and spare the natural environment for unnecessary further intervention.

Contents

1 Introduction

The Norwegian energy system is facing enormous challenges in the transition to a fossil-free society. The on-going electrification of transport and industry, together with establishment of new power-intensive industries, calls for rapid and extensive increase in both production of renewable electricity and enhancement in the transmission grid capacity, as is highlighted in the recent report by the Energy Commission (Sørgård et al., 2023). This will require vast investments and put an increased pressure on the already threatened natural environment.

At the same time, there are several possibilities for reducing the demand for electricity through energy efficiency measures and the use of alternative energy carriers and heat pumps for heating. Today, the building sector is dominating the electricity demand in the Norwegian power system. Cold periods in the winter, and the inefficient use of electricity for heating, are the driving force for investments in the power system. Reduced energy use in buildings and more widespread use of waterborne heating systems and district heating have great potential to reduce the electricity demand, and at the same time contribute to increased energy flexibility, during periods when the grid is most heavily loaded. Integrated and efficient energy systems, with interaction in the different energy carriers, is lifted up as one of the main focus areas and a prerequisite for a robust, competitive and environmentally friendly energy supply for Norway in the recently published Energi21 strategy (Mostue et al., 2022).

There is however little knowledge on the actual energy reduction potential of energy efficiency measures, or the impact of increased use of district heating on the energy system. The Energy Commission estimates that increased energy efficiency in buildings has a realistic energy reduction potential of 15-20 TWh from today’s level by 2030, although there is a great uncertainty related to this estimate (Sørgård et al., 2023). Regarding district heating, the Commission estimates that the production could be increased by 2-4 TWh by 2030, and the double of this by 2040. In the research project FlexBuild, it is estimated that district heating could contribute to an increased annual production of 5 TWh, considering the amount of waterborne heating system that exists today (Sartori et al., 2022).

The current use of district heating for buildings’ heating in Norway is 5.6 TWh (SSB, 2022a). The total energy use in households and commercial buildings is 78 TWh (Olje- og energidepartementet, 2021), out of which approximately 53 TWh goes for heating purposes. The share of district heating of the total heat supply is thus approximately only 10%. How would an increase in the use of district heating, combined with energy efficiency measures in buildings, affect the anticipated future needs for increasing the grid capacity?

In a previous study, the potential for ambitious energy efficiency measures combined with maximal use of heat pumps in reducing the total energy demand for buildings was estimated (Sandberg et al., 2022). Compared with 2020 level, the reduction potential was estimated to 12.7 TWh by 2030 and 21.3 TWh by 2050. The study did however not evaluate the impact of increased use of heat pumps on the total demand for electricity or the peak power demand. The use of district heating as a measure to reduce electricity demand was beyond the scope of this previous study.

The objective of the present study is therefore to quantify the potential of increased energy efficiency in buildings and the use of district heating and heat pumps on the future power demands in Norway. Building up on the results from the FlexBuild-project, the project will apply the tools PROFet (Heimar Andersen et al., 2021; Lindberg et al., 2019) and RE-BUILDS (Sandberg et al., 2021) to forecast the future energy demand in the Norwegian building mass, divided into three different groups with regards to population density. District heating is prioritized for heat supply in high- and medium density areas, and heat pumps in rural areas. Consequently, the energy system modelling tool Integrate is applied to assess the impact of increased heat supply from district heating, considering the different sources applied for heat production (Bakken et al., 2007; Kauko et al., 2022).

1.1 Disposition

The report is organized as follows. Section 2 presents the methodology for assessment of the building mass and its energy use, and the different scenarios evaluated. Section 3 presents the approach for the energy system modelling. Section 4 presents the results from the assessment of the building mass and the energy system modelling, and Section 5 concludes the report.

1.2 Terminology

The terms *energy demand* and *energy use* in this memorandum follow the FME ZEN terminology. Thereby, *energy demand* is a theoretical size used to describe the energy demand linked to energy services and energy needs in buildings such as the demand for energy for heating of domestic hot water, space heating, ventilation, lighting, plug loads and so on. When calculating the energy demand, losses in the system are ignored. Depending on the system boundary, the calculated energy demand is referred to as net energy demand or gross energy demand. *Energy use* is a measurable size which can be linked to both energy services and energy carriers (such as electricity, fuels, district heating etc.), which also considers losses within the building. Therefore, in Section 2 the energy demand is calculated and used to calculate the energy use, which in turn is given as input to the energy system model described in Section 3.

2 Assessment of the building mass and its energy use

The energy that is needed to cover the electricity and heat demand of the building stock depends on factors related to the building stock, such as its size and composition, the building purpose (i.e. residential buildings, offices, hotels, etc.), and the energy demand intensity. Moreover, it also depends on factors related to the technologies used to cover the needs for space heating and domestic hot water. Namely, it is necessary to know the types of technology present in the building stock, its efficiencies, and their energy carriers. A schematic representation of the calculation process and needed data to assess the energy use in the building stock of Norway is shown in Figure 1.

The process is simple but not easy, because of the amount of input data and assumptions needed. For the results to be useful, it is necessary to have detailed data on the current state of the building stock, as well as estimations for its development. There should also be a tool for forecasting what would the energy and heat demand of the building stock be. It is also necessary to have estimates for the distribution of heating technologies in the building stock, as well as estimates on how their distribution will develop in the future, and to know their efficiencies. Finally, before any projections can be made for development under a given scenario, the model should be calibrated with available statistical data. This section will present the approaches followed for each of these steps, as well as the tools and data used to this purpose.

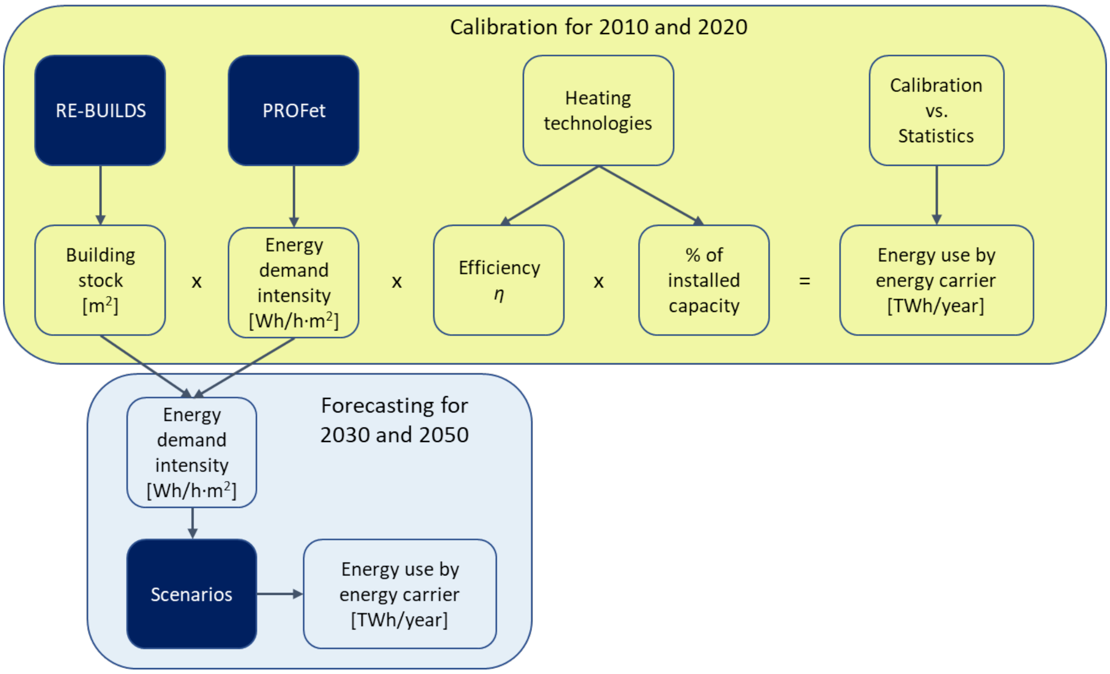


Figure 1 Calculation procedure of energy use by the building stock in the development scenarios.

2.1 Building stock: RE-BUILDS

The development of the building stock in the country is modelled using RE-BUILDS (Sandberg et al., 2021). This tool addresses the dynamic development of the complete building stock, including both residential and non-residential buildings. The demand for floor area, and thus the long-term development of the building stock, is estimated based on Population, Lifestyle parameters, Demolition rates and Renovation rates.

RE-BUILDS also allows including some types of granularity or additional characteristics, such as the stock in each energy market area, access or not to a thermal network, and type of heating (Point Source [PS] or Waterborne [WB]). These three types of differentiation are needed for the analysis here presented, as the presence or absence of a thermal network dictates whether a building can cover its heat demand by importing heat from the grid; further, the type of heating determines the technologies that are viable in the buildings. For example, neither district heating nor ground-source heat pumps can be used in buildings where there is not a WB heating system. The building stock in Norway in 2020, disaggregated by the mentioned characteristics, is shown in Table 1.

Another important capability of RE-BUILDS is that the renovation rates reflect the percentages of renovations that lead to an energy upgrading, and that include a conversion from PS to WB heating system. This allows a better insight to the development of the energy demand and energy use by the building stock, as the energy upgrades influence how much energy needs to be supplied by the heating system, while the presence of WB or PS heating determines the type of technologies that can be used.

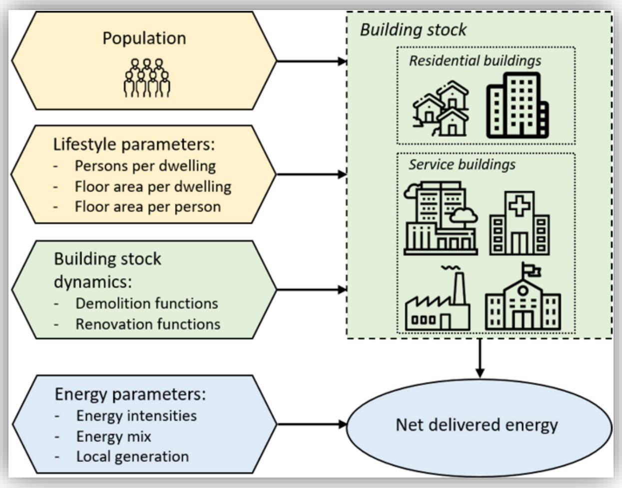


Figure 2 Conceptual model outline of RE-BUILDS. Adapted from (Sandberg et al., 2021).

2.2 Energy demand intensity: PROFet

PROFet (Heimar Andersen et al., 2021; Lindberg et al., 2019) is an aggregated load profile generator which can predict hourly load profiles of space heating demand, domestic hot water demand and electric specific demand for a given building floor area – or a combination of buildings – and a temperature profile. It considers different building types – houses, apartments, and nine types of service buildings – and efficiency levels ranging from average of the national stock to buildings with energy efficiency like that of passive houses. The tool consists of a regression model based on measured data from 2,5 mill m^2 of heated area in existing buildings in Norway. Detailed information about the methodology is given in (Heimar Andersen et al., 2021; Lindberg et al., 2019), and the estimated energy demand of the Norwegian building stock in 2020 is shown in Table 2.

In this study, the energy demand of the building stock has been calculated separately for each of the five energy market areas in Norway (NO1 to NO5), using representative weather data for the cities of Oslo, Kristiansand, Trondheim, Tromsø and Bergen. Moreover, in line with the granularity made possible by the RE-BUILDS model, the building stock in each energy market area is further divided by energy efficiency: *regular*, *efficient*, and *very efficient* buildings; by access to a thermal grid: large-scale district heating, local district heating, and no thermal network; and by heating system: Point Source (PS) or Water Borne (WB).

Table 1 Building stock in Norway in 2020 by building type, efficiency and type of heating, and with access to a large district heating (DH) or local heating grid (LH), or with no access to a thermal grid (NTN), in m^2.

	House			
	Regular		Efficient	
	PS	WB	PS	WB
DH	53 481 429	7 292 922	8 143 146	1 110 429
LH	83 206 411	11 346 329	12 669 106	1 727 605
NTN	31 439 885	4 287 257	4 787 074	652 783
	Apartment			
	Regular		**Efficient**	
	PS	**WB**	**PS**	**WB**
DH	7 591 393	4 652 789	3 977 303	2 437 702
LH	10 423 190	6 388 407	5 460 945	3 347 031
NTN	3 768 468	2 309 706	1 974 386	1 210 107
	Service			
	Regular		**Efficient**	
	PS	**WB**	**PS**	**WB**
DH	13 803 589	19 062 099	3 024 724	4 177 000
LH	20 431 652	28 215 139	4 477 104	6 182 668
NTN	7 555 825	10 434 234	1 655 677	2 286 411

Table 2 PROFet estimates of the electricity and heat demand in the Norwegian building stock in 2020, in TWh.

	House	Apartment	Service
Electricity	8.8	2.1	16.7
SH	26.4	5.4	11.2
DHW	4.4	2.2	2.4
Total	**39.6**	**9.7**	**30.3**

2.3 Heating technologies

There are three main aspects of the heating technologies which influence the annual energy use by energy carrier: the share of the energy demand in the building stock that each heating technology covers, their energy carriers (electricity, district heating, biomass, etc.), and their efficiencies for space heating and for domestic hot water preparation. The values shown in this section are the adjusted values after the calibration process.

2.3.1 Efficiencies and energy carriers

The technologies included in this study are those currently in widespread use in Norway; their energy carriers and efficiencies after model calibration are shown in Table 3. The efficiency of the heat pumps has been adjusted to reflect the portion of their generation that is used for DHW preparation. Heat pump efficiency decreases as output temperature increases, and DHW demand requires higher temperatures than space heating demand. Furthermore, the efficiency of heat pumps is different between building types because the share of DHW preparation in the total heat demand depends on the type of building. Moreover, air-source heat pumps in houses tend to be air-to-air heat pumps, whereas in larger buildings they are air-to-water heat pumps, and the former usually have lower efficiencies than the latter.

Table 3 Energy carriers and efficiencies of heating technologies.

		Efficiency		
Technology	**Carrier**	**House**	**Apt.**	**Serv.**
Electric heater	Electricity	98 %	98 %	98 %
Electric water heater	Electricity	98 %	98 %	98 %
Heat pump air-source	Electricity	170 %	210 %	210 %
Heat pump ground-source	Electricity	240 %	260 %	260 %
Pellets boiler	Biomass	90 %	90 %	90 %
LPG boiler	Natur. Gas	90 %	90 %	90 %
District Heating	DH	95 %	95 %	95 %
Wood stove	Biomass	40 %	40 %	0 %

2.3.2 Share of installed capacity in the building stock

The availability of each technology to cover the space heating and domestic hot water demand in the different scenarios is determined by several conditions: the type of building, the type of demand, the type of heat distribution in the building, access, or lack thereof, to a thermal network, and the year and scenarios themselves. Regarding building types, some technologies are better suited, or simply more popular, for houses than for apartments, and service buildings also tend to prefer other technologies than residential buildings. The type of distribution is determining to the choice of technology as well since technologies such as ground-source heat pumps or district heating require a waterborne heating system to function. Moreover, some technologies, such as air-to-air heat pumps, can cover space heating demand but not domestic hot water demand. Access to a thermal network determines whether district heating can be used or not. Finally, the year and scenario determine how, and how much, the shares of technologies change. A summary of the criteria that determine the availability and share of heating technologies is shown in Figure 3, and the distribution of heating technologies in 2020 is shown in Figure 4.

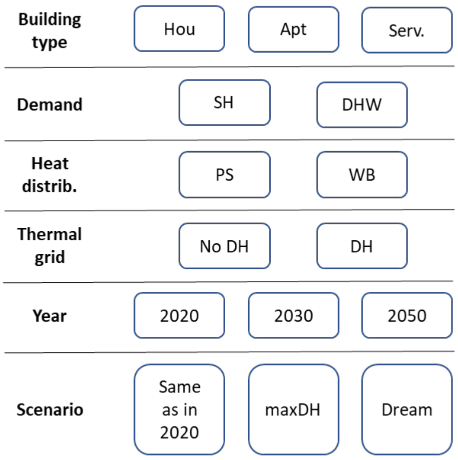


Figure 3 Criteria for the availability and share of installed capacity of heating technologies.

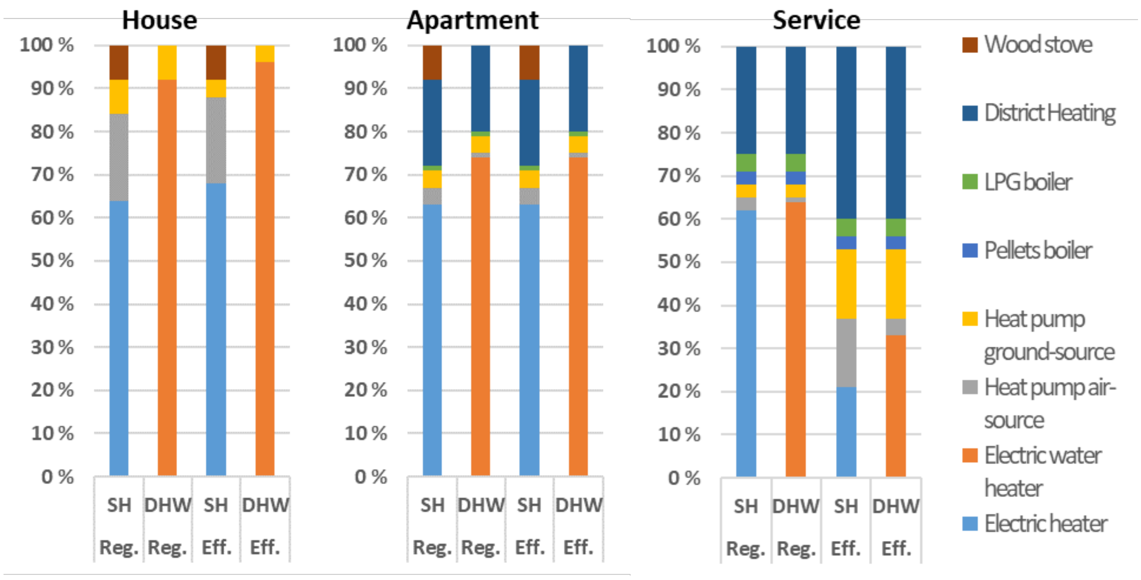


Figure 4 Distribution of heating technologies in the Norwegian building stock in 2020.

2.3.3 Wood as heating technology

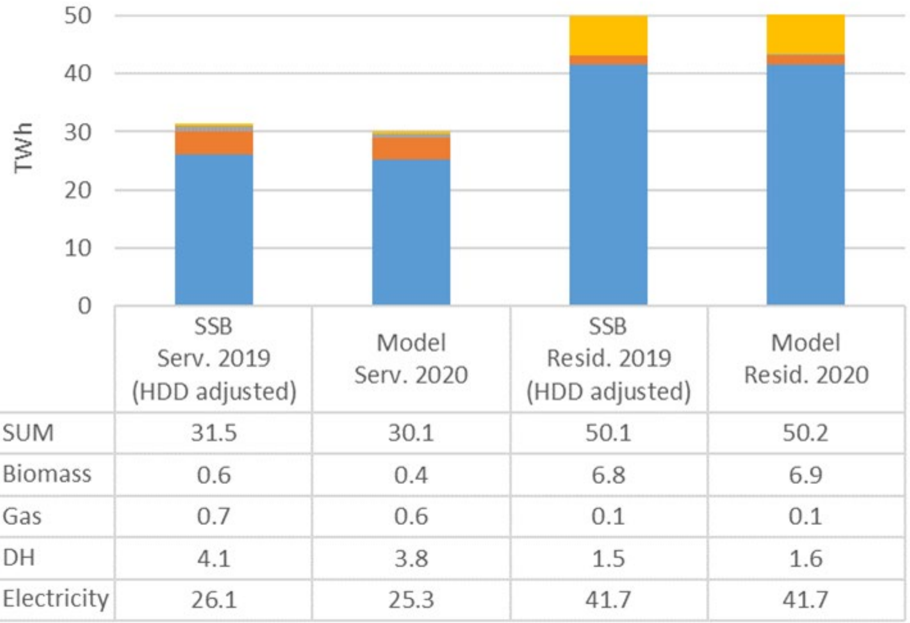
The use of wood in this study is treated differently from the other technologies. It is only available in residential buildings, and its use is related to seasons, day of the week and time of the day, and not strictly related to outdoor temperatures. The use of wood is here considered to be directly controlled by the building occupants according to the following rules:

- It is only used between September 16 and April 15.
- During weekdays it is used from 6:00 to 8:00 and from 18:00 to 23:00, and it covers 15% of the space heating demand.
- During weekends it is used all day, and it covers 25% of the space heating demand.

The development of this set of rules, as well as the resulting energy use, were part of the calibration process described in the next section.

2.4 Calibration results in 2020

The results from the model are compared to statistical data for calibration purposes. Particularly, the technology efficiencies and distribution in the building stock were adjusted so that the total energy use would reach values similar to those published by Statistics Norway (SSB), the Norwegian statistics bureau (SSB, 2022b). The results from the model and the statistical data are shown in Figure 5. The statistical data is from 2019, whereas the model uses representative weather profiles that aim to represent an average year. Therefore, to compare the statistical data with the results from the model, the statistical data is adjusted for *heating degree days* (HDD). That is, the annual energy demand is multiplied by a factor to compensate the deviation between the weather of the year 2019 and the average weather. The comparison shows that model results are close to the statistical data. The energy use in residential buildings shows an error within 0.1 TWh, with biomass and district heating use being higher than the statistics. The error in the energy use in service buildings is higher, reaching a deficit of 1.4 TWh distributed among all energy carriers, but remains within 5% of the statistical data, and is deemed acceptable for the purpose of this study.



	SSB Serv. 2019 (HDD adjusted)	Model Serv. 2020	SSB Resid. 2019 (HDD adjusted)	Model Resid. 2020
SUM	31.5	30.1	50.1	50.2
🟨 Biomass	0.6	0.4	6.8	6.9
■ Gas	0.7	0.6	0.1	0.1
🟧 DH	4.1	3.8	1.5	1.6
🟦 Electricity	26.1	25.3	41.7	41.7

Figure 5 The statistical data on energy use in 2019 adjusted for Heating Degree Days (HDD) (SSB, 2022b), and the calculated energy use in 2020.

2.5 Scenarios

The scenarios are meant to represent different strategies towards reducing energy use in the building stock. A summary of the main characteristics of the four scenarios is shown in Table 4.

The *Baseline* scenario is meant to represent a *Business-as-usual* development of the building stock and choice of heating technologies. In this scenario, all new construction adheres to the current energy efficiency regulations, and as such they are treated as *efficient* buildings; there are no *very efficient* buildings in this scenario. Further, only 20% of the renovated buildings are energy upgraded. This results in 80% of renovations having no impact on the energy demand. As for heating technologies, the standard selection based on the SSB data and model calibration in 2020 is set to remain the same until 2050, including the existing share of WB heating.

The *Energy efficiency* [EnEff] scenario presents a situation where the focal point for energy savings is the thermal insulation of the building stock. In this scenario it is stipulated that all new construction must adhere to passive-house standards, and thus are considered very efficient. Further, all the renovated buildings must be energy upgraded. This means leads to a reduction in the energy demand of the stock, which in turn leads to a reduction in the energy use. However, this scenario does not include any actions to favour access to thermal grids, nor does it include actions that may promote using more efficient technologies, such as favouring waterborne systems and/or heat pumps.

The *maximum District Heating* [MaxDH] scenario represents a case where thermal grids are given priority for heat supply to the building stock. In this scenario, all new and renovated buildings get waterborne heating to make it possible for them to use heat from a thermal grid. Moreover, if a building has waterborne heating and access to a thermal grid, it is stipulated that the building must be connected to that grid (as opposed to having the choice to use a different technology). Because of this, it is intrinsic to this scenario that the efficiency of the thermal grids have a stronger impact on the efficiency of the energy system than in other scenarios.

The *Dream* scenario is a combination of the EnEFF and MaxDH scenarios, plus a technology-oriented efficiency measure: where District heating is not available, all buildings must use heat pumps to cover their space heating and domestic hot water demands by 2050.

Table 4 Key characteristics of the four development scenarios.

Scenario	Energy efficiency (building envelope)	Heating technology
1-Baseline	**BAU** - New construction: TEK17 - 20% of renovated buildings are energy upgraded	**Standard selection** Based on SSB data and model calibration for 2020 (incl. existing share of waterborne heating)
2-MaxEff	**MAX** - New construction: passive house - 100% of renovated buildings are energy upgraded	**Standard selection**
3-MaxDH	**BAU+WB** - All new and renovated buildings (even without energy upgrade) get waterborne heating	- Max DH where possible - Elsewhere **standard selection**
4-Dream: MaxEff + MaxDH + HP	**MAX+WB**	- Max DH where possible - Elsewhere **heat pumps**

3 Energy system model

The energy system modelling was carried out using the Integrate-tool developed by SINTEF Energy Research for the optimisation of integrated energy systems with several energy carriers (Bakken et al., 2007; SINTEF, 2022). Integrate can be used to optimise the development of an energy system, while taking into account the projections in energy demand and the different technological possibilities and costs for energy supply. It includes conversion between energy carriers, as well as distribution, storage, end-use measures and restrictions on CO_2 emissions. Integrate considers both operational and investment costs in the optimisation, however, in the present study, only operational costs in terms of costs for energy were considered.

3.1 System boundaries

Figure 6 illustrates the adopted approach for energy system modelling. The energy system for each price zone was modelled separately, with no linking (power lines) in between them. That is, each zone had its own supply of energy: electricity and district heating. Each price zone was further divided to three subareas, depending on the by access to a thermal grid, as explained in section 2.2:

- High-density (HD) areas: large-scale district heating
- Medium-density (MD) areas: local district heating
- Rural areas: no thermal network

For HD and MD areas, there were thus two separate load points: one for heat and one for electricity. For rural areas, only electric load was present, resulting in five load points in total, as shown in Figure 6.

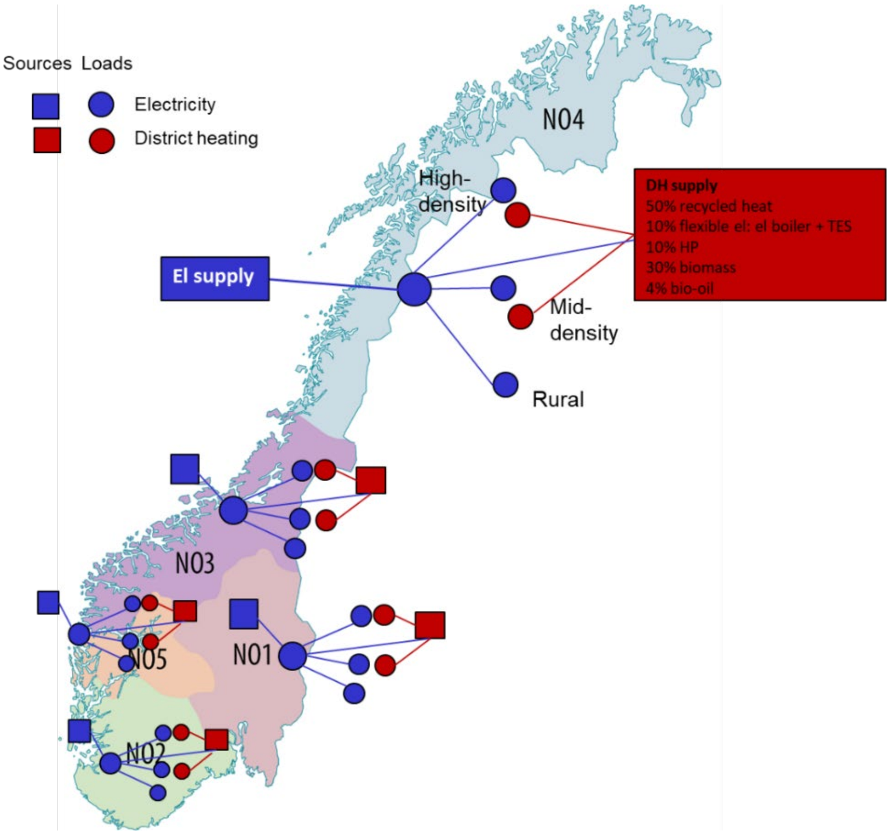


Figure 6 Approach for the energy system modelling.

Figure 7 shows the energy system model in Integrate applied for each price zone, including all the different heat production units as well as thermal energy storage. The heat production will be explained in more detail in section 3.4.

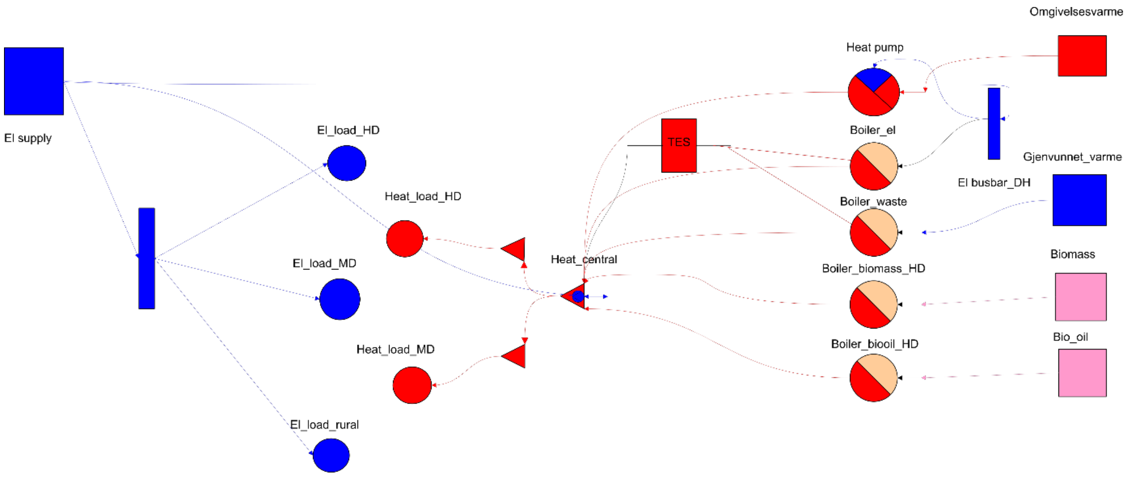


Figure 7 The energy system model in Integrate for each price zone.

3.2 Planning periods

Integrate optimizes the operation of the energy system for a given number of representative periods in a year, and thereafter calculates the optimal investment path for a given planning period, considering changes in production and demand for energy in this period. For the operational optimization in the present study, one week (168 hours) was chosen as the length for the representative period, and a year represented with four weeks: winter, swing (spring and autumn), summer and peak. Table 5 shows the dates and duration for these four representative periods.

Table 5 Representative periods (seasons) for the model in Integrate.

	Period	Except	Duration (weeks)
Winter	05.11. -18.03.	01.01.-07.01.	18
Swing	19.03.-03.06 & 03.09-04.11.		20
Summer	04.06.- 02.09.		13
Peak	01.01.-07.01.		1
			52

The data for energy demand was available for three years: today (2020), 2040 and 2050. For the analysis in Integrate, three planning periods were thus considered, as shown in Table 6. Note that for the present study, no investment options were considered, but the availability of energy and infrastructure for energy distribution was merely set to increase with the increase in demand.

Table 6 Planning periods in Integrate.

Planning period	Corresponding year
2020-2030	2020
2030-2040	2030
2040-2050	2050 (future)

3.3 Energy demand

For each load point and price zone, and each planning period, weekly demand profiles for the representative periods were created, using the data generated with RE-BUILDS and PROFet as explained in section 2. The weekly profiles were created through sectioning each representative period (see Table 5) into weeks and taking an hour-per-hour average of these profiles. Note that due to this periodization and the averaging, the final energy demands applied in the model deviated slightly (in the order of 0.1%) from the results obtained with the demand side modelling. Figure 8 shows as an example the weekly demand profiles for NO1 in the first planning period (2020-2030), for the different subareas and seasons.

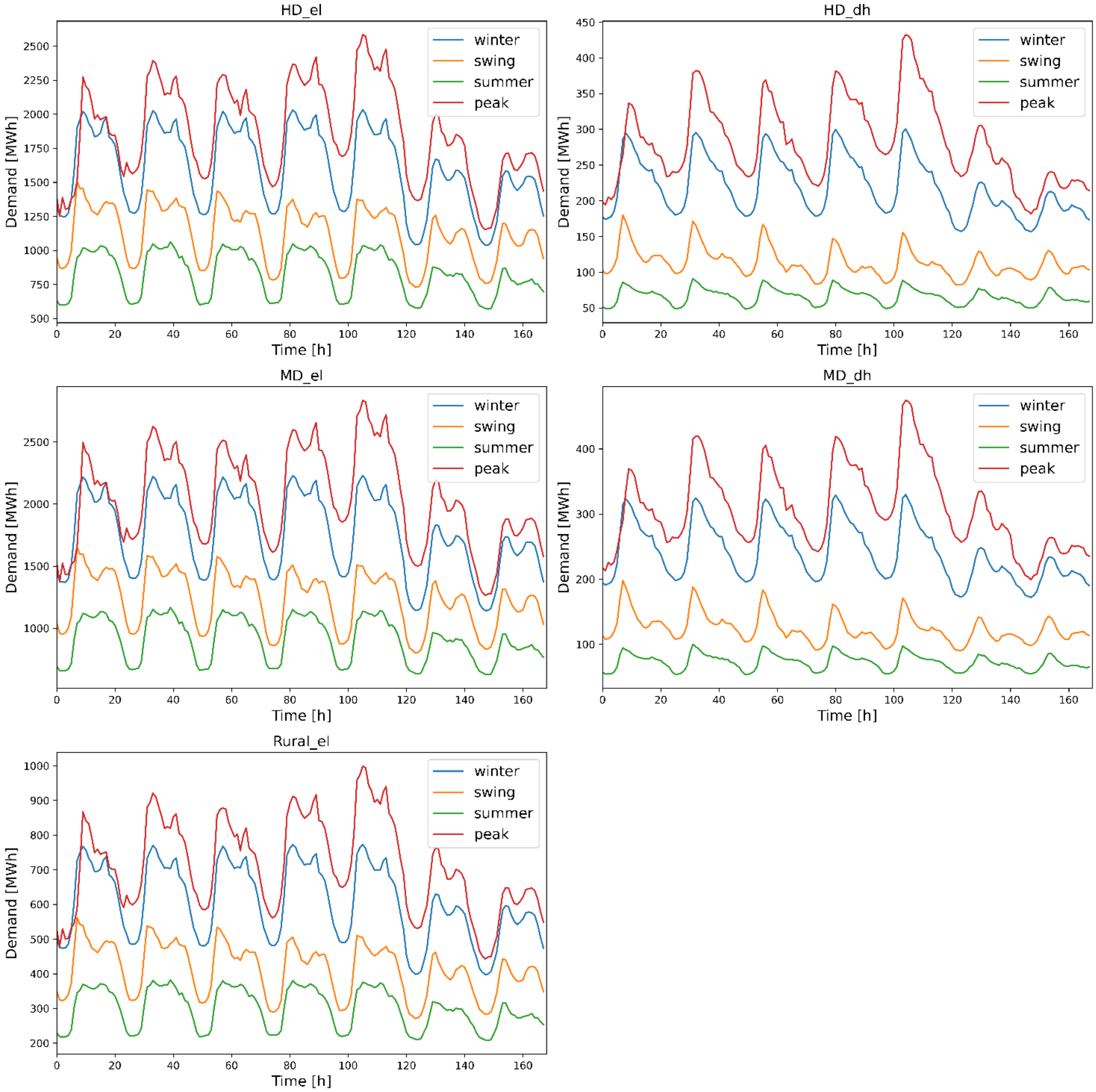


Figure 8 Weekly demand profiles for the different seasons and subareas for NO1, in the first planning period. Note the different y-axis scales in the different graphs.

3.4 Energy supply

For electricity supply, the available capacity for each prize zone was set equal to the maximum demand in 2050. No distribution losses were considered.

For district heating, the division of sources was set according to the information given by the Norwegian district heating association on a national level (Figure 9), apart from the fossil peak load sources, which were replaced with bio-oil. Thus, the following share per source was assumed for each price zone:

- 50 % recycled heat (industry, waste incineration)
- 26 % biomass
- 10 % heat pumps
- 10 % flexible electricity (i.e., dispatchable load)
- 4 % bio-oil

The capacity limit for each source and for each year was calculated using this division and order of sources and the annual district heating demand curve for each price zone as shown in Figure 10 for NO1 in 2050. The same division was applied for both large- and small-scale district heating (high- and medium density populated areas), due to lack of better knowledge on the distribution of sources for in particular small-scale district heating. Waste incineration is used exclusively in large district heating systems, but on the other hand, industrial waste heat is used for district heating in many small municipalities in Norway. Thus, the given distribution of sources is assumed to be representative for entire Norway. Note that Integrate chooses the cheapest mixture of sources for each point of time, depending on the available capacity. Thus, the resulting share per source could deviate from the assumption.

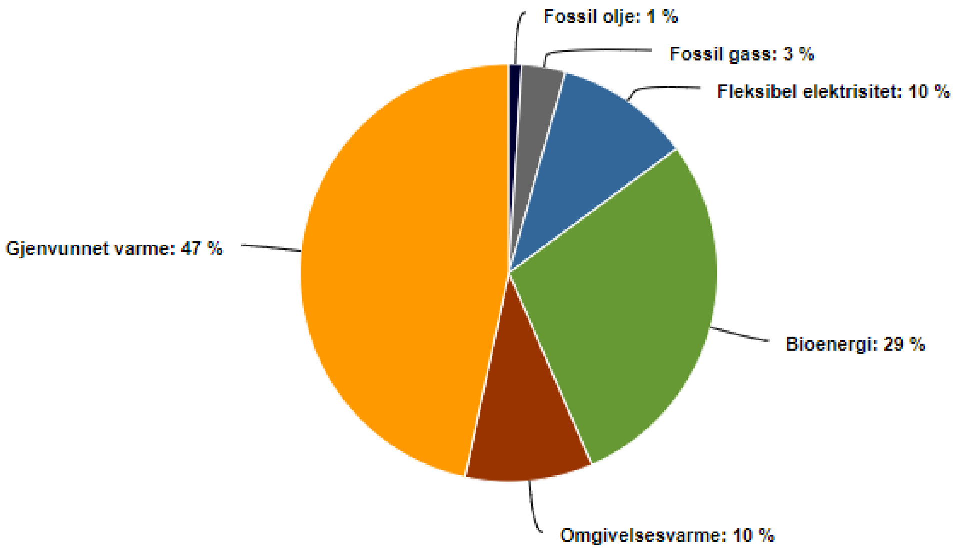


Figure 9 Energy sources applied in the Norwegian district heating supply in 2021 on a national level based on (Norsk Fjernvarme, 2022).

Many Norwegian district heating systems have a thermal energy storage (TES) tank implemented, and in addition the piping network itself represents a thermal storage that many district heating suppliers use actively to reduce peak demands. It was hence decided to include a TES tank in the district heating supply system, to represent the thermal flexibility available in TES systems. Table 7 shows info on some known TES tanks for Norwegian district heating suppliers. Based on these data, and knowing that not every district heating system has a TES tank, the size of the TES was in the present study set to 0.01% of the total district heating demand in the system.

Table 7 TES tanks in Norwegian district heating systems.

Site	Total DH supply [GWh]	TES size [m^3]	TES capacity [MWh]	TES capacity vs total supply
Eidsiva Bioenergi - Hamar	173	6000	280	0.16%
Statkraft Varme - Heimdal	710	5000	350	0.049%
Statkraft Varme - Gardermoen	140	2000	117	0.084%
Bodø Energi	63	925	60	0.095%

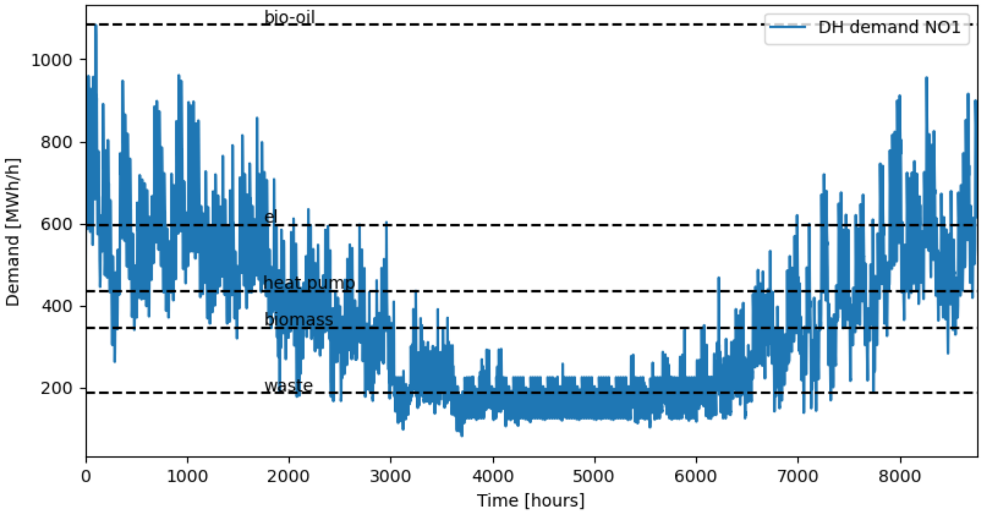


Figure 10 Hourly demand for district heating (large- and small-scale) for NO1 in 2050, together with capacity limits for the different heat sources.

3.5 Energy prices

For district heating sources waste/recycled heat, biomass and bio-oil, constant prices were applied throughout the year and for the entire planning period (Table 8). For electric boiler and heat pump, the spot price for electricity was used, the same applied for the electric specific loads (Figure 11). For heat pump, a seasonal performance factor (SPF) of 3 was assumed.

The electricity prices were based on data from Nord Pool, using an hourly average price from period 2015-2022 to represent the prices for 2020. For the following planning periods, the prices were scaled up according to the baseline scenario in NVE's long-term power market analysis (Birkelund et al., 2021). All fees, taxes and subsidies were excluded from the analysis. Furthermore, as mentioned in 3.2, no investment costs were included in the present study. Investment costs could easily be included in the modelling, but the challenge is to set correct costs in such a large-scale analysis.

Table 8 District heating prices

Source	Price [NOK/MWh]	Emission coefficient [kgCO$_2$/MWh]
Waste / recycled heat	1	0
Biomass: wood chips	220	0
Bio-oil	850	0
Heat pump – SPF 3	Dependent on el-price	0

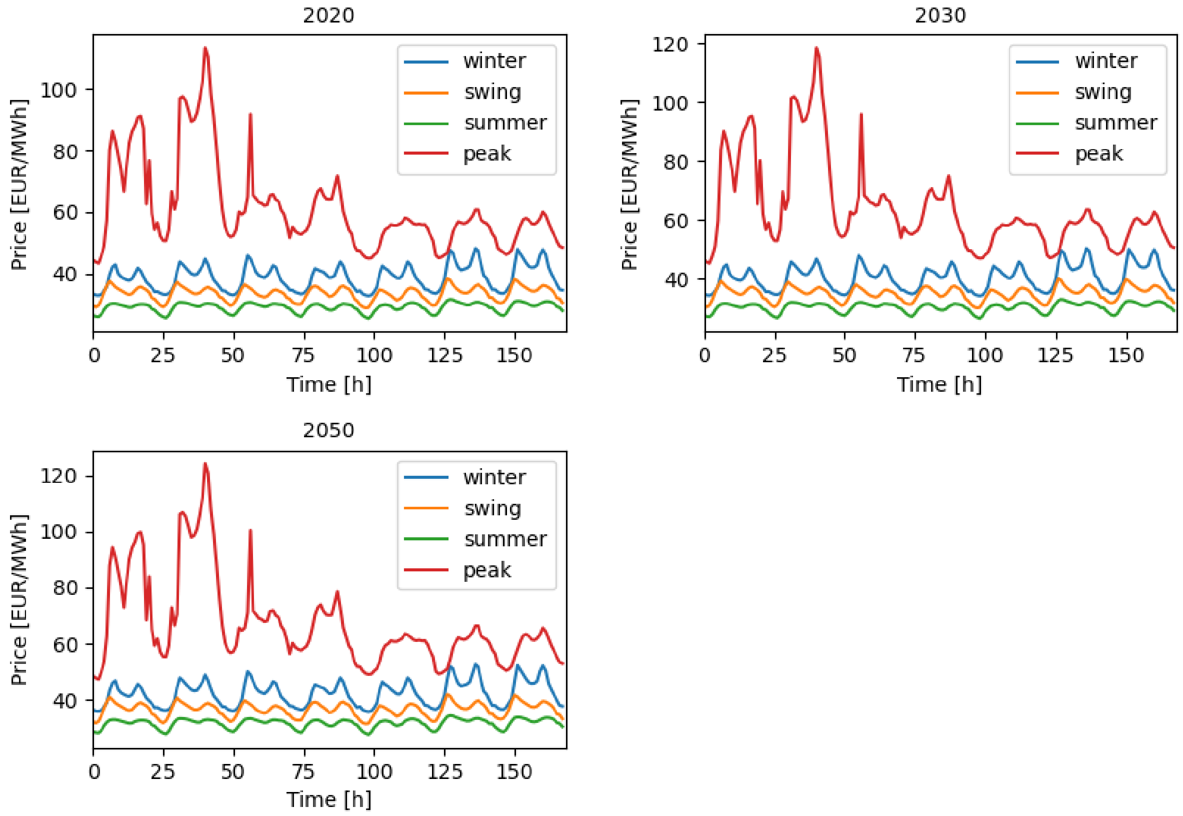


Figure 11 Electricity prices for the representative weeks in different seasons and years for NO1.

4 Results

4.1 Assessment of the building mass

4.1.1 Energy use

The energy use by carrier in the four development scenarios is shown in Table 9. The energy use in 2020 is only shown for the *Baseline* scenario since these values are the same in all scenarios. The Baseline scenario shows an increase in the total energy use of roughly 6 TWh by 2050, mainly concentrated in electricity and district heating. In this scenario there are few mitigation actions to reduce the growth of energy demand in the building stock, and there is also limited shift towards efficient technologies. Further, there is no increased share of WB heating in buildings, so the increased use in district heating, while significant, does not reach its full potential. It should also be noted that energy use increases by 7% for electricity and by 20% for heat. This seems to indicate that growth in the building stock mostly takes in areas where there is access to a thermal grid.

The results of the *Energy Efficiency* scenario indicate that the actions aimed to curtail the growth of energy demand in the building stock are able to counteract its growth: the total energy use reduces by over 2 TWh in 2050 compared to 2020. It also shows a significant difference with respect to the Baseline scenario, using 8 TWh less by 2050. As expected, since the shares of technologies remain the same as in the Baseline, the reduction of energy use is distributed proportionally among the carriers. Nevertheless, this scenario indicates that these actions on energy efficiency are able to curtail the growth of energy demand, but they do not reach a significant reduction with respect to the values in 2020.

The *maximum District Heating* scenario leads to the highest total energy use in 2050 among the four scenarios, and the energy use of district heating increases by 155%, whereas the rest of the carriers show reductions. The development of energy use in this scenario is mostly caused by the differences in efficiencies between the electricity-driven technologies. The efficiencies of district heating and direct electric heating technologies are similar, thus the share of the building stock where district heating replaces direct electric heat would represent a nearly 1:1 conversion ratio from electricity to district heating. However, district heating can only be used in buildings with WB systems, where it is also possible to use heat pumps, and thus there is a trade-off between district heating and heat pumps, the latter having remarkably higher efficiencies.

The *Dream* scenario is the only one that reaches a relatively high reduction of energy use in 2050 compared to 2020, decreasing by 16%. The reduction in use of electricity reaches over 18 TWh, caused both by the higher energy efficiency in the building stock, and by the higher amount of heat pumps in it. Conversely, there is a large increase in the use of energy from the thermal networks, reaching 13 TWh, an increase of 140% compared to 2020. Another significant result of this scenario is that it leads gas and pellets to phase out; wood continues to be used, yet this relates to the special considerations for this carrier described above.

Table 9 Energy use by carrier in the four development scenarios for the Norwegian building stock, in TWh.

		Electricity	DH	Pellets	Gas	Wood	Total
Baseline	2020	66.9	5.4	0.4	0.7	6.9	80.4
	2030	69.0	5.8	0.4	0.7	7.0	82.9
	2050	71.7	6.5	0.4	0.7	7.0	86.2
EnEff	2030	66.9	5.6	0.4	0.6	6.6	80.2
	2050	65.5	5.9	0.3	0.5	5.9	78.1
max DH	2030	67.0	8.2	0.4	0.6	7.0	83.1
	2050	65.4	13.8	0.3	0.5	7.0	87.0
Dream	2030	58.6	8.8	0.3	0.4	6.6	74.8
	2050	48.5	13.0	0.0	0.0	5.9	67.5

4.1.2 Peak loads

The peak loads in the electricity and district heating grids in each scenario and in each market in 2050 area are shown in Figure 12. For comparison, the peak loads in each market area in 2020 are shown in Table 10. The *Baseline* scenario shows that the development of the building stock does not cause a strong increase in the peak load of the electric grid, ranging between 1% and 4% only. In contrast, the peak loads in the district heating grids increase by 13% to 22%. This is in line with the observation above that growth in the building stock mostly takes place in areas with access to a thermal network. The *EnEff* scenario leads to a reduction of the peak loads in the electricity grid between 6% and 10%, but to an increase in the district heating grid between 4% to 7%. This indicates that the energy efficiency measures are enough to reach a net decrease of the peak load of electricity but are not sufficient to curb the growth of demand in the district heating grids. The *MaxDH* scenario shows an interesting outcome: even though there are no efficiency measures in this scenario, the shift towards thermal grids causes a reduction of the peak load of the electricity grid like that of the *EnEff* scenario. This leads, however, to a very large increase in the peak loads in the district heating grids, reaching roughly 2.5 times the peak loads in 2020. In turn, the *Dream* scenario causes peak loads in the district heating grids that are only slightly lower than the *MaxDH* scenario; nevertheless, this scenario also reaches the highest reductions in the peak loads in the electricity grids, with values around 40% lower than in 2020.

Table 10 Peak loads in each market area in 2020, in MW.

	NO1	NO2	NO3	NO4	NO5
El	6 418	3 868	2 319	1 568	1 706
DH	907	451	240	130	187

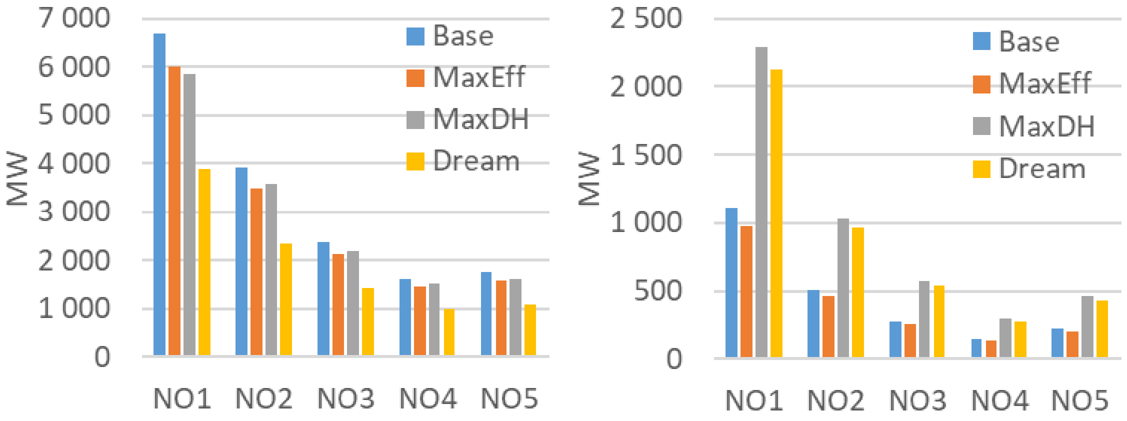


Figure 12 Peak loads in each market area in the electricity (left) and DH (right) grids in 2050.

4.2 Energy system model

From the four different scenarios considered for development of the building mass (see section 2.5 and Table 4), three were analysed with Integrate: *Baseline*, *MaxDH* and *Dream*. In the following, first the results for energy use, peak energy demand, district heating production and energy production costs are present in a more detailed level for NO1, followed by results summarized for Norway in total.

4.2.1 NO1

Table 11 and Table 12 show the total and maximum demand and production, respectively, for electricity and district heating, for the baseline scenario. The total production is equal to the demand for both district heating and electricity, demonstrating that the model works as expected and that all the demands are covered. The total production of electricity (Table 12) includes electricity for district heating production through heat pump and electric boiler, as well as a minimal demand for pumping in the district heating system, and subtracting these demands yields the same number as the total electric specific demand in (Table 11).

Table 11 Total and maximum demand for electricity and DH for NO1 for the different years and sub-areas in base case.

	2020-2030		**2030-2040**		**2040-2050**	
	El [GWh]	DH [GWh]	El [GWh]	DH [GWh]	El [GWh]	DH [GWh]
HD	10 754	1 232	11 174	1 327	11 791	1 502
MD	11 803	1 352	12 264	1 456	12 942	1 648
Rural	3 999		4 139		4 344	
Tot	**26 556**	**2 584**	**27 578**	**2 783**	**29 077**	**3 150**

Table 12 Total and maximum production of electricity and DH for NO1 in base case.

	2020-2030		**2030-2040**		**2040-2050**	
	Tot [GWh]	Max [GW]	Tot [GWh]	Max [GW]	Tot [GWh]	Max [GW]
El tot	26 985	6.58	28 040	6.77	29 616	7.03
El for DH	428	0.16	461	0.17	538	0.19
DH	2 584	0.91	2 783	0.97	3 150	1.07

Figure 13 shows the peak demands for electricity and DH for the different years and scenarios, and the different seasons. The share of electricity used for DH is in general small compared to the total peak electricity demand; however, it is largest in the winter and peak periods. At the same time, the reduction in peak electricity demand in the *MaxDH* and *Dream* scenarios compared to *Baseline* is most prominent in the winter and peak periods.

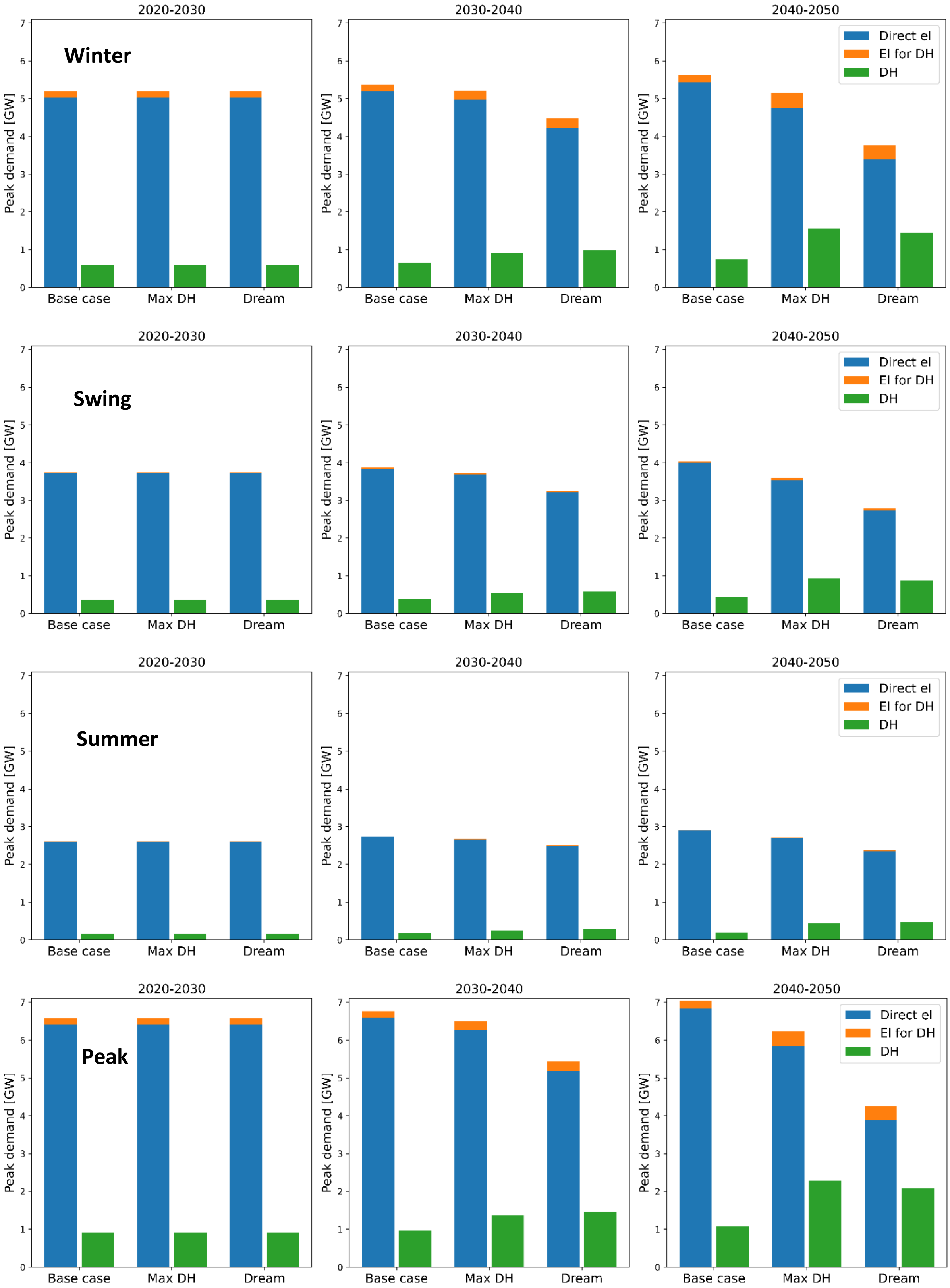


Figure 13 Peak electricity and DH demands for NO1 for the different years and scenarios, in the different seasons: winter, swing, summer and peak.

Figure 14 shows the total annual energy demands and the peak demands for the different scenarios in the final planning period. Both the *MaxDH* and *Dream* scenario reduce the electricity demand significantly, although the reduction is the largest in the dream scenario. The total energy demand (electricity + DH) is higher in *MaxDH* compared to the *Baseline*. In this scenario, all buildings that have access to a thermal grid and have waterborne systems will use DH. This means lower penetration of heat pumps compared to base case, hence slightly higher energy use. The share of electricity consumption for district heating is small compared to total electricity demand. Comparing the two graphs in Figure 14, it can be observed that the share of DH of the total peak demand is larger than for the total demand. The contribution of DH is thus largest during the peak periods when demand is high.

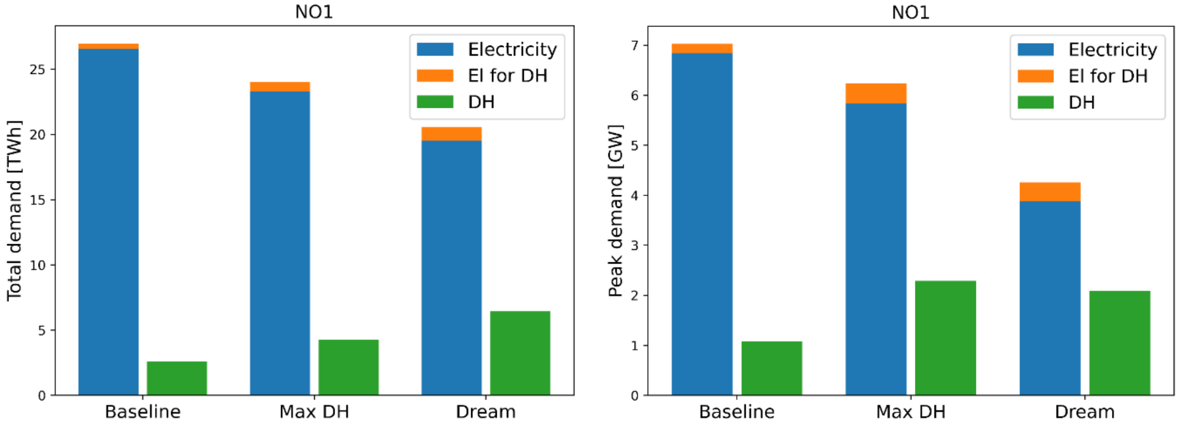


Figure 14 Total annual energy demands (left) and peak demands (right) for NO1 for the last planning period.

Table 13 gives values for the peak demands for electricity and DH for the final period in the different scenarios. In the *MaxDH* scenario, the peak demand for electricity is reduced by 0.79 GW compared to the base case, while the peak demand for DH increases by 1.22 GW. In the *Dream* scenario, the peak demand for electricity is reduced by 2.59 GW, while the peak demand for DH is increased by only 0.75 GW compared to the base case. This highlights the importance and impact of energy upgrade, and the use of heat pumps where waterborne heating is not feasible.

Table 13 Peak demands for electricity (in total and for DH) and DH for the final period (2040-2050) in the three scenarios.

	Base case [GW]	MaxDH [GW]	Dream [GW]
El tot	7.03	6.24	4.25
El for DH	0.19	0.40	0.37
DH	1.07	2.29	2.08

Figure 15 shows the weekly total DH production by source in the different planning periods, scenarios and seasons. The distribution per source varies little for the different years and scenarios, as the capacity of each source is scaled to the demand for each planning period and scenario (see section 3.4). Heat pump is the source that is applied most after recycled heat, and these two sources cover the demand entirely in summer and swing periods. In the winter, electric boilers and biomass contribute in as well, and in the peak period, a substantial share of bio-oil is needed. In the peak and winter periods, the share of biomass is higher for the *MaxDH* than in the *Dream* scenario due to the higher demand, probably making it more cost-efficient to cover the increased demand with biomass rather than electric boilers.

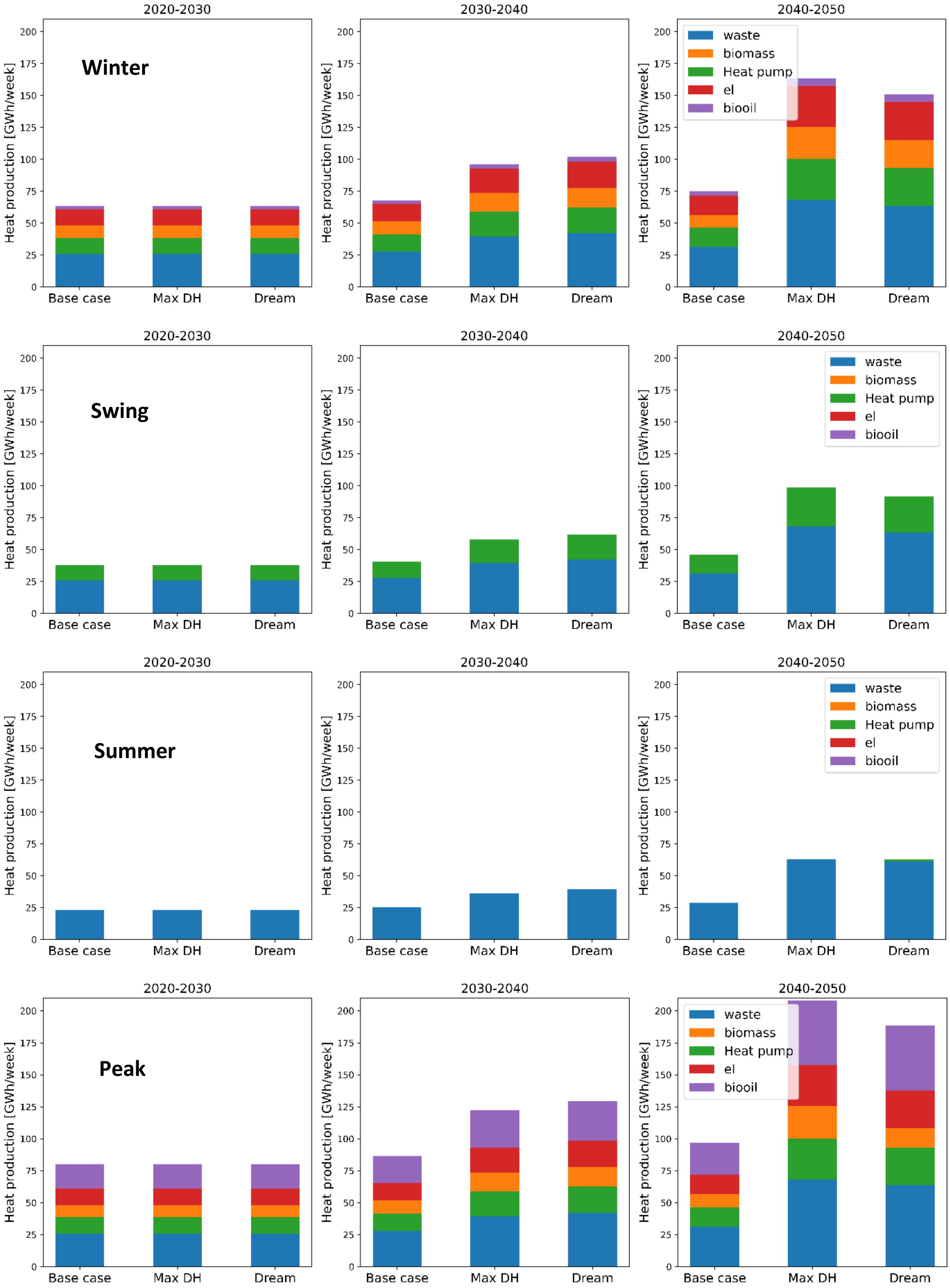


Figure 15 Weekly total DH production by source for the different years and scenarios, in the different seasons: winter, swing, summer and peak.

Table 14 shows the share per each DH production source in the final planning period for the different scenarios. The share of heat production from recycled heat (waste/industrial waste heat) is approximately 50 % as was the starting point (see section 3.4), while the share of biomass is significantly lower than 26 % that was set as a premise, and the share of heat pumps is conversely higher than the assumed 10 %. This results from the fact that the model chooses the cheapest selection of sources with the given capacity limits for each point of time, and heat production by heat pump has thus been more cost efficient than by biomass, given the assumed prices for biomass and electricity (see section 3.5). The heat production by electric boiler is approximately 10%, which was the starting point, while the share of bio-oil is lower than the assumed 4 %. The lower peak production by bio-oil is probably a result of the TES tank, enabling to reduce the use of the most expensive heat source.

Table 14 The yearly share per each source for DH production in the final period (2040-2050) for the different scenarios.

	Base	MaxDH	Dream
Recycled heat	50.3 %	50.3 %	50.4 %
Biomass	17.3 %	18.7 %	19.0 %
Heat pump	19.7 %	19.1 %	18.9 %
Electric boiler	10.6 %	10.1 %	9.8 %
Bio-oil	2.1 %	1.7 %	1.9 %

Figure 16 shows the operational costs for the different scenarios and planning periods for NO1. The costs are reduced clearly from in the *MaxDH* scenario, but in particular in the *Dream* scenario, compared to the *Baseline*. The reduction is in both cases most clear in the final planning period. Note that the operational costs are a direct result of the assumed energy prices, cf. section 3.5.

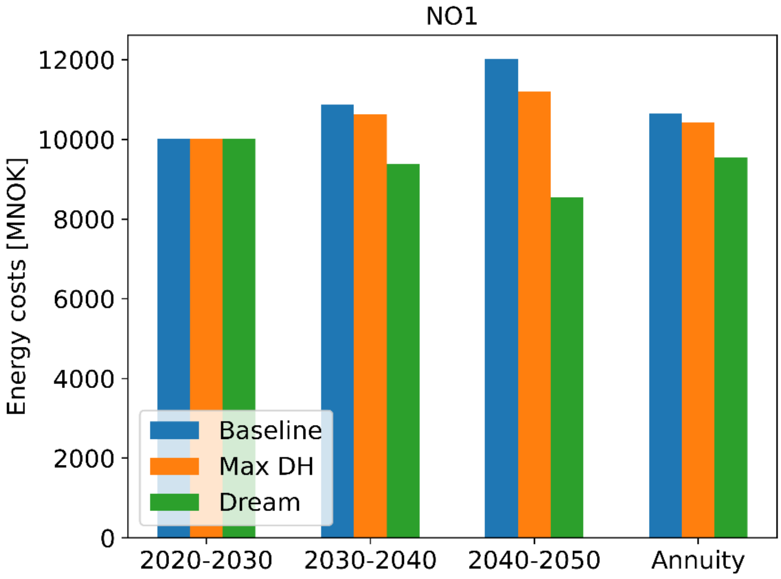


Figure 16 Operational costs for NO1 in the different scenarios and planning periods.

4.2.2 Norway

Figure 17 shows the total energy demands for the building mass in Norway in the three planning periods and scenarios, for electricity and district heating, and Table 15 shows the values for the annual demands for electricity and district heating, as well as the change from the 2020 level for the different years. Within 2030, the total electricity demand is increased by 0.5 TWh (+0.7%) in the *MaxDH* scenario and reduced by 7.8 TWh (-11.5%) in the *Dream* scenario when comparing to the 2020 level. Within 2050, the total electricity demand is reduced by 0.2 /17.2 TWh (0.3% / 25.5%) in *MaxDH* / *Dream* scenarios. Compared to business-as-usual (baseline scenario) in 2050, the total electricity demand is reduced by 7% in the *MaxDH* scenario and by 31% in the dream scenario. The total energy demand (electricity and district heating combined) increases from 2020 to 2050 in all scenarios but the dream scenario.

Note also that the total energy demand in the *MaxDH* scenario is higher than in the *Baseline* in 2030 and 2050, as in *MaxDH* all buildings that have access to a thermal grid or waterborne systems will use district heating. This means lower penetration of heat pumps, hence higher total energy demand.

In a previous study, a scenario similar to the *Dream* scenario was evaluated; however, by maximizing the use of heat pumps instead of district heating (Sandberg et al., 2022). In this study it was assumed that all new and renovated buildings have a liquid-water heat pump with a seasonal COP of 2.5, and that all existing small houses that are not renovated get an air-to-air heat pump with a seasonal COP of 1.5. Buildings using district heating were in this study converted to heat pumps to minimize the total energy demand. Compared with 2020 level, the estimated reduction in total energy use was 12.7 TWh by 2030 and 21.3 TWh by 2050. The reductions in total energy demand (electricity + district heating) in the *Dream* scenario in the present study are 4.4 TWh by 2030 and 9.6 TWh by 2050. The total reduction in energy use obtained with conversion to heat pumps is thus more than twice as high than with conversion to district heating; however, the study by Sandberg et al. did not evaluate the change in electricity demand, nor the peak power demand. A scenario looking at maximum penetration of heat pumps, considering also the change in electricity and peak power demands, should be evaluated as a continuation of the present study.

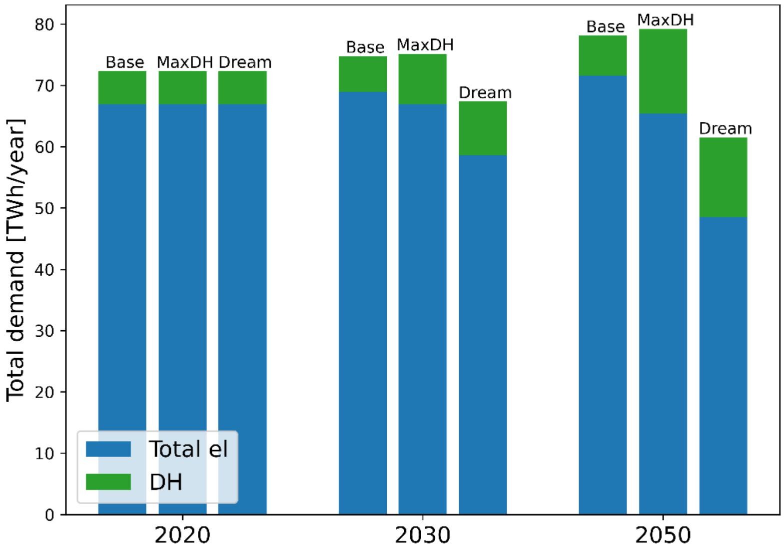


Figure 17 Total annual energy demands for the building mass Norway in the three planning periods and scenarios.

Table 15 The total annual demands for electricity and district heating in the different years and scenarios, and the change in demand from the 2020 level in 2030 and 2050.

	Electricity			**District heating**		
TWh/year	Baseline	Max DH	Dream	Baseline	Max DH	Dream
2020	67.7	67.7	67.7	5.4	5.4	5.4
2030	69.9	68.2	59.9	5.8	8.2	8.8
2050	72.7	67.5	50.5	6.5	13.8	13.0
Δ % 2030	3.2	0.7	-11.5	7.0	51.2	62.3
Δ % 2050	7.3	-0.3	-25.5	19.8	154.7	140.0

Figure 18 shows the peak energy demands for the whole Norway in the three planning periods and scenarios, and Table 16 shows the values for peak demand in electricity and district heating. Note that the peak energy demands are calculated by simply summing up the peak demands for the individual price zones, without considering the timing, and represent thus a worst-case scenario. The peak power demand is reduced by 5% / 35% from the 2020 level in the *MaxDH* / *Dream* scenarios. The peak demand for district heating is increased by 43% in the *MaxDH* scenario and by 25% in the dream scenario compared to the 2020 level. Compared to business-as-usual, the peak electricity demand is reduced by 9% in the *MaxDH* scenario, and by 39% in the *Dream* scenario in 2050.

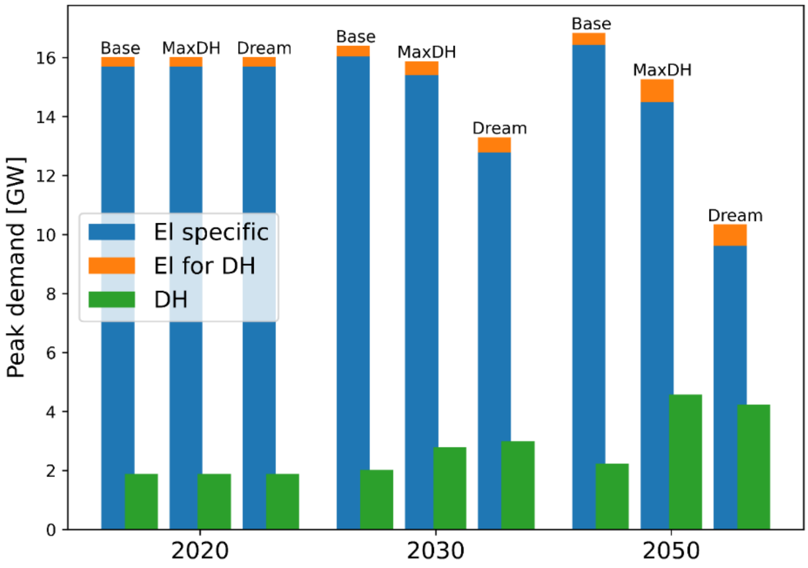


Figure 18 Peak energy demands for Norway in the three planning periods and scenarios, calculated by summing up the peak demands for the individual price zones.

Table 16 The total peak demands for electricity and district heating in the different years and scenarios, and the change in peak demand from the 2020 level in 2030 and 2050.

	Electricity			**District heating**		
GW	Baseline	Max DH	Dream	Baseline	Max DH	Dream
2020	16.0	16.0	16.0	1.9	1.9	1.9
2030	16.4	15.9	13.3	2.0	2.8	3.0
2050	16.8	15.3	10.3	2.2	4.6	4.2
Δ % 2030	2.4	-0.8	-17.0	7.5	48.4	59.1
Δ % 2050	5.2	-4.6	-35.4	19.1	143.1	124.8

Figure 19 shows the annual energy costs from 2020 to 2050 in the different scenarios. Note that the total energy cost is lower in 2050 in all scenarios compared to the *Baseline* even though *MaxDH* had higher total energy consumption. This has several reasons, among others the fact that 50% of heat production is based on recovered heat with a system cost set at NOK 1/MWh; and heat pumps provide more efficient use of electricity. Moreover, thermal storage allows the use of electricity when it is cheapest.

Looking at the development of costs from 2020 to 2050, the trend is increasing in all scenarios apart from the *Dream* scenario. In this scenario, the energy costs are reduced with -7% by 2030 and -17% by 2050 compared to the 2020-level. This highlights the importance of energy efficiency measures to avoid significant cost increases for energy production. Note that the investment costs for increased energy production and distribution by the district heating network or the power grid were not included in the model due to lack of available data for these costs.

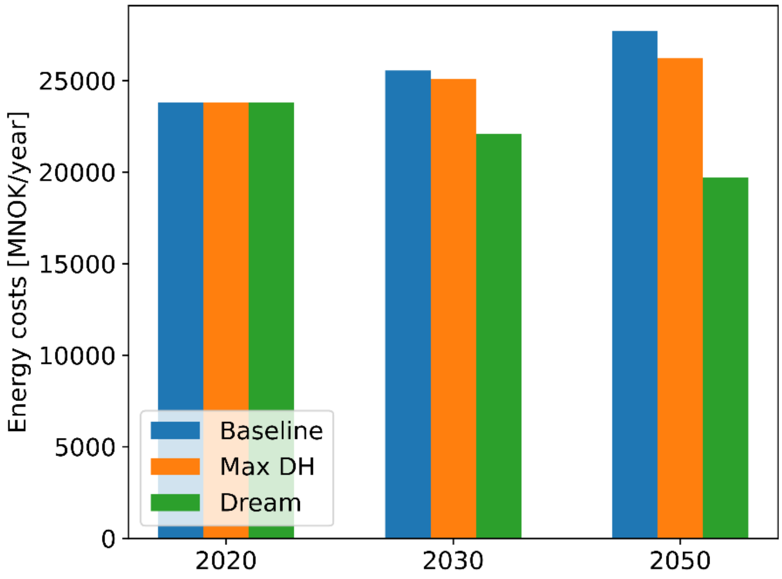


Figure 19 Annual energy costs from 2020 to 2050 in the different scenarios.

5 Conclusions

In this study, we have modelled the energy demand of the Norwegian building stock towards 2050 in different scenarios with respect to energy efficiency and the use of district heating. Further, the projected energy demand was analysed with an energy system model to account for different energy sources used in the production of district heating. The main objective of the study was to quantify the potential of increased energy efficiency in buildings and use of district heating on the future power demands in Norway. The main conclusions are as follows.

Energy efficiency and district heating will contribute to counteract the increase of energy demand due to a growing building stock, but heat pumps are needed to reach a reduction in building's total energy demand compared to 2020
The energy demand of the building stock in 2030 and 2050 can remain similar to 2020 if ambitious energy efficiency standards are enforced, with an 8% reduction in electricity use and a 6% increase in district heating use in 2050. Alternatively, maximising the access to and use of district heating networks, without ambitious energy efficiency measures, also reduces the electricity consumption by 8%. This will however increase the demand for district heating in the building stock by 155%, from 5.4 TWh in 2020 to 13.8 TWh in 2050, and lead to an increase in total energy use in the building stock by 6.6 TWh compared to 2020. It is only when ambitious energy efficiency standards, maximum use of district heating, and maximum use of heat pumps in rural areas are all combined, that the energy use of the building stock can be reduced notably. In this case, the total energy use in the building stock in 2050 became 12.9 TWh lower than in 2020 (-16%) – or 18.8 TWh lower than in a business-as-usual scenario in 2050. The largest share of the reduction is in total electricity use; by 2050 the electricity use was 23 TWh (-32%) lower in this scenario than when continuing business-as-usual. This is partially compensated by an increase in district heating demand of 7.6 TWh compared to 2020.

Large potential for increasing the share of district heating
The scenarios where the use of district heating is maximised show that district heating can contribute to cover a significant share of the energy use in the building stock. Already by 2030, the use of district heating by the building stock can increase from 5.4 TWh to between 8.2 and 8.8 TWh. This increase (2.8-3.4 TWh) is in line with the estimates of the Energy Commission (2-4 TWh) (Sørgård et al., 2023).

Energy efficiency and district heating reduce the pressure on the grid when the demand is highest
Continuing with business-as-usual will lead to an increase in peak power demand in the building stock from 16.0 to 16.4 GW (+2%) by 2030 and to 16.8 GW (+5%) by 2050. With maximal use of district heating (without ambitious energy efficiency measures), peak power demand in buildings could be *reduced* to 15.9 GW (-1%) by 2030 and to 15.3 GW (-5%) by 2050. Combining maximal use of district heating, ambitious energy efficiency standards, and maximising use of heat pumps allows a reduction in the peak power demand in buildings to 13.3 GW (-17%) by 2030 and to 10.3 GW (-35%) by 2050 compared to 2020 level. This is 6.5 GW lower (-39%) when comparing to the business-as-usual scenario in 2050.

District heating allows increased flexibility in the energy supply

District heating gives the opportunity to choose the cheapest and least polluting combination of sources available at a given point of time. Half of the district heating demand in Norway is covered with “recycled heat”, industrial excess heat or waste incineration, and this fraction was reflected also in the modelling results. Large-scale heat pumps supplied 19-20% of the district heating load in the model, and district heating heat pumps were applied in favour of biomass for heat production to a larger degree than what was the starting point assumption of 10%. Furthermore, district heating allows greater flexibility for load shifting due to the inertia of waterborne systems. This flexibility can further be increased with thermal energy storage, which allows for maximizing the production with least-cost and least polluting sources. In the present study, thermal energy storage was implemented in the model to reflect the storage capacity in both the piping networks as well as existing accumulator tanks. This resulted in reduced the demand for peak heating with bio-oil from the assumed 4% share down to approximately 2%.

Combining energy efficiency, district heating and heat pumps reduces the system costs for energy

Combination of ambitious energy efficiency standards with maximal use of district heating and heat pumps in rural areas lead to reduced system costs for energy with -7% by 2030 and -17% by 2050, compared to the 2020-level. The project has however not looked at costs for individual customers: it is possible that the scenario that gives the lowest system cost is not the cheapest option when individual actors are faced with the choice of implementing the suggested measures. The framework conditions and investment support for energy efficiency measures and district heating should be investigated and improved and render these measures real, conflict-free alternatives for increased power production. Moreover, the study did not consider the investment costs required for increased energy production or distribution by the district heating network or the power grid. Investment costs are easy to include in modelling; the challenge is to find realistic data for the costs for building district heating networks and extending power grid capacity, or for implementing the necessary energy efficiency measures in buildings. Such an evaluation would however be an interesting and crucial continuation of the study.

Collective vs. local heating solutions

The study did not evaluate the possibility of maximizing local heat pumps as an alternative in medium- and high-density areas where district heating was considered to be feasible. This was the main topic of a previous study (Sandberg et al., 2022), which did also demonstrate larger reduction in total energy use than what was obtained in the present study. This previous study did however not evaluate the increase in total electricity or peak power demand which would result from a high number of heat pumps in urban areas; nor did it look at the possibilities for flexibility through interaction between the power grid and district heating systems with thermal energy storage. A scenario maximizing the use of local heat pumps also in urban areas should therefore be evaluated as a continuation of the present study, to understand their potential impact in the electricity consumption patterns.

References

Bakken, B. H., Skjelbred, H. I., & Wolfgang, O. (2007). eTransport: Investment planning in energy supply systems with multiple energy carriers. *Energy*, *32*(9), 1676–1689. https://doi.org/10.1016/j.energy.2007.01.003

Birkelund, H., Arnesen, F., Hole, J., Spilde, D., Jelsness, Silje, Aulie, F. H., & Haukeli, I. E. (2021). *Langsiktig kraftmarkedsanalyse 2021 – 2040* (No. 29/2021). Norges vassdrags- og energidirektorat (NVE). https://www.nve.no/energi/analyser-og-statistikk/langsiktig-kraftmarkedsanalyse/

Heimar Andersen, K., Krekling Lien, S., Byskov Lindberg, K., Taxt Walnum, H., & Sartori, I. (2021, September 1). *Further development and validation of the 'PROFet' energy demand load profiles estimator*. 2021 Building Simulation Conference. https://doi.org/10.26868/25222708.2021.30159

Kauko, H., Pinel, D., Graabak, I., & Wolfgang, O. (2022). Assessing the potential of seasonal thermal storage for local energy systems: Case study for a neighborhood in Norway. *Smart Energy*, *6*, 100075. https://doi.org/10.1016/j.segy.2022.100075

Lindberg, K. B., Bakker, S. J., & Sartori, I. (2019). Modelling electric and heat load profiles of non-residential buildings for use in long-term aggregate load forecasts. *Utilities Policy*, *58*, 63–88. https://doi.org/10.1016/j.jup.2019.03.004

Mostue, L., Taule, H., Borgen, S. T., & Jebsen, S. H. (2022). *Energi21—Strategi 2022*. Olje- og Energidepartementet.

Norsk Fjernvarme. (2022). *Fjernkontrollen*. https://www.fjernkontrollen.no/

Olje- og energidepartementet. (2021). *Norsk Energibruk*. Energifakta Norge. https://energifaktanorge.no/norsk-energibruk/

Sandberg, N. H., Lien, S. K., Lindberg, K. B., & Sartori, I. (2022). Mål om 10 TWh energisparing i bygningsmassen: Hvordan ligger vi an og hva er potensialet? *Praktisk økonomi & finans*, *38*(1), 4–22. https://doi.org/10.18261/pof.38.1.2

Sandberg, N. H., Næss, J. S., Brattebø, H., Andresen, I., & Gustavsen, A. (2021). Large potentials for energy saving and greenhouse gas emission reductions from large-scale deployment of zero emission building technologies in a national building stock. *Energy Policy*, *152*, 112114. https://doi.org/10.1016/j.enpol.2020.112114

Sartori, I., Lindberg, K., Sandberg, N., & Synne Krekling, L. (2022). *Flexbuild Annual Report 2 – Technical report with results analysis* (No. 87; p. Appendix B: PROFet). SINTEF akademisk forlag.

SINTEF. (2022). *Integrate*. Integrate. https://www.sintef.no/en/software/integrate/

Sørgård, L., Andresen, Ø., Hauglie, A., Ringkjøb, H.-E., Seim, H., Tomasgard, A., & Fredriksen, B. F. (2023). *Mer av alt – raskere* (2023:3). Norges offentlige utredninger (NOU).

SSB. (2022a). *Fjernvarme og fjernkjøling*. Fjernvarme og fjernkjøling. https://www.ssb.no/energi-og-industri/energi/statistikk/fjernvarme-og-fjernkjoling

SSB. (2022b). *Produksjon og forbruk av energi, energibalanse og energiregnskap*. https://www.ssb.no/energi-og-industri/energi/statistikk/produksjon-og-forbruk-av-energi-energibalanse-og-energiregnskap

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