Centre for Sustainable Energy Studies

CenSES Energy demand projections towards 2050 - Reference path

A Position Paper prepared by FME CenSES

The objective of the national Centres for Environmental-friendly Energy Research (FME) is to establish time-limited research centres which conduct concentrated, focused and long-term research of high international calibre in order to solve specific challenges in the field.

FME CenSES will develop fact based knowledge for strategic decisions, relevant both for government and industry. The focus is knowledge for a national energy policy, for national and international climate policy and for strategies of innovation and commercialization.

CenSES Energy demand projections towards 2050 - Reference path

A Position Paper prepared by FME CenSES

CenSES

IFE
Institute for Energy Technology

UiO : Centre for Technology, Innovation and Culture
University of Oslo

HØGSKULEN i SOGN OG FJORDANE

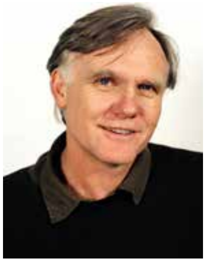
NTNU
Kunnskap for en bedre verden

Author list

Eva Rosenberg
Institute for Energy Technology

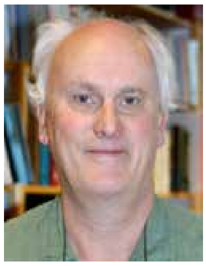
Kari Aamodt Espegren
Institute for Energy Technology

Erling Holden
Sogn og Fjordane University College



Olav Wicken
University of Oslo, TIK

Marianne Ryghaug
NTNU Department of Interdisciplinary Studies of Culture



Knut Holtan Sørensen
NTNU Department of Interdisciplinary Studies of Culture

Table of Contents

1. Executive summary

As opposed to most other European countries, Norway has no official, public energy projection. We have therefore developed an energy projection towards 2050, with openness to data and detailed discussions of parameters and resulting energy demand. It is not a prediction, but a projection, with assumptions based on discussions among the CenSES partners. The objective is to have a platform for further analyses within CenSES and other interested users, where assumptions can be openly presented. The intention is to develop alternative paths based on future discussions, as a way of improving the knowledge of how to achieve a sustainable future energy system.

The analysis gives an understanding of the high uncertainties about future energy demand. Four scenarios are presented, all presenting a possible future, and the total energy use differs with about 65 TWh in 2050. The electricity consumption differs with approximately 45 TWh from the lowest to the highest use in the four scenarios. Main parameters varying in the scenarios are the levels of industry activity and energy efficiency implementation as presented in Table 1. The reference scenario is based on an industry activity at the present level and minor implementation of energy efficiency.

A two-step methodology is used where the demand of energy services is calculated first. This is input to the energy system model TIMES-Norway that calculates the energy consumption. The calculated use of total energy and different energy carriers highly depend on the assumptions used in the analyses. The demand calculations are based on the development of drivers and indicators of each demand sector. A major driver is the population projection that is based on the medium national growth of Statistics Norway 2012. The assumptions are discussed with CenSES-partners, and the authors have full responsibility for the results and conclusions presented in this paper.

In the reference path, final energy consumption increases by 30 TWh to about 250 TWh in 2050. The increased electricity consumption is 21 TWh to 134 TWh in 2050. Implementation of profitable energy efficiency measures can reduce the final energy consumption by 4 TWh in total while the electricity use increase by 7 TWh (-2% and +6% respectively). In total, profitable energy efficiency measures including heat pumps can reduce the energy consumption in 2050 by about 23 TWh. Illustrations of some of these scenarios are included in this paper as "stories" describing literary how possible futures might become.

Table 1 *Overview of analysed scenarios and the change in demand/energy/electricity use in 2050 compared to 2010*

Scenario	Energy Efficiency Implementation	Industry activity	Exogenous energy prices	Change in 2050 compared to 2010		
				Stationary energy demand	Energy use	Electricity use
REF	Small	Present	Constant at present level	+18 TWh (+11%)	+30 TWh (+13%)	+21 TWh (+18%)
REF-EE	High				-4 TWh (-2%)	+7 TWh (+6%)
LOW	High	Low	Increasing	+3 TWh (+2%)	-23 TWh (-10%)	-9 TWh (-8%)
HIGH	Small	High	Constant at present level	+35 TWh (+22%)	+43 TWh (+19%)	+37 TWh (+33%)
FROZEN	No	Present		+18 TWh (+11%)	+52 TWh (+23%)	+28 TWh (+25%)

Electricity production

The hydro power production increases in the reference path by 33 TWh towards 2050, while wind power production increases by 9 TWh in 2020-2030 and is back at the present level in 2050. The investments in wind power are done during the period with electricity certificates. The net electricity trade increases to 19 TWh in 2030 and is calculated to 14 TWh in 2050 in the reference path. The wind power production increases with higher electricity trading prices as in the LOW activity scenario. If the discount rate is increased from the 4% used in these analyses, the wind power production decrease. The net power trade is strongly dependent on the exogenously given trading prices. Even in the HIGH activity scenario with a substantial increase in Norwegian industrial activity, the Norwegian power production is high enough to meet the demand.

Transportation

The projection of transportation demand is based on the National transportation plan, done by Institute for Transport Economics. According to the projection freight transport have the highest increase, and the demand will double from 2010 to 2050. Transport modes using road represented 60 % of the energy use in transport in 2010, while domestic sea transport represented 22 %. The growth in transport demand of the reference path is higher than the population growth, thus an alternative scenario with a transportation demand based on the population growth is analysed; in the energy efficiency and the low activity scenario. Due to more efficient vehicles, the energy use by cars decreases in all scenarios, except "frozen" where only gasoline and diesel cars are in use. The introduction of new types of cars is of high importance, since it can be able to half the energy consumption by cars; however it will require a huge effort in technology development. Equally important will be to reduce the demand for car transportation and policies addressing this issue has to be strong.

Residential sector

A population growth of 38% until 2050 is calculated to give an increased dwelling area of 60%, but the residential energy service demand is only calculated to increase by 25% due to increased energy efficiency. The residential energy consumption is in the reference path analysed to increase by about 12% and if all profitable energy efficiency measures in addition is implemented the energy consumption may remain at the present level until 2050. The dwelling area in 2050 is divided in about 45% area built after 2010, and most of the rest is refurbished dwelling area built before 2010, with a small share of dwellings that have not been renovated to an improved energy standard. Energy use per capita continues to decrease in the reference path.

Service sector

The building area of the service sector is calculated to be increased by 48% in 2050, compared to an increase in energy service demand of 18%. About half of the area in 2050 will be built after 2010 and the rest will be refurbished, with the assumptions used in the analyses presented here. The energy consumption per capita is calculated to decrease by 10% until 2050, at the same time as the electricity use per capita decrease by almost 20%. The most important parameter for future energy consumption in buildings is the population development.

Industrial activity and uncertainty

To illustrate the uncertainty of particularly the energy

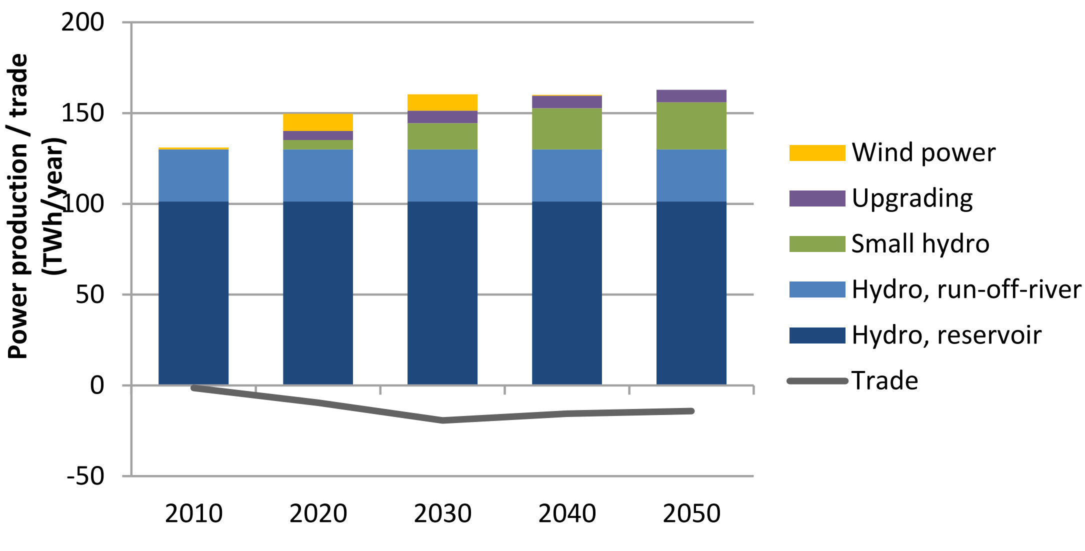


Figure 1 *Power production and net electricity trade 2010-2050 in the reference path (TWh/year)*

demand of industry two alternative scenarios are analysed. In the high activity scenario the development of increased Norwegian production of energy intensive products are included. If this happens at the same time as no profitable energy measures are implemented and the transportation demand continues to increase, the final energy consumption is calculated to increase by 43 TWh and electricity use increase by 37 TWh compared to 2010. This high electricity demand can be met by Norwegian renewable electricity production without a need for net electricity import. If in addition policies contribute to implement profitable energy efficiency measures the increased energy consumption of the high activity scenario can be held at the same level as in the reference path.

The low activity scenario assumes higher energy prices with an increased electricity export and a decreased Norwegian industrial production. It also includes implementation of profitable energy efficiency measures and less transportation demand. In this case, the final energy consumption in 2050 is calculated to 23 TWh less than in 2010 and the electricity consumption to 9 TWh less. With the targets of renewable energy production, this gives a huge export of electricity with a maximum of more than 60 TWh in 2030. Political decisions and policy measures have an important role in how future energy consumption will actually develop. Domestic processing of Norwegian renewable energy to high quality products combined with a strong focus on energy efficiency can result in a moderate increase in energy consumption, mainly renewable electricity. This development implies a strong business policy along with a willingness to improve domestic energy efficiency targets and low-carbon solutions.

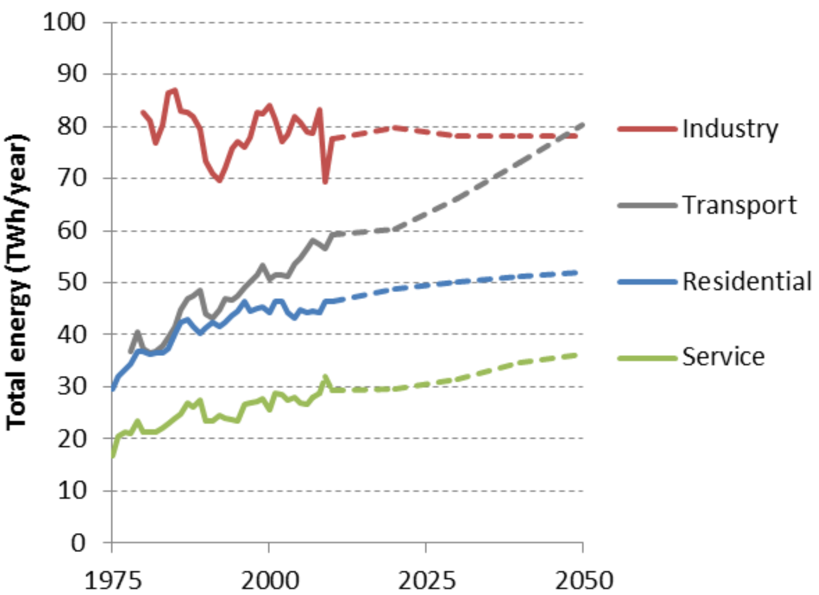


Figure 2 *Total energy use per sector; statistics 1975-2010 and projection REF 2010-2050 (TWh/year)*

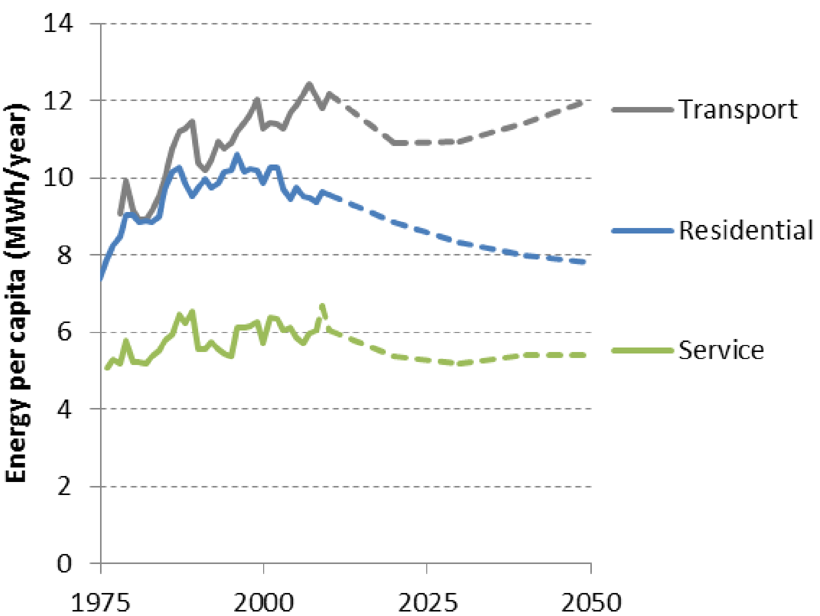


Figure 3 *Energy use per capita and year per sector; statistics 1975-2010 and projection REF 2010-2050 (MWh/ capita and year)*

2. Introduction and scope

The development of energy demand is a key driver of the future energy system. Many user partners and research partners of CenSES are dependent on energy demand projections in their work with energy systems analyses and planning. The type of projection needed differs e.g. concerning geographical area, energy carriers, demand sectors and time levels. The lack of an official Norwegian energy demand projection with a transparent view of assumptions is a drawback for many partners. A common interest for energy demand projections and the need of common assumptions in comparative analyses of future energy systems is identified within CenSES. The common projection can be used as a basis for new analysis in future research projects and in the work with CenSES scenarios.

The last public energy demand projection was presented in 2006 [1] while later governmental energy demand projections are concealed in other foresight documents such as the National budgets where some data are public but most of the assumptions are not. Some data on electricity forecasts are available, but no data of total or useful energy demand. In [1] the electricity consumption increased by about 50%. "Perspektivmeldingen 2011" projected the electricity demand in 2050 to increase by 33% [2], a considerable lower growth than the NOU five years earlier. Common for the governmental work is the use of general equilibrium models, while the work in this paper is based on a technology rich bottom-up approach. Energy demand projections with similar models have resulted in increased electricity demand in 2050 of 3-18% (with and without energy efficiency measures) which is significantly lower than the macro-economic model results [3]. It would strengthen the studies of future energy use if assumptions and background data are public available. It would then be possible to discuss and develop alternative paths and thereby improve the knowledge of how to achieve a sustainable future energy system.

The objective of this work is to present a common long-term energy demand projection with a detailed description of major assumptions. It is not a prediction, but a projection, with assumptions based on discussions among the following CenSES partners:

- Statnett
- Statkraft
- NVE
- Enova
- Transnova
- Miljødirektoratet
- Vestlandsforskning
- SINTEF Energi
- SINTEF Teknologi og Samfunn
- Universitetet i Oslo, TIK-senteret
- Institute for Energy Technology

The analyses are carried out by Institute for Energy Technology (IFE) in 2013-2014. The authors have full responsibility for the results and conclusions presented in this paper.

This paper presents the main parts of the energy demand projections. More details of the work can be found in the report [4] and, upon request, the authors can send projection data electronically. The analyses framework, i.e. the methodology, scenarios and assumptions, is presented first in this paper. It is followed by presentations of energy demand projections by end-use sector divided in the residential, service, industry and transport sectors and a summary of total energy use and electricity production. Finally, a discussion of the energy demand projections can be found in the last chapter.

3. Analysing framework

3.1. Methodology

Energy service demands of residential, service, industry (incl. offshore) and transportation are calculated in the first step. The demand of energy services is calculated as an activity multiplied by an indicator. Secondly, the energy system model TIMES-Norway is used to analyse the consumption of energy carriers. Alternative scenarios are analysed to illustrate the uncertainty of the reference path. These include different developments of the industry, alternative transportation projections, implementation of energy efficiency measures, alternative population projections and alternative energy prices (see description in section "Scenarios").

The base year of the analyses is 2010 and the analysed horizon is to 2050. The focus is on end-use demand, both of energy services and energy carriers, while energy production and trade is additional information. Projection of both energy carriers and important parameters are compared to statistics. Particularly the parameter projections are based on past development and used assumptions rest on considerations of present statistics. The reference path is based on the middle alternative of the population projections of Statistics Norway 2012 [5].

Energy by end-use such as heating and electricity specific purposes is an important input but the statistics is of poorer quality than the statistics of energy carrier consumptions. This work is based on an evaluation of present information and discussion of the best available energy by end-use to use in this study.

Energy efficiency is included in the reference path through renovation of buildings and improved efficiencies of end-use demand (such as heat pumps, new, more efficient vehicles etc.). Investments in other energy efficiency measures such as heat recovery, improved core processes, behavioural measures etc. are not included in the reference path. An alternative analysis of future energy demand is done with possibilities to invest in profitable energy efficiency measures.

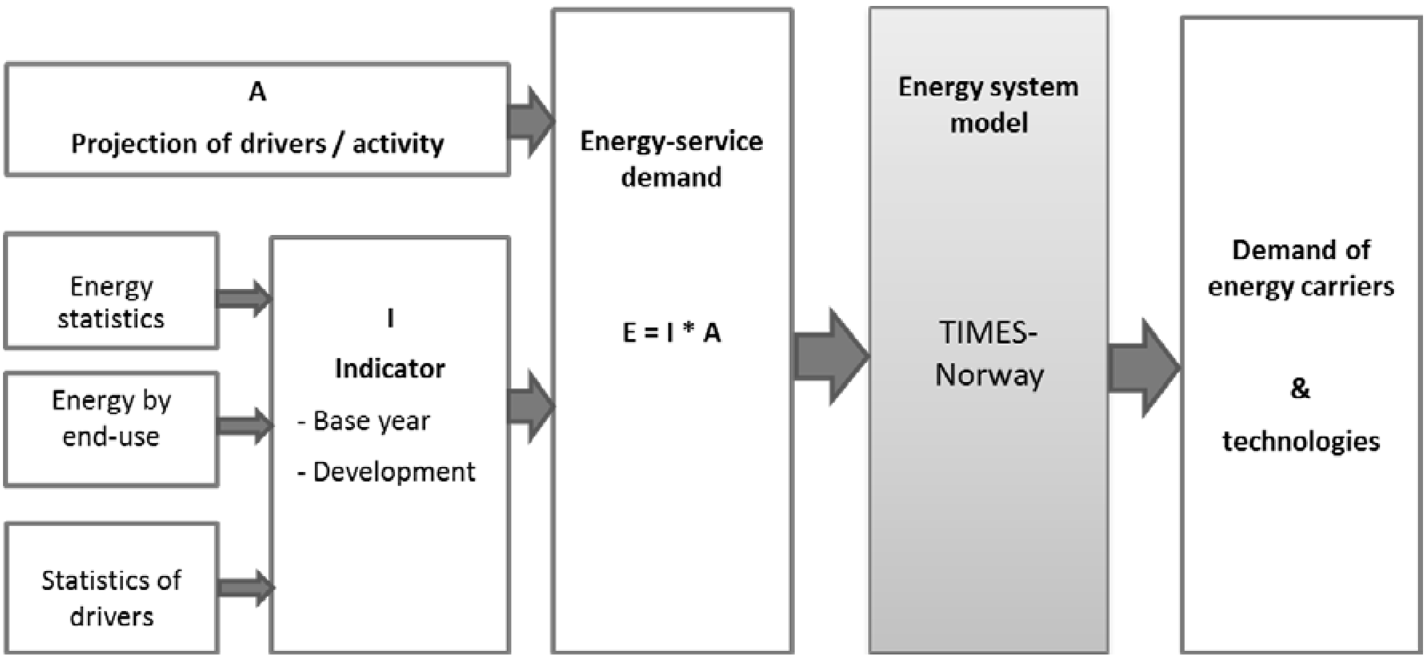


Figure 4 *Principal methodology sketch*

TIMES-Norway – model description

TIMES (an acronym for The Integrated MARKAL-EFOM System) is a bottom-up techno-economic model generator for local, national or multi-regional energy systems, which provides a technology-rich basis for estimating energy dynamics over a long-term, multi-period time horizon. It gives a detailed description of the entire energy system including all resources, energy production technologies, energy carriers, demand technologies and demand sectors. The model assumes perfect competition and perfect foresight and is demand driven. Thus the projected energy demand has to be given exogenously to the model, and the TIMES model aims to supply energy services at minimum global cost by making equipment investments, as well as operating, primary energy supply and energy trade decisions.

TIMES-Norway is developed by Institute for Energy Technology (IFE) on commission of The Norwegian Water Resources and Energy Directorate (NVE) and the development started in 2008. The time horizon of the model is from 2010 to 2050, with a flexibility of analysing years within this frame. TIMES-Norway covers all onshore energy use in Norway and the country is divided in five regions with exchange of electricity between adjacent regions and neighbouring countries.

The structure of the TIMES-Norway model is illustrated in Figure 5. The demand for various energy services, energy price information and resource costs and availability are given exogenously to the model. On the energy supply side, several conversion processes are represented in detail; e.g. electricity and heat production. Transmission and distribution include high and low voltage grids, as well as district heating. Energy carriers used as industrial feed stock (such as natural gas in chemical industry) are included as non-substitutable energy carriers with corresponding CO2-emissions. Transportation by passenger cars is modelled with many different technologies, including hybrids, battery electric vehicles, fuel cell vehicles, plug-in hybrids and internal combustion engine vehicles [6, 7].

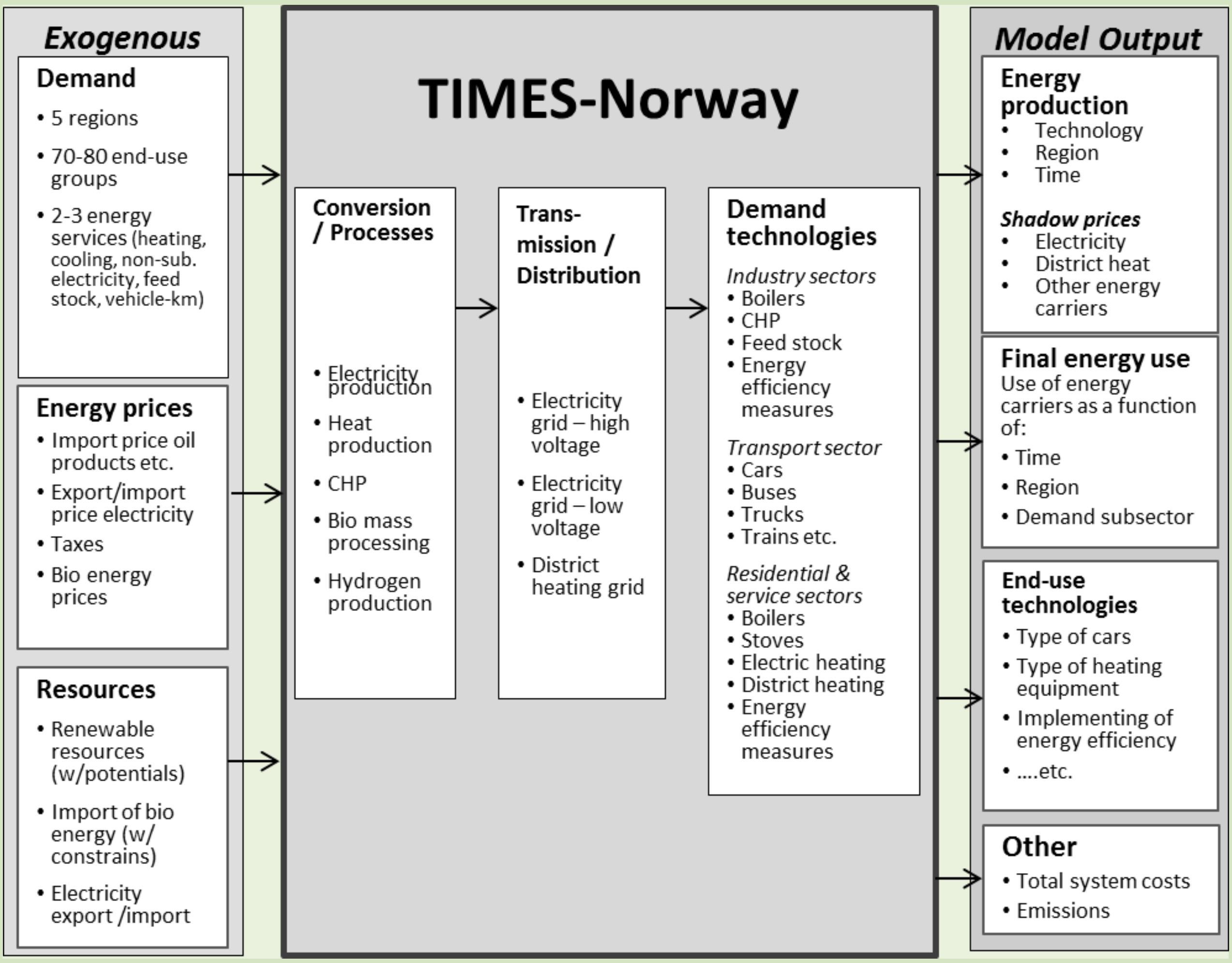


Figure 5 *Principal drawing of TIMES-Norway*

3.2. Scenarios

The main scenario is the reference path, called REF. This scenario is based on present policies and decided changes of the energy use of 2010. The population projection used in the reference path is the main middle alternative published by Statistics Norway in 2012 [5]. The building regulation in force is "TEK10" and new buildings are based on this regulation. In order to illustrate the uncertainty of the reference path, a few alternative scenarios are analysed. Several other scenarios are of great interest and the intention is to continue the work with more scenario analyses in 2015. The present work includes the following scenarios analysed with TIMES-Norway:

REF
Reference path with the assumptions previously described. Based on present policies and decided industry close downs/production increases. General energy efficiency measures are not included, but the effects of present policies are included. Low energy and passive house standards are not included. Battery electric vehicles (BEV) are restricted to maximum 50 % of passenger car demand.

REF-EE
Energy efficiency (EE) measures are available in TIMES-Norway and profitable energy efficiency will be implemented. More efficient transportation results in a decreased growth of transport demand.

FROZEN
The objective of this scenario is to illustrate what would happen if the present energy system is used to serve a growing population. Passenger cars are restricted to gasoline and diesel combustion cars with improved efficiency of new cars. Buildings will not reduce energy use when refurbished and the directive of energy labelling and lighting has no effect.

HIGH
The energy demand of industry is increased and there is no restriction of battery electric vehicles (BEV).

LOW
Decreased energy demand of industry, possibilities to invest in energy efficiency measures, decreased transport demand and higher energy prices (based on [8] and [9]).

Constant energy prices 2016 – 2050 are used in all scenarios but LOW. In scenario LOW, the development of fossil energy prices and bio energy are based on WEO 2013 [8]. The electricity trade prices in LOW are considerable higher compared to the other scenarios.

Table 2 *Analysed scenarios with differences compared to the reference path of each demand sector*

Scenario	Industry	Households	Tertiary	Transport	EE-measures	Energy prices
REF					No	Constant 2016-2050
REF-EE	EE	EE	EE	Less transport demand (more efficient)	Yes	Constant 2016-2050
FROZEN	-	No effect of renovations and present directives	No effect of renovations and present directives	Present car types	No	Constant 2016-2050
HIGH	Higher activity	-	-	No restrictions BEV	No	Constant 2016-2050
LOW	Lower activity EE	EE	EE	Less transport demand	Yes	Increasing 2010-2050 (WEO2013)

3.3. Assumptions

Different energy prices used as input to TIMES-Norway are presented in Table 3. The energy taxes of 2014 are assumed to be constant until 2050. From 2020 the tax of biodiesel is assumed to be the same as for petroleum diesel. TIMES-Norway has a possibility to invest in 2nd generation biodiesel production from 2025 and this product can be used in pure biodiesel vehicles. Imported biodiesel may only be used for mixing with petroleum diesel. Financial support to specific technologies is modelled with the present level until 2020, and is then removed.

Zero-emission vehicles are exempted from nonrecurring tax and VAT until 2020 and then get the same taxes as other vehicles. The nonrecurring tax is assumed to be calculated based on the same principles as today until 2050, resulting in a low investment cost of cars using 2nd generation bio fuels. The use of electricity for heating is restricted in accordance with the building regulation code of 2010.

Table 3 *Energy prices (incl. energy taxes but not VAT), bio energy potentials and rates used as input to TIMES-Norway (possible investments in brackets)*

	All scenarios but LOW	Scenario LOW	Potential /Capacity		Other
	2016-2050	2050	2020	2050	
	NOK 2005/MWh	NOK/MWh			
General discount rate					4%
VAT households					25%
Hydro and wind potentials					
- Hydro			33.8 TWh/year	33.8 TWh/year	
- Wind, onshore			41 TWh/year	41 TWh/year	
- Wind, offshore			10.3 GW	10.3 GW	
			Export/Import (+new investment)		
Electricity trade					
- SE1	273	441	600/700 MW		
- SE2	245	441	1300/850 MW		
- SE3	245	441	2095/2145 MW		
- FIN	245	441	100/100 MW		
- RUS	245	441	0/56 MW		
- DK	255	469	1000 (+700) MW		
- NL	312	496	700/700 MW		
- DE	259	484	(1000) MW		
- UK	407	591	(1000) MW		
Electricity certificate price	165	0			
Grid fee					
- Industry, high voltage	25	25			
- Industry, low voltage, firm power	144	144			
- Industry, low voltage, occasional	59	59			
power	189	189			
- Tertiary sector, firm power	101	101			
- Tertiary sector, occasional power	229	229			
- Residential sector					
Petroleum fuels			unlimited	unlimited	
- Light fuel oil, buildings	786	1132			
- Light fuel oil, industry	498	815			
- Heavy fuel oil	492	802			
- Diesel for transportation	939	1191			
- Gasoline	1129	1332			
Bio fuels					
- forest chips	184-223	250-303	3.2 TWh/y	4.2 TWh/y	
- wood logs	150	150	0 TWh/y	8.6 TWh/y	
- by-products from industry	0-187	0-253	3.9 TWh/y	3.9 TWh/y	
- fire wood	107-207	181-281	8.3 TWh/y	8.3 TWh/y	
- pellets, imported	400	476	unlimited	unlimited	
- municipal waste			2.6 TWh/y	2.6 TWh/y	

4. Projections by sector

4.1. Residential sector

4.1.1. Energy service demand

The projection of energy service demand of households (E) is calculated as dwelling area (A) multiplied by specific energy service demand (I):

E = A * I = dwelling area (m^2) * specific energy service demand (kWh/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 4. 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. The reasons behind the assumptions are described in [4]. The relative evolution of both historical data from 1970 to 2012 and projection 2012-2050, with 2010 as the base year is presented in Figure 6.

Table 4 *Key statistics and assumptions used in the projection of residential energy service demand*

	Starting year	Starting value	2030	2050	Yearly growth 2010-2050
Population (mill.)	2010	4.858	6.037	6.681	0.80%
Households (mill.)	2010	1.587	1.982	2.197	1.08%
Persons per household	2010	2.24	2.07	2.00	-0.28%
Share of multifamily houses of new dwellings	2000-2013	55.9%	56%	56%	
Area per new dwelling (m^2/dwelling)	2009-2013				
- single family house		163.8	164	164	
- multifamily house		93.0	93	93	
- average		133.0	133.0	133.0	
Renovation rate (% per year)			2.0%	2.0%	
Demolition rate (% per year)			0.3%	0.3%	
Alternative population projections:					
- Low LLML	2010	4.858	5.607	5.646	
- High HHMH	2010	4.858	6.553	8.393	

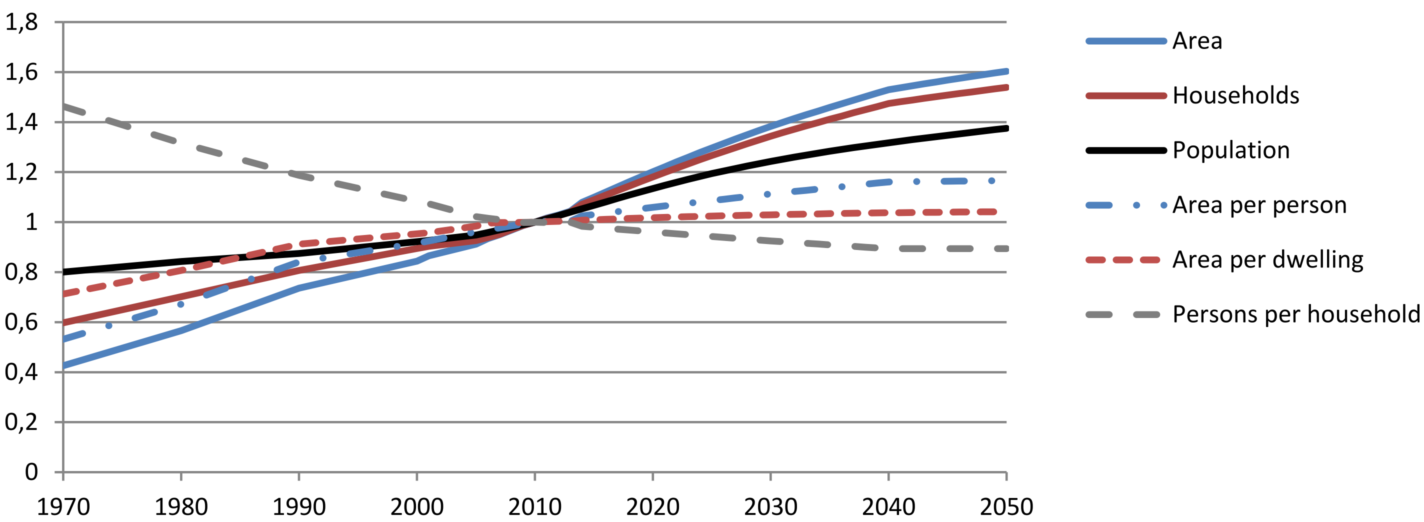


Figure 6 *Relative development of key parameters of residential projection; statistics 1970-2012, projection 2012-2050; 2010=1*

The energy service demand by end-use is an important premise for calculation of future energy demand. The input used for the present calculations are based on publications from NVE, Statistics Norway and building regulations of 2010. The resulting energy service demand for space heating, water heating, lighting and other electricity specific use and for each dwelling type (new and existing single family houses and multifamily houses) is presented in Table 5.

The residential energy service demand from 2010 to 2050 based on the described assumptions is presented in Figure 7. The reference path includes energy efficiency improvements from renovations and estimated effects of the directives of energy labelling of appliances and lighting. The energy service demand will increase from 44 TWh in 2010 to 51 TWh in 2030 and 55 TWh in 2050 in the reference path. Energy efficiency reduces the demand by 7 TWh in 2050 in the reference path compared to a frozen efficiency path. The dwelling area increase from about 263 mill. m^2 in 2010 to about 420 mill. m^2 in 2050, an average yearly increase of 1.2%. If the population projection instead of following the middle path of Statistics Norway will develop according to the high or low projections [5], the energy service demand is calculated to 24% higher or 15% lower than the reference path in 2050 (+13 TWh to – 8 TWh in 2050), as presented to the right in Figure 7.

Table 5 *Residential energy service demand by end-use in 2010, kWh/dwelling*

	Existing dwellings			New dwellings		
	All	Single fam.	Multi fam.	All	Single fam.	Multi fam.
Space heating	12 300	14 600	5 900	7 800	10 700	4 000
Water heating	2 600	2 900	1 700	2 300	2 900	1 700
Lighting	1 000	1 100	700	900	1 100	700
Other el. specific	3 500	4 000	2 300	3 200	4 000	2 300
Total	19 400	22 600	10 600	13 800	18 700	8 700

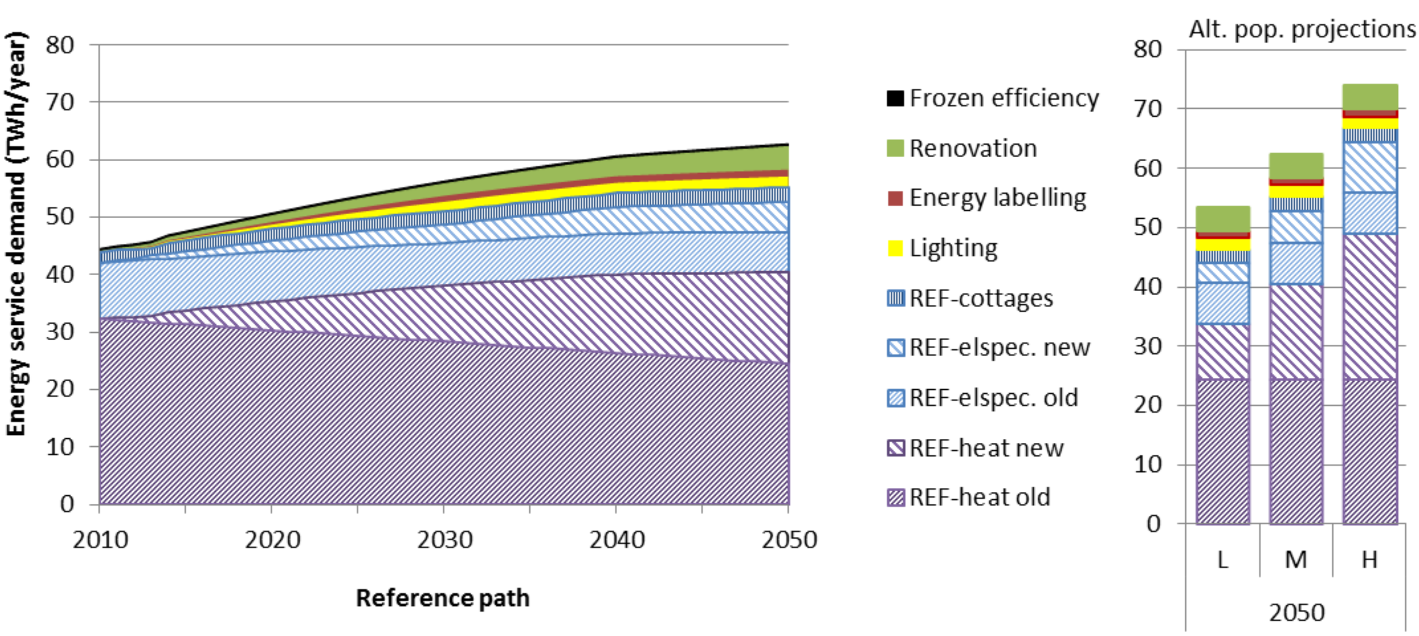


Figure 7 *Residential energy service demand 2010-2050 for the reference path to the left and with alternate population projections on the right; L=low, M=medium, H=high population growth, (TWh/year)*

4.1.2. Energy consumption

The residential energy service demand is analysed with TIMES-Norway resulting in a demand of energy carriers and use of different end use technologies. The energy consumption is calculated to 52 TWh in 2050 and of this 38 TWh is electricity in the reference path. The development of total energy as well as electricity from 1970 to 2012 (statistics) compared to projected future energy use to 2050 is presented in Figure 8 [10]. Due to the strong increase in population, both total energy and electricity use increase slightly, but less than the population growth. The indicators "energy use per person" and "electricity use per person" both decrease more than the past years. Both total energy and electricity increased fast in the period 1970-1990, but from about 1995 the consumption has flattened. Due to the very strong population increase in the used population projection, the energy consumption is projected to increase slightly, but not of the same magnitude as in the 1970s and 1980s, thanks to more efficient use.

The technologies used according to the analyses of the reference path are mainly air-air heat pumps in new single family houses and existing single family houses continues to use direct electric heating in combination with fire wood but with an increasing share of heat pumps. Multifamily houses will use a combination of district heat and biomass boilers, but existing multifamily houses will also continue to use direct electric heating.

Analyses with a possibility to invest in energy efficiency measures decrease the energy use by 6 TWh in 2050, resulting in the same energy use as in the base year. This comes in addition to the investment in heat pumps in the reference path and the energy efficiency included in the projection of energy service demand of 7 TWh in 2050.

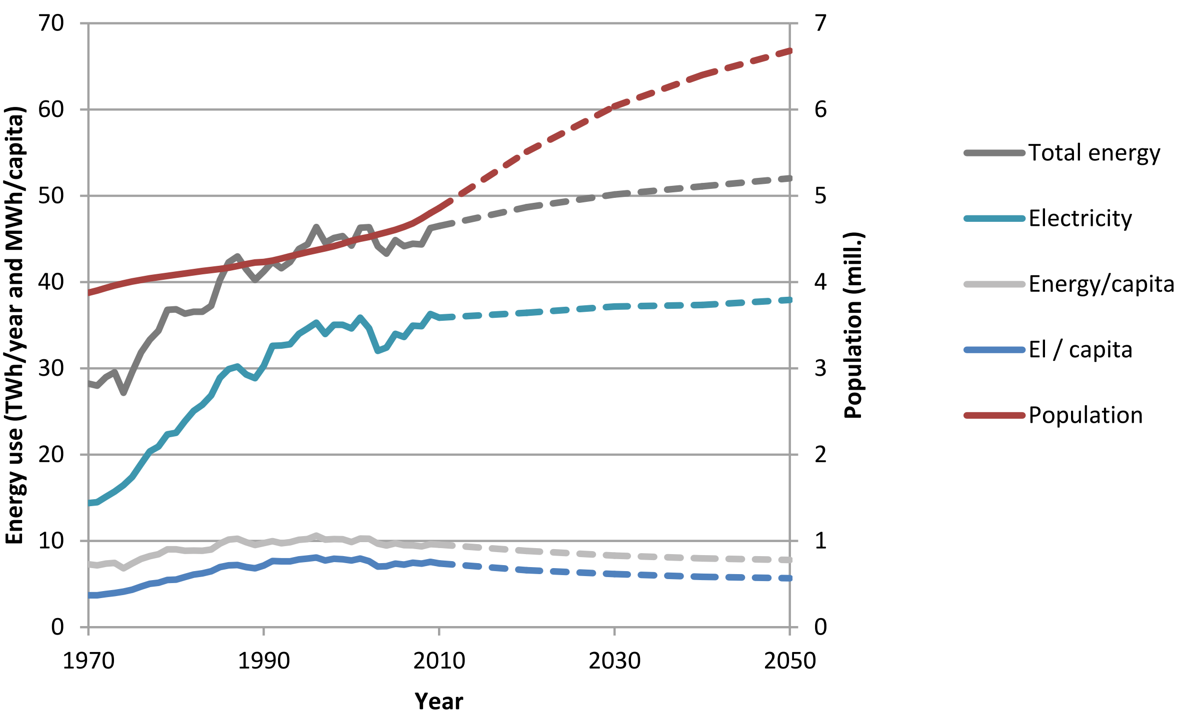


Figure 8 *Development in the reference path of residential total energy use, electricity use, energy and electricity use per capita and population. Unbroken line is statistics 1970-2009 and dash line is projection 2010 - 2050 (TWh/year, MWh/year & capita and mill. persons)*

More energy-efficient residential buildings in the future?

by Marianne Ryghaug and Knut Holtan Sørensen, NTNU

For a long period of time, efforts to improve the energy quality of residential buildings seemed to have little impact on the consumption of energy. This was probably a result of people using larger part of their buildings, due to increased overall energy comfort. Moreover, the average area of dwellings grew. During the last 10-15 years, it seems the trend has turned. The average area of dwellings is levelling out, while in most cases, all areas in the building are already utilised. Energy efficiency measures are having an effect, even if it is fairly moderate. Another important point is that the way people act within a building, in terms of heating, use of energy-demanding equipment, showering, and so on, varies substantially. This means that increased levels of energy quality may have little effect if the actions of the habitants counter this. Or, the reverse, if routines with respect to energy consumption change, like reduced indoor temperature, energy consumption may be reduced without any changes in the energy quality. The interaction between the energy quality of a residential building and the behaviour of the residents is complex and unfortunately not well understood.

Reference scenario – what happens if we remain on the same path?

Remaining on the same path implies a fairly constant effort of engaging with energy efficiency as part of the efforts to renovate existing buildings, while new buildings are constructed with increased energy standards. There are some impacts from these activities in terms of reduced energy consumption. These impacts may be reinforced through a tendency towards increased concern about climate issues that slowly spills over into some reduction in the use of energy. On the other hand, population growth due to immigration will continue and will be the most influential parameter. It is believed that the population of Norway will increase by 38 % by 2050, and this will represent a demand for more residential buildings even if the current trend of urbanisation will contribute to reduced average area of dwellings. Since population growth and urbanisation means a future demand for more new buildings the ratio of new and old buildings may change so that the average energy quality is increased. This, together with uncertainties regarding transport, introduces uncertainties also in the reference scenario. Nevertheless, because of population growth, energy consumption is expected to grow also in the reference scenario.

Climate mitigation scenario – on the path towards reductions

Current climate policy in Norway aims at making mitigation efforts largely unnoticeable to the public. This may change if a larger share of emission cuts is to be taken in Norway. According to our studies, there is a substantial, but latent willingness to engage in energy saving activities if this is made a collective obligation through suitable measures. Three set of activities could happen: First, a more sustained effort to raise the energy quality of existing buildings. Second, a change in energy-related habits like small reductions in indoor temperature, a more concerned use of electrical equipment, shorter periods of showering, etc. Third, a shift in transportation practices related to a mix of increased use of collective transportation and electric/hydrogen-based vehicles. Technological changes may also contribute. Greater concern with climate issues may stimulate the already dynamic introduction of heat-pumps in many dwellings, combined with a more conscious use of this technology. Currently, the energy saving effect of heat-pumps is questionable. Also, both white and brown goods are becoming more energy efficient.

The relative share of the building stock that has low energy or passive house standard will increase substantially in the years to come. However, the energy saving potential seems precarious. There has been an unfortunate tendency among the technologically oriented advocates of such solutions to be quite optimistic with respect to the saving potential of these new types of buildings. There has been too little concern regarding how people actually live in such building, and the obvious need for dialogue and learning has largely been overlooked. If these challenges are being taken more seriously, a larger share of the saving potential may be realised.

Currently, there is a strong belief that so-called smart metering and smart grids will produce a reduction in residential consumption of energy. These beliefs are mainly unwarranted but upheld through very optimistic assumptions about the way increased and updated information about energy consumption and price mechanisms will affect households. However, again, the level of concern for climate changes may factor in here. At present, there is little reason to expect an impact of the abovementioned new technologies. Again, if dialogue and learning are taken more seriously, this may make the technology more effective.

Engagement with low carbon technologies, like electrical vehicles, solar panels and other energy producing technologies delivering electricity and/or heat to the buildings holds some promise. Such artefacts may increase the interest in and concern for the way energy is being used. Earning money from feed-in tariffs or saving money by being increasingly independent from the public grid may introduce a higher level of engagement and produce energy citizenship where taking greater responsibility for energy saving may be a result.

4.2. Service sector

4.2.1. Energy service demand

In this work, the primary and tertiary sectors and the construction sector is gathered in one sector called "service" for simplicity.

The projection of energy service demand (E) of non-residential buildings is calculated as building area (A) multiplied by specific energy service demand (I):

$E = A * I$ = building area (m^2) * specific energy service demand (kWh/m^2) =
$A_{new} * I_{TEK10} + A_{refurbished} * I_{refurbished} + A_{existing} * I_{existing}$

The future area of non-residential buildings is calculated as:

$A = A_{2010}$ * population growth * intensity factor

where the intensity factor is the annual area growth per capita. The last 14 years this intensity factor has been in average 1.6 for all subsectors where area is a relevant parameter. This factor is assumed to decrease linearly to 1.0 in 2025 and remain at that level until 2050.

Subsectors of the service sector where area is not a relevant parameter are calculated as the energy demand of the base year multiplied by the population growth.

The energy service demand by end-use is an important premise for calculation of future energy demand. The input used for the present calculations are based on building regulations, statistics of total energy consumption and areas and the data used are presented in Table 7. A more detailed discussion of the assumptions and calculations can be found in [4].

The total area of non-residential building will increase from about 90 mill. m^2 in 2010 to about 133 mill. m^2 in 2050 with these assumptions. The annual new build rate is then in average 2.5% in the beginning of the analysing period declining to 0.7% in 2050. The energy service demand of service will based on these assumptions increase from about 35 TWh in 2010 to 42 TWh in 2050, see Figure 9. The reference path includes energy efficiency improvements from renovations and estimated effects of the directives of energy labelling of appliances and lighting. The energy service demand increases by 18% in the reference path. Energy efficiency improvements reduce the demand by 4 TWh in 2050 in the reference path. If the population projection instead of following the middle path of Statistic Norway will develop as in the high or low projections, the energy service demand is calculated to be 25% higher or 16% lower than the reference path in 2050, as presented to the right in Figure 9.

4.2.2. Energy consumption

The energy service demand of the service sector was analysed with TIMES-Norway resulting in a demand of energy carriers and use of different end-use technologies. The energy consumption is calculated to increase by 7 TWh to 36 TWh in 2050 in the reference path and of this, 26 TWh is electricity. The development of total energy as well as electricity from 1970 to 2012 (statistics) compared to calculated future energy use towards 2050 is presented in Figure 10. The population growth is considerable higher than the increase in both total energy and electricity use. The indicators "energy per capita" and "electricity per capita" both decreases towards 2050, more than in the past. Analyses with the possibility to invest in energy efficiency measures decrease the total energy use by 3 TWh in 2050.

Table 6 *Key statistics and assumptions used in the projection of the energy service demand of tertiary sector*

	2010	2030	2050
Population (mill.)	4.858	6.037	6.681
Annual area growth/ pop. growth	1.6 %	1.0 %	1.0 %
Annual renovation rate		2.0%	2.0%
Annual demolition rate		0.5%	0.5%

Table 7 *Non-residential energy service demand by end-use in 2010 (kWh/m^2)*

	Existing/New buildings			
	Heat	El. specific	Cooling	Total
Education	100/90	69/41	0	169/132
Health	137/100	130/100	0	267/189
Hotel and rest.	171/120	171/90	30/25	372/235
Offices	115/54	145/90	23/19	284/163
Trade	114/83	113/92	34/34	262/210

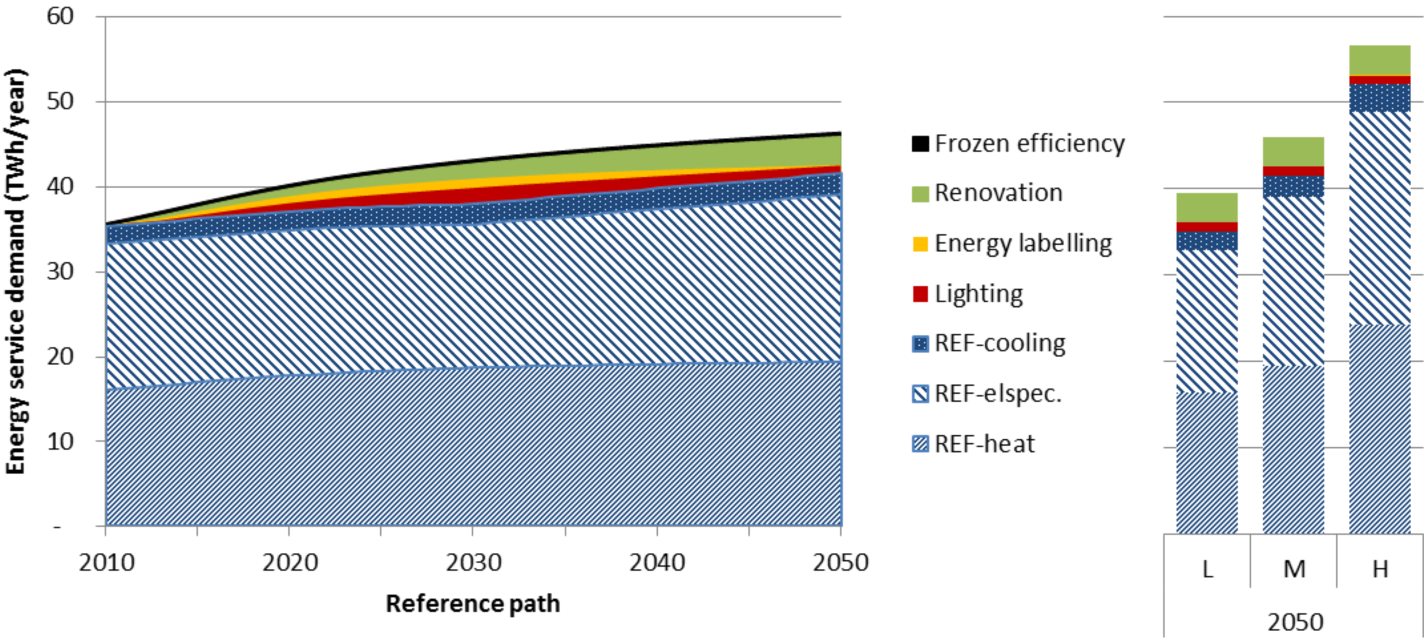


Figure 9 *Energy service demand of tertiary sector, primary sector and building construction 2010-2050 in the reference path to the left and with alternate population projections to the right (TWh/year)*

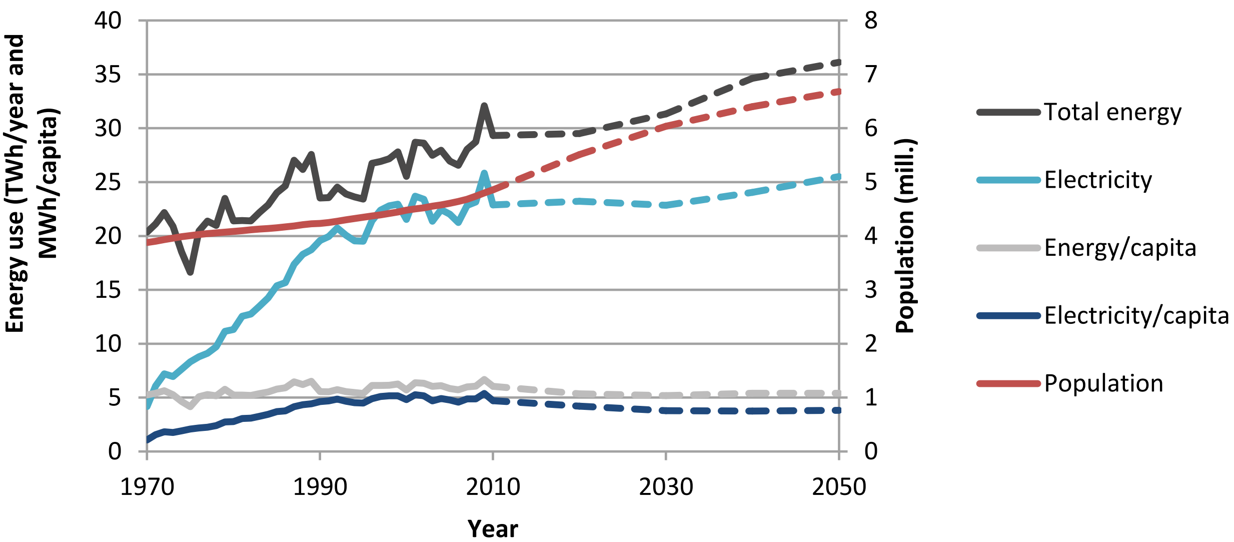


Figure 10 *Development in the reference path of service total energy use, electricity use, energy and electricity use per capita and population. Unbroken line is statistics 1970-2009 and dash line is projection 2010 - 2050 (TWh/year, MWh/capita & year and mill. persons)*

4.3. Industry sector

4.3.1. Energy service demand

The future Norwegian industrial energy demand is very uncertain and depends on several factors outside the scope of this work (e.g. global demand of important products such as primary metals, prices of raw materials and products, international competition etc.). Industry demand is highly dependent on a small number of decisions with major impact on total Norwegian energy use. The reference path is therefore in principle based on assumptions of constant activities and indicators of all industrial sectors (measured in ton or similar physical production units). An increase of monetary activities combined with an equal decrease of the indicator, results in the same energy demand. Close downs of plants or production increases carried out or decided up to 2014 are included in the projection. Recently have the decisions of the pilot plant at Karmøy and the electrification of Utsira contributed to an increased electricity consumption of 2 - 3 TWh towards 2030, but this is not yet included in the reference path. Investments in energy efficiency measures are not possible in the reference path, but in the REF-EE scenario. In all analyses it is possible to invest in energy efficient heating plants such as heat pumps.

To illustrate the high degree of uncertainty of the industrial development, two alternate scenarios are analysed. A strong focus on industry development in combination with constant energy prices at the present level is the basis for the HIGH activity scenario. Lower industrial activities in combination with higher energy prices are analysed in the LOW activity scenario. The key assumptions of the industry scenarios are described in Table 8 and the electricity specific demand is presented in Figure 11.

Compared to the present specific electricity demand, the reference path will increase the demand by 3.5 TWh in 2020 and by 1.7 TWh from 2030 to 2050. The reference scenario includes power from grid to some offshore activities. The High activity scenario will increase the demand by 8 TWh in 2020 and more than 16 TWh from 2030. This scenario assumes increased production of energy intensive products such as aluminium and a high electrification of the offshore activities. In the Low activity scenario (with high energy prices) the demand decreases by 10 TWh from 2040. In this scenario, the power from grid to offshore activities will decrease from the present level and be zero in the middle of the analysing period. It also includes the closing down of more pulp and paper industries as well as some primary metal production.

Table 8 *Key assumptions of the industrial scenarios*

	REFerence path	HIGH activity scenario	LOW activity scenario
Aluminium production	Increased production at Hydro Sunndal	- Pilot plant Hydro Karmøy - New plant Hydro Karmøy	
Other metal production and chemical industry	Close down of REC, Becromal in 2011-2012	Additional new production	Close down of metal production plants
Pulp & paper	Close down of Tofte, Follum, Moss, Hunsfos, Folla in 2011-2013		Close down of several pulp & paper plants
Petroleum activities	Power from grid to Troll A, Kollsnes, Valhall, Goliat, Gjøa, Martin Linge, Ormen Lange, Snøhvit	- Melkøya/Snøhvit power from grid supply total demand and a new train 2 - Utsira – power from grid	Decreased power from grid to offshore petroleum activities
Other industry		New industrial activity	Decreased activities of other industry
Electricity specific demand compared to 2010	+3.5 TWh in 2020 +1.7 TWh in 2030 - 2050	+8 TWh in 2020 +16 TWh in 2030 +17 TWh in 2050	-0.4 TWh in 2020 -4 TWh in 2030 -10 TWh in 2040

4.3.2. Energy consumption

The decided production increases and decreases of the reference path results in a small decrease in total energy use from 2010 to 2050 (-2 TWh). The use of electricity increases and the use of oil, gas and biomass decreases. The energy use can be reduced by 10 TWh if profitable energy efficiency measures are implemented. The high activity scenario results in an increased energy use of 15 TWh compared to the present use. The energy use decrease by 27 TWh if the industry development is as in the low scenario with higher energy prices and implementation of profitable energy efficiency measures.

The electricity consumption in industry varies in the analysed scenarios from a rather constant consumption in the reference path with energy efficiency possibilities (-1 TWh in 2050 compared to 2010) and a small increase without energy efficiency (+5 TWh in 2050) to an increase of 21 TWh in 2050 in the high activity scenario and a decrease of 14 TWh in 2050 in the low activity scenario. The electricity consumption has increased 10 TWh the past 30 years and has been rather constant the last 15 years, see Figure 13 [10].

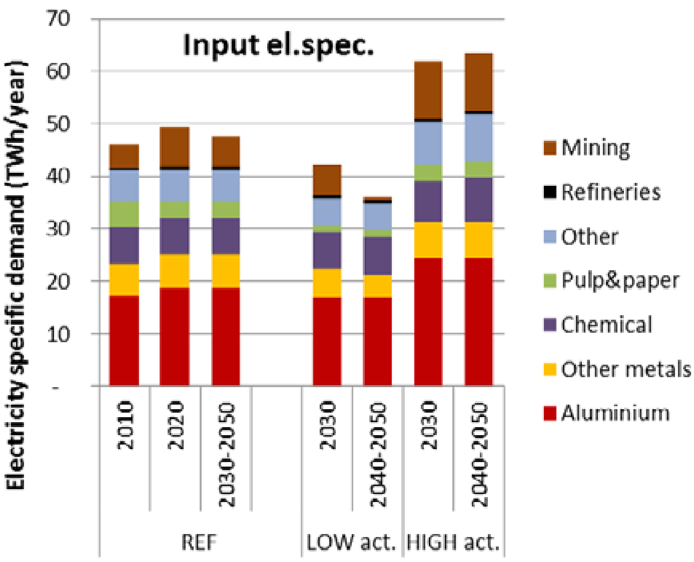


Figure 11 *Electricity specific demand in industry 2010-2050 in the reference path, the LOW activity scenario and in the HIGH activity scenario; Input to TIMES-Norway (TWh/year)*

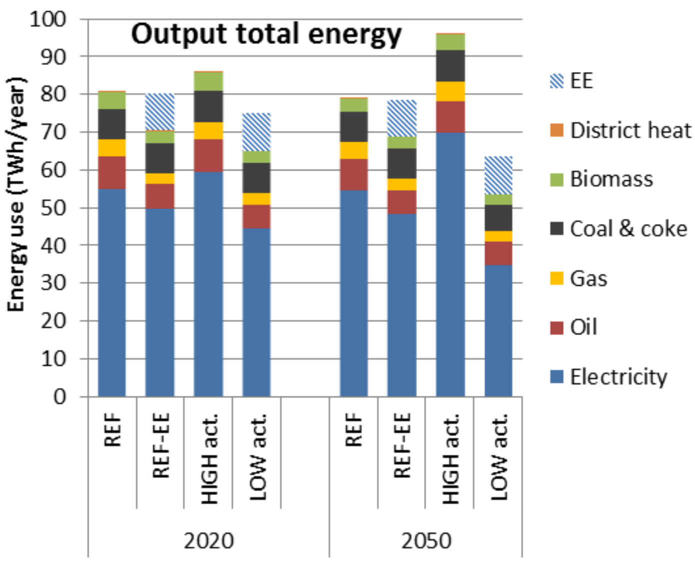


Figure 12 *Energy use by energy carrier in the analysed industry scenarios in 2020, 2030 and 2050; Output from TIMES-Norway (TWh/year)*

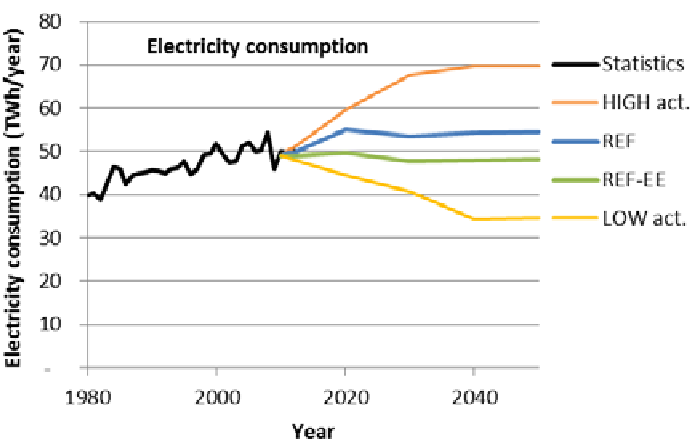


Figure 13 *Statistical development of electricity use 1980-2012 and projection from 2010 to 2050 in the analysed industrial scenarios (TWh/year)*

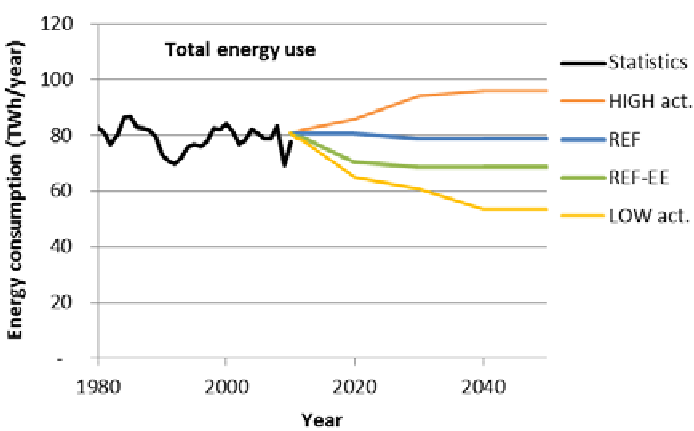


Figure 14 *Statistical development of total energy use 1980-2012 and projection from 2010 to 2050 in the analysed industrial scenarios (TWh/year)*

Can power-intensive industry increase energy demand?

by Olav Wicken, UiO

'High activity' industry scenario

Under the high activity scenario, industrial power consumption will increase by 17 TWh from the current level. Some investment plans have already been made. Hydro will build a pilot plant for a new aluminium production process at Karmøy, with a plan to follow up with a full-scale plant before 2030. In the high activity scenario we expect that other aluminium factories, as well as other energy-intensive industries (basic metals, chemical production), will expand and increase their power consumption. We also expect new energy-intensive industries (data centres) to be developed, and that the energy consumption of other industries will increase significantly. In addition, we have assumed that the electrification of the offshore sector will intensify, and that today's industries will not experience plant closures.

Implicit in the scenario is a different development going forward than we have experienced in recent decades. The industry consumption increased between mid-1980s and the turn of the millennium by 10TWh. Since then the consumption has remain at the same level.

What would it take for the high activity scenario to be realized? The two main user sectors are the offshore sector and energy-intensive industries.

Electrification of the offshore sector will require 5 TWh of power from the central grid. This involves that in addition to the plants decided to be fully or partly connected to the grid (Troll A, Kollsnes, Valhall, Goliat, Gjøa, Martin Linge, Ormen Lange and Snøhvit), also Snøhvit/Melkøya will become fully connected. Also electrification of Utsira is included in the scenario. This does not necessarily reflect increased consumption, but would be a transition from fossil-based power (gas) on platforms to renewable power from the central power grid. Since the cost of connecting offshore installations to the power grid is greater than local power generation, the industry has by and large met electrification proposals with reluctance. This is illustrated by the decision making process relating to electrification of Utsira which clearly shows that increased electrification of the oil and gas industry is dependent on government regulations and policy requirements for new industrial fields to be linked to the regular power grid.

Expansion in power consumption from electricity intensive industries requires large scale investments. This can happen if the industry has the ability to innovate (improve quality of products and increase production efficiency) and can produce with low costs. Norway has strong competence in chemical and metallurgical processes. Investments in the Norwegian power intensive industry have been based on development of new processes or improvement of existing ones. Hydro expected that their process for magnesium would become a major growth industry in the 1980s. Elkem's development of polysilicon was the basis for investments in new processes for the solar industry in the 2000s. Hydro's investments in Karmøy revolve around testing more energy efficient aluminium production. However, innovation ability is not enough for industry to remain in Norway. Magnesium was started in Canada, but has not been the profitable major industry Hydro had hoped for, and the silicon industry flagged when competition from China became too strong.

The decision to invest in Norway vs. invest in other markets is closely linked to prices of the main input factors. In power intensive industries power prices have become the single most important competitive factor due to increasing automation. The lack of investments in the industry in Norway 2000-2011 may be explained by increasing power prices. Today, electricity prices are historically low and are expected to remain low. This opens a window of opportunity for expansion of the industry. A basic assumption for future investments in power intensive industries is that power prices remain at a low level. In a liberal power market this implies high supply compared to demand. In our scenario, where industrial consumption is expected to increase by more than 15TWh, investment in production of power has to increase for prices to remain low. That in turn presupposes that the regulatory framework for the power sector is such that investors will want to expand in electricity intensive industries as well as in new power supplies - in spite of low electricity prices.

4.4. Transportation sector

4.4.1. Energy service demand

The projection of transportation demand towards 2050 is based on input to the National transportation plan, done by Institute for Transport Economics [11, 12]. The development of each sub-sector relative to the transportation demand in 2010 is presented in Figure 16. The demand for freight transport on road is increasing the most and it is motivated by the expected economic growth and increased international trade. The passenger road traffic will increase by approx. 1 % annually. The growth of the reference path is higher than the population growth and an alternative scenario with an increased transportation demand based on the population growth is analysed in the REF-EE and LOW scenarios.

The technology development has a great impact on the projection of energy use of transportation. Important modelling parameters include future investment costs, efficiencies, production costs and availabilities of new fuels as hydrogen and biofuels. The development of investment costs and efficiencies of passenger cars used in the analyses are presented in Figure 17 and Figure 18. Use of battery electric cars is limited to 50% of the passenger car demand in the reference path. Second generation biofuels produced in Norway is available from 2025 in the analyses. The present policy with exemption of nonrecurring tax and VAT of hydrogen and electric cars is assumed to continue until 2020 and then these cars have the same taxes as other cars. The calculation principles of the nonrecurring tax are assumed to be as they are today and therefore zero emission vehicles, such as biofuel, battery and hydrogen will continue having the low nonrecurring tax.

Investment cost for new vehicles is based on a study carried out at Joint Research Centre (JRC) in the Netherlands, with an exception for hydrogen vehicles (FCEV) as the costs of FCEV seems very optimistic with an investment cost [4, 13]. The costs for new types of vehicles are assumed to decrease as function of time. As the Norwegian market is limited, it is not considered any decrease in investment cost as function of sales volumes.

The energy use in transport was 58 TWh in 2010. Energy use by trailer and delivery truck represented 27 % of the total energy use in transport in 2010. According to the projection freight transport will increase from 12.5 mill vehicle-km in 2010 to 25.7 mill vehicle-km in 2050, and are having the highest increase of the transport modes. Transport modes using road (car, freight and bus) represented 60 % of the energy use in transport in 2010, while domestic sea transport represented 22 % of the energy use.

4.4.2. Energy consumption

The energy use for transportation will decrease in the reference path due to more efficient vehicles. If future passenger cars would be the present mix of vehicles, the energy use by cars in 2050 would be 25 TWh as in the Frozen scenario of Figure 20. The energy efficiency gain of the reference path is about 11 TWh for passenger cars in 2050 or 7 TWh less than in 2010. One very important assumption is the continued low investment cost of biofuel cars, based on the present calculation method, and cost and availability of Norwegian second generation biofuels. Further analyses have to be done to illustrate the importance and robustness of the different parameters.

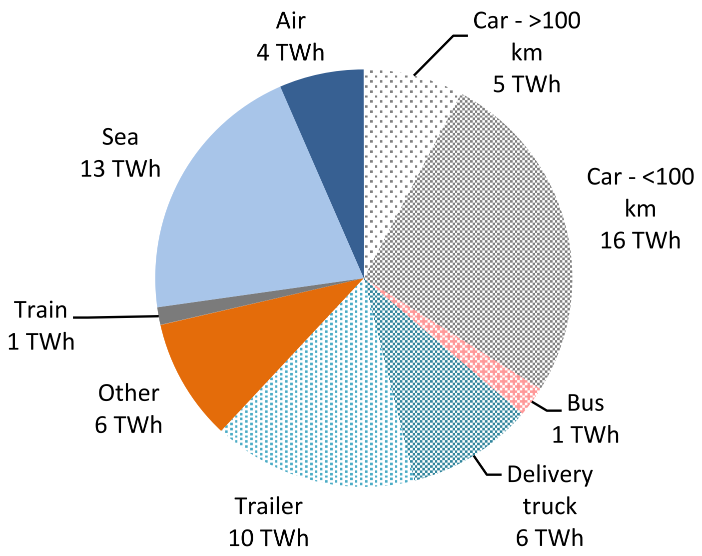


Figure 15 *Energy use in transport in 2010 (TWh)*

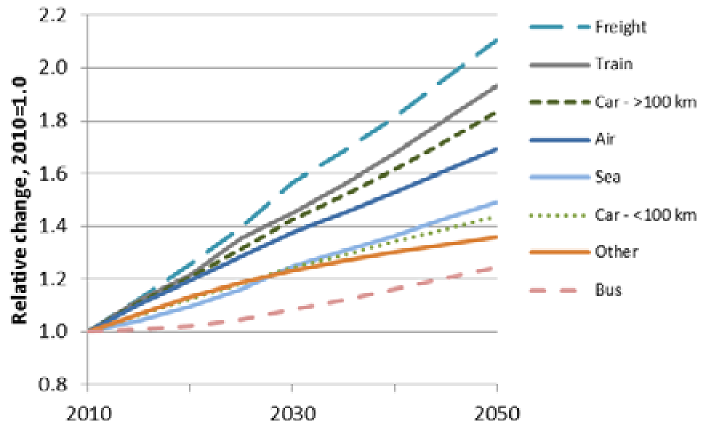


Figure 16 *Relative development of different types of transportation, 2010-2050*

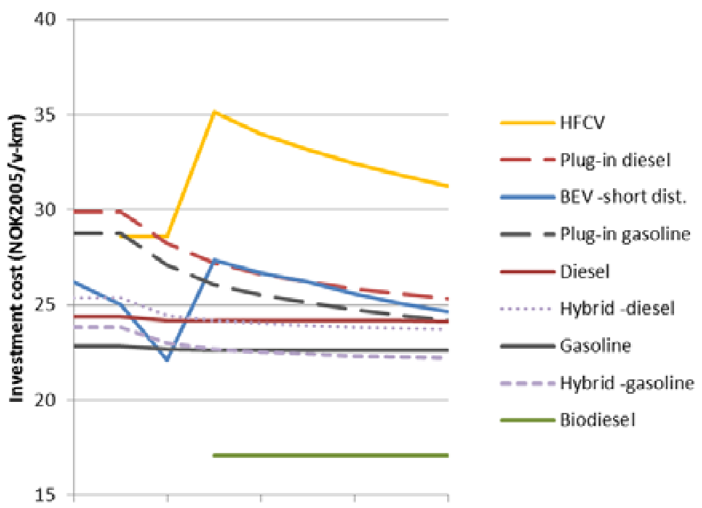


Figure 17 *Development of investment costs, incl. taxes, for different types of cars (kNOK2005/Mvkm)*

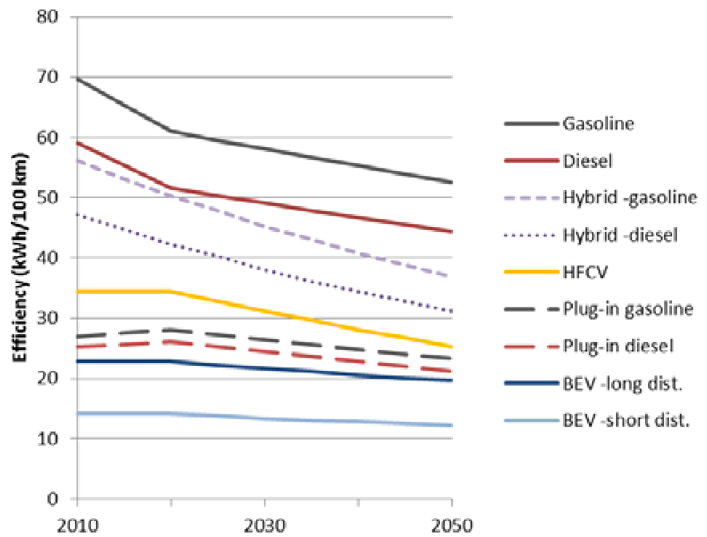


Figure 18 *Development in cars efficiencies (kWh/100 km)*

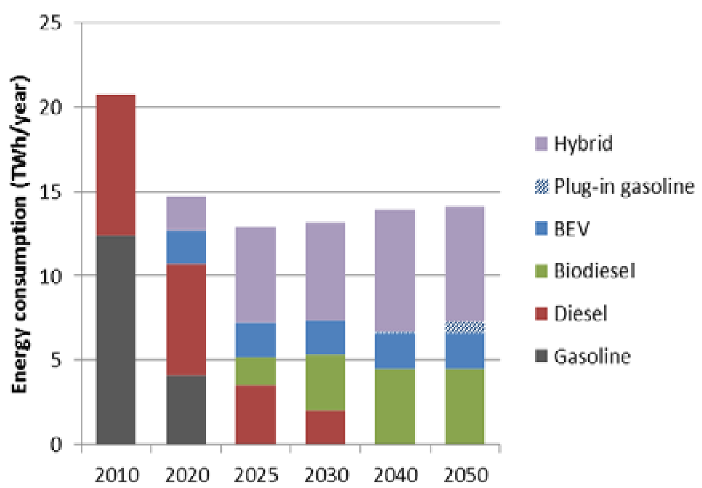


Figure 19 *Energy use by cars in the reference path, 2010-2050 (TWh/year)*

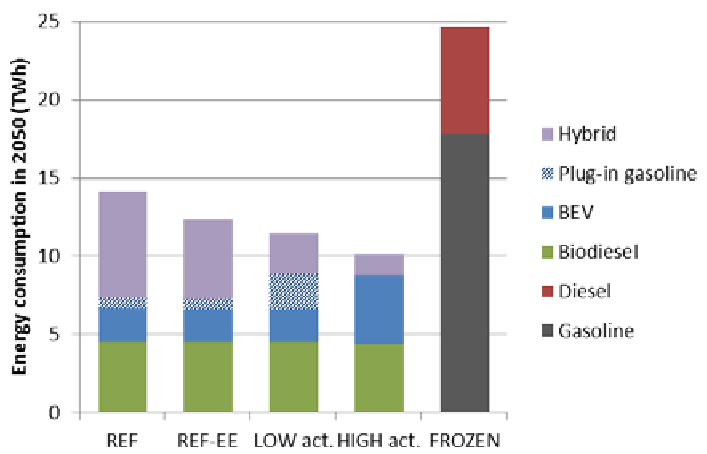


Figure 20 *Comparison of energy use by cars in the analysed scenarios in 2050 (TWh/year)*

4.4.3. Story – Transport

"This high activity scenario is a low-energy scenario for cars"

by Erling Holden, Sogn og Fjordane University College

A renewable and carbon-neutral car culture is possible...

For passenger car travel, the High Activity Scenario (hereafter called "High Activity") is a low-energy scenario. The current energy use of 21 TWh has fallen to 10 TWh in 2050, i.e. a reduction of 11 TWh or 52%. This development is a dramatic break from the gradual - and at times strong - growth in energy use for passenger transport that we've seen since the first cars came on the road around 100 years ago. High Activity is also a renewable-energy scenario where today's petrol and diesel vehicles are replaced with mainly battery-powered electric vehicles (or "EVs") and vehicles that use biodiesel fuel (or "biodiesel").

Under the right conditions, renewable energy sources produce the fuel for these cars. And not only that, but let's also imagine that the production and use of these fuels takes place entirely without greenhouse gas emissions. High Activity thus shows a possible future in which our cars cut today's energy consumption by half, use only renewable-energy sources and do not contribute to greenhouse gas emissions. All this without the need to think about travelling less, or using more public transportation. It doesn't get better than that!

The reality is that some fossil fuels will likely remain in use in 2050. This means that we should still expect some greenhouse gas emissions from cars a few decades from now. With the goal of reducing greenhouse gas emissions by 80% or more, for example, a technology-based scenario like High Activity can do half the job. Less travel, more cycling and walking, and increased use of public transport will do the rest.

… but there are a lot of hurdles to overcome

All in all, the news is good. But we need to look more closely at whether the "right conditions" are realistic. Is it true that EVs and biodiesel cars are carbon neutral?

Let's start with electric cars. The question is whether the electricity that powers EVs is carbon-neutral or not, and the discussion is wide-ranging and at times quite heated. It is also difficult to get a good grasp of. Some people argue that since Norway generates electricity from hydropower, the EV is an excellent climate choice. (Does this mean that we should avoid EVs in coal-powered Denmark?). Others argue that the electric power that goes to EVs could instead replace marginal fuels in Europe (currently coal), which suggests a terrible climate cost for EVs. In between are those who claim that the electricity in an increasingly integrated European power market should be calculated from the overall mix of power production in Europe. Depending on whom you listen to, the electric car is a good, terrible or so-so climate strategy.

Today's electric cars can reduce emissions by 30%, if they replace a gasoline or diesel car (an important and not entirely unproblematic assumption). If all of European electricity production gradually becomes based on renewable energy, or if we somehow manage to successfully capture and store the CO2 from power plants, emissions could be reduced by 100%. This scenario certainly suggests a brighter future than the continued use of petrol and diesel, even if it is wishful thinking.

So, what about biodiesel? Today, so-called first-generation biodiesel is used, which includes canola, soybean, sunflower, coconut, or palm oil as raw materials. Fat from animals or fish may also be used. A wide range of life-cycle analyses shows that the use of these raw materials only slightly reduces greenhouse gas emissions when compared to petrol and diesel cars. Under particularly unfortunate circumstances, biodiesel emissions can actually even be greater! In addition, it is troubling to produce fuel from raw materials that could instead be used for food in a world where many people are still dying of starvation.

Second- and third-generation biofuels (including biodiesel) that use wood and algae as raw materials are being developed as alternatives. Using these resources can contribute to significant reductions in greenhouse gas emissions, without competing with food production. Although we have a way to go to develop these fuels, possibilities do exist for a climate-neutral fuel.

How do we get to the High Activity Scenario?

The transportation system consists of three interlocking subsystems. The energy system delivers fuel; the means of transport system provides cars, and the infrastructure system enables us to get around. All these subsystems need to change dramatically if we are to achieve High Activity. We have to shift to renewable energy - this is possible. We need to create electric and biodiesel cars - also possible. We need to create an infrastructure for charging EVs and refuelling biodiesel everywhere - also possible. We're not asking for the moon here.

It could be harder to alter the behaviour of people in these systems. Fossil-based energy companies must rethink or be replaced, which they probably will not do without a fight. Automakers must stop producing petrol cars and concentrate on making new cars. Okay, they're on their way, but they're still earning enough on the sale of petrol and diesel cars that they will push back as long as possible. The government needs to implement measures to facilitate this transition. The political wrangling about the continuation of the incentive scheme for EVs is an indication that the transition won't be a shoe-in. Last but not least, as motorists we have to choose electric and biodiesel cars when we seek out dealers. As creatures of habit, satisfied with the qualities that petrol and diesel cars give us, we are likely to face the biggest challenge right here - the moon landing if you will.

The only fly in the ointment

In spite of the challenges we face, it is certainly not impossible to envision a scenario in which our cars do not have to be the environmental problem they currently are. High Activity is possible. Two other transportation areas are perhaps more formidable: shipping and aviation. As the scenarios in this report indicate, we can assume that freight transport energy usage will continue to go through the roof until 2050, since we cannot depend on 50-tonne battery-powered trucks. Meanwhile, many efficiency improvements in logistics and engine technology have already been taken out of the equation because of the tough competition in the industry. We will have to look into reducing the volume of transportation and transferring freight from roads to sea and rail.

Flights are also – and literally - skyrocketing. We are increasingly travelling by air, especially on long flights abroad (which are not included in the scenario calculations in this report). We may need to shift towards vacationing closer to home while we wait for a battery pack that can power a 400-tonne jumbo jet.

5. Total energy consumption

5.1. Final energy consumption

With the assumptions presented in this paper, the energy service demand for stationary use increase by 11% in the reference path from 2010 to 2050 and the energy consumption increase in the same period with 8%, see Table 9. The transportation demand increase substantially but due to particularly more efficient technologies, the increase of energy consumption of transportation is less. For example is the demand for travelled distance by passenger cars 53% higher in 2050 compared to 2010, but the energy consumption is reduced by 33% due to more efficient cars.

While electricity consumption the last 15 years has been at the same level, use of petroleum products has increased, due to increased transportation. Our analyses show that the trend of increased use of oil products will not continue, despite a very strong increase in transportation demand. With the assumptions used, the increase in total energy use will be met by an increased use of biomass and electricity. The increased electricity consumption of the reference path is almost the same as in the path of the National Budget of 2011 [2] an increase from 2010 to 2030 of 15 and 13 TWh respectively.

In the scenario with a possibility to invest in energy efficiency measures, the increase in total energy use is decreased to only 5% more than the use of 2010. With a high activity in industry, the final energy use increase by 19% at the same time as the electricity consumption increase by 33%. The opposite is noted in the scenario with a low industrial activity; final energy use and electricity use decrease by 8-10%. This means that the activity level in industry has large impact on both total energy and electricity use.

In order to illustrate possible outcome of future energy consumption, different population projections [5] are combined with the high and low activity scenarios of industry. The low scenario of Figure 21 and Figure 22 is a combination of the low population projection of Statistics Norway 2012 (LLML) with the Low activity scenario earlier described. The high scenario of Figure 21 and Figure 22 is a combination of the high population projection of Statistics Norway 2012 (HHMH) and the High activity scenario of this paper. The high population projection increases the energy consumption of buildings in 2050 with about 25 TWh more than the reference path, while the high industrial activity increase the use by approximately 17 TWh. The low population projection decreases the energy consumption of buildings with about 13 TWh in 2050 compared to a decrease of industry energy use of 15 TWh due to reduced activity (excl. energy efficiency measures). Final energy consumption increased by 31 TWh the last 24 years [14] and is calculated to increase by 29 TWh the next 25 years. The electricity consumption of Figure 22 includes use in district heating plants, but doesn't include grid losses. Grid losses are calculated to 13 TWh in 2050 in the reference path.

5.2. Electricity production

The hydro power production increases in the reference path by 33 TWh towards 2050, while wind power production increases by 9 TWh in 2020-2030 and is back at the present level in 2050. The investments in wind power are done during the period with electricity certificates. The net electricity trade increases to 19 TWh in 2030 and is calculated to 14 TWh in 2050 in the reference path. The wind power production increases with higher electricity trading prices as in the LOW activity scenario. If the discount rate is increased from the 4% used in these analyses, the wind power production decrease.

The net power trade is strongly dependent on the exogenously given trading prices. In the LOW activity scenario the trading prices are the highest at the same time as the Norwegian electricity use is at the lowest, and therefore the net trade is highest in this scenario. But even in the HIGH activity scenario with a substantial increase in Norwegian industrial activity, the Norwegian power production is high enough to supply the demand.

Table 9 *Energy service demand and final energy consumption in the reference path*

	Energy service demand					Final energy consumption («purchased»)				
	2010	2030	2050	Unit	Change 2010-2050	2010	2030	2050	Unit	Change 2010-2050
Primary sector	3.2	3.9	4.3	TWh	+34%	3.2	3.9	4.3	TWh	+ 38%
Construction	1.6	2.0	2.2	TWh	+38%	1.6	2.0	2.2	TWh	+38%
Service	30.5	32.0	35.2	TWh	+15%	29.3	31.3	36.1	TWh	+23%
Residential	44.0	51.1	55.3	TWh	+26%	46.5	50.2	52.0	TWh	+12%
Industry	77.7	78.1	78.1	TWh	+1%	80.7	78.9	78.7	TWh	-2%
Sum stationary	157.0	167.1	175.1	TWh	+11%	161.3	166.3	173.4	TWh	+8%
Passenger cars	32.3	41.5	49.4	Bv-km	+53%	20.8	13.2	13.9	TWh	-33%
Buses	0.64	0.69	0.79	Bv-km	+24%	1.4	1.5	1.7	TWh	+19%
Trucks	12.2	19.1	25.7	Bv-km	+108%	15.8	21.6	29.2	TWh	+85%
Other transport	23.4	29.7	35.3	TWh	+50%	23.4	29.7	35.3	TWh	+ 51%
Total energy						223	232	253	TWh	+14 %

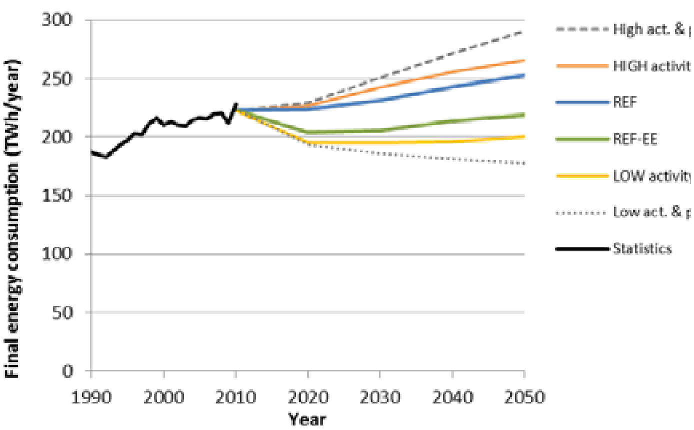


Figure 21 *Statistical final energy consumption 1990-2013 and projection of final energy consumption of analysed scenarios 2010-2050 (TWh/year)*

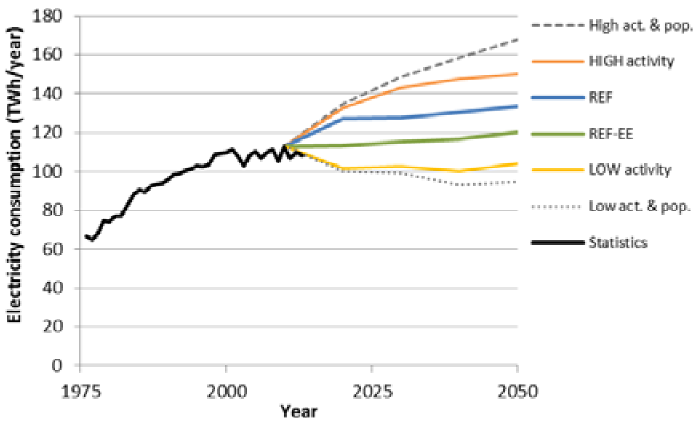


Figure 22 *Statistical electricity consumption 1976-2013 and projection of electricity consumption of analysed scenarios 2010-2050 (TWh/year)*

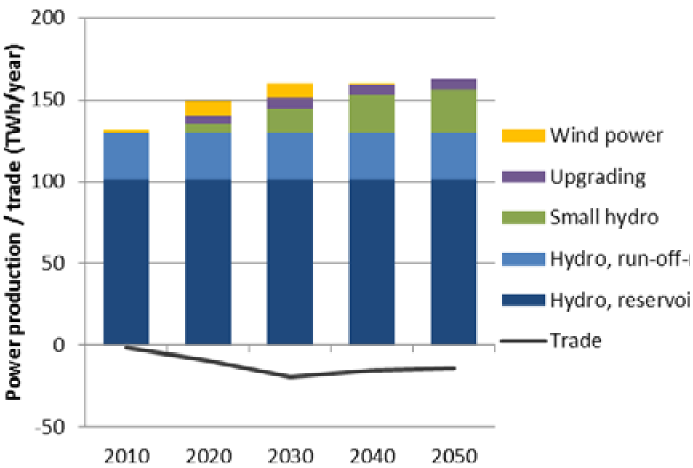


Figure 23 *Power production and net electricity trade 2010-2050 in the reference path (TWh/year)*

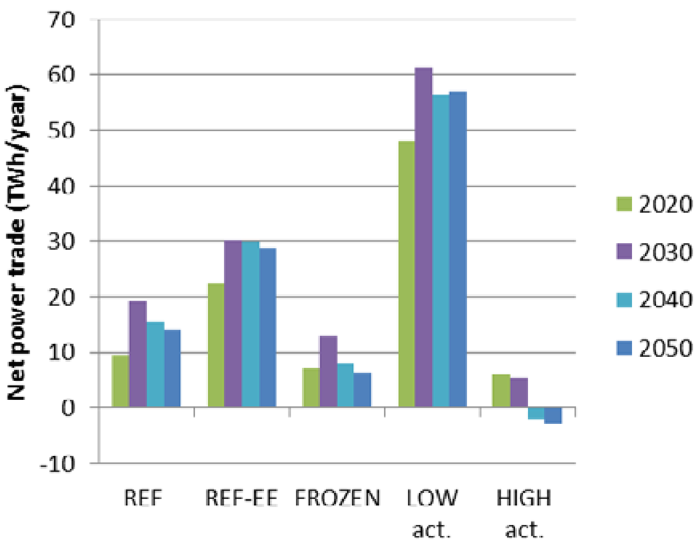


Figure 24 *Net power trade with neighbouring countries in the different scenarios in 2020-2050 (TWh/year)*

6. Discussion

This paper presents a possible energy demand projection and do not have the objective to predict the future energy use. The need of energy demand projections among CenSES user and research partners initiated the work. The last public energy demand projection is almost 10 years old, while later governmental energy demand projections are concealed in other foresight documents. Some data on electricity forecasts are available, but no data of total or useful energy demand and most assumptions are not openly accessible. The lack of an official Norwegian energy demand projection with a transparent view of assumptions made it desirable to develop this projection.

An energy projection was developed during the work with "Perspektivmeldingen 2013", but it is not public available. The electricity consumption of power intensive industry is explained to be unchanged, which is in accordance with our reference path [15]. "Energiutredningen" includes a projection of electricity production and consumption towards 2030 [16]. The use of electricity was calculated to increase by 13 TWh from 2010 to 2030 in the reference path, by 27 TWh in the "expansive scenario" and by 14 TWh in the "tight scenario" [2]. The growth is expected in general consumption, while power intensive industry is assumed to be unchanged. The last public available energy projection was presented in 2006 in the White Paper "A climate-friendly Norway" [1]. Here, the total energy consumption was calculated to increase from 229 TWh in 2000 to 333 TWh in 2050 and the electricity consumption was calculated to increase from 126 TWh in 2000 to 197 TWh in 2050. The expectations of future electricity production have been dramatically changed from the expected need of 59 TWh gas power in 2050 in the 2006-projection to the present expectations of a power surplus by many actors. The public available projections have all a higher growth than the CenSES Reference path, see Figure 25.

The work in this paper is developed through several workshop discussions with CenSES partners interested in the area. The analyses are carried out by IFE and narrative stories underpinning the projections are written by some of the other CenSES research partners.

There are many uncertainties related to development of an energy projection towards 2050. Some are addressed in this paper, partly as alternative scenarios, but many others have to be studied in succeeding work. Five scenarios are analysed (REFerence, REF-EE with Energy Efficiency-measures, LOW industry activity, HIGH industry activity and FROZEN). They represent varying inclusion of explicit energy efficiency measures, external given energy prices and level of industry activities, see Figure 26. Uncertainties of great importance are related to data assumptions, scenario definitions and model imperfections and some of these are addressed here.

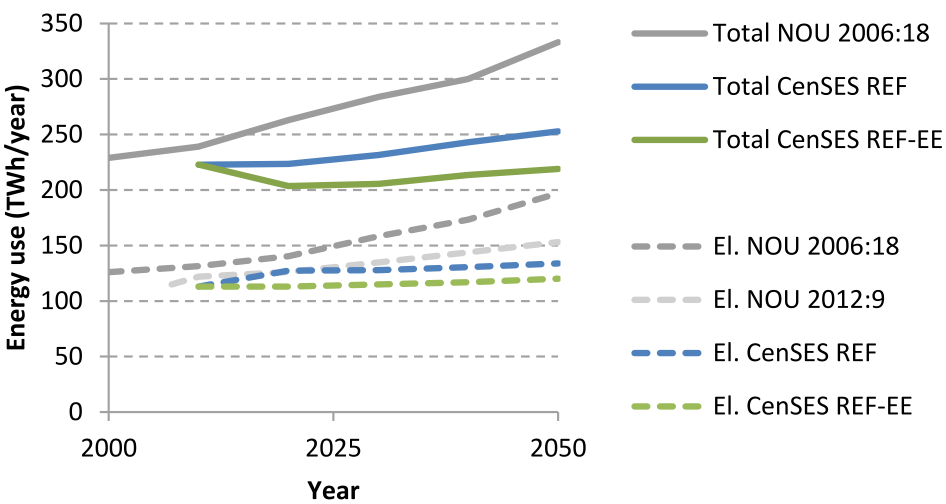


Figure 25 *CenSES Reference path and REF-EE compared with official projections; total energy consumption and final electricity consumption (TWh/year)*

Scenarios
In the REFerence path, energy efficiency is included through renovation of buildings and improved efficiencies of end-use demand, but investments in other energy efficiency measures like heat recovery, improved processes, behavioural measures etc. are included in the alternative scenario REF-EE. This is done to analyse the impact of efficiency measures, and to shed light on challenges related to energy efficiency.

The efficiency measures are profitable; however all the measures are not actually implemented. Behavioural aspects and barriers related to implementation of efficiency measures have not been included in the analysis. Part of the energy efficiency potential will probably be implemented with the present policies, resulting in a reference path between REF and REF-EE in the analyses presented. Further implementation of efficiency measures will require an increased focus, and political efforts such as explicit targets of energy efficiency can be one way to increase energy efficiency. If all profitable energy efficiency measures are implemented in both industry and buildings, the energy use will decrease enough to cover the increased demand of the high industry activity scenario or the high population growth.

Prices for energy carriers being imported to and exported from Norway is an important factor in the analysis, especially the electricity import/export price, as this have a huge impact on the net power trade. In all scenarios, but LOW, the electricity import and export price is constant in the period 2016-2050.

In the LOW scenario with higher import and export prices, the net power trade is highest, due to decreased domestic energy demand as well as increased power production. Instead of increased electricity export, it is possible to increase domestic electricity use. In the HIGH activity scenario, the electricity demand in industry and transport increases. This higher activity level is possible without being dependent on a net import of electricity. Production of hydrogen by electrolysis is another example of how to utilize excess electricity that might be interesting if the technology development becomes a success, but this has not been included in this work. Also electricity in buildings has a potential to grow, beyond the growth observed in the reference path, if restrictions on electricity for heating is removed. The new building regulation proposition opens for increased use of electricity for heating, but this is not included in the analyses carried out in this paper. Analysis results show an excess of electricity in most scenarios that can be used for more electricity for heating but then also the power profile should be studied.

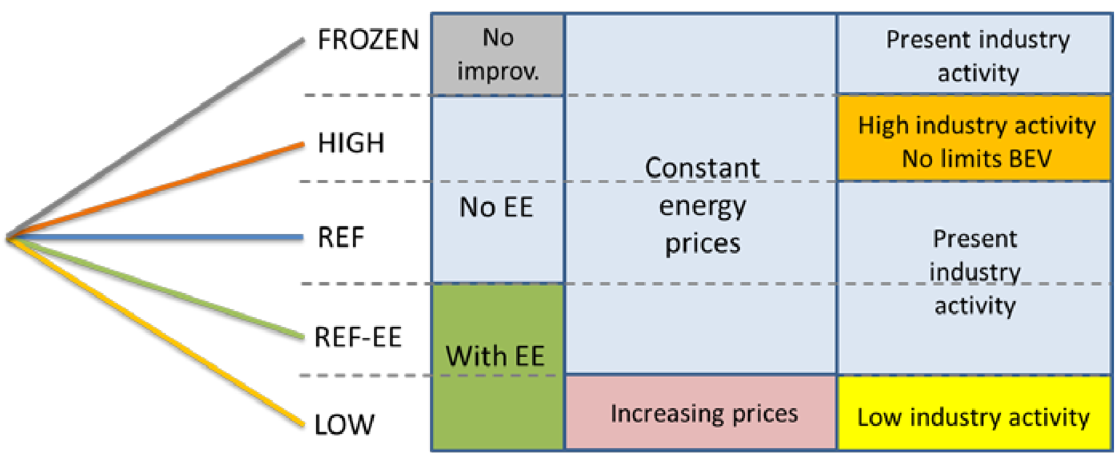


Figure 26 *Main parameters of the five scenarios analysed (light blue were nothing is changed compared to the REFerence scenario; EE = energy efficiency measures included)*

Assumption uncertainties
Data assumptions, e.g. the development of new technologies, are uncertain both with respect to investment cost, to efficiencies and to the time horizon for the development. One example of consequences of data uncertainties is the investment of wind power in the reference path. We observe that we will get no re-investment in wind power when the technical life time of the power plant is exceeded. This means that onshore wind power is only profitable as long as the electricity certificate market is in operation. How the investment cost will develop for new wind farms compared to the re-investment to replace existing wind farms is however uncertain. The investment cost will be somewhat lower, though more important are barriers related to e.g. license, grid connection and public engagement which is already handled. This kind of barriers is not part of the analysis.

Another example is the future development in vehicle technologies and production of new transportation fuels. Over the last decade there has been a gradually improvement of vehicle efficiencies, and a continued gradual improvement in the future is anticipated. Important uncertainties in the transport sector with a great impact on the analyses are among others:

- What will the maximum share of vehicles that can be battery electric vehicles be?
- When will 2nd generation bio fuels based on waste from forest be available?
- How will the cost of building new refueling infrastructure for road transport develop?

If production of sustainable bio fuels for transport is delayed, or not available in the analyzing period, there will be an increased use of petroleum based fuels, in hybrid and plug-in hybrid vehicles.

How climate change will impact the energy system is uncertain, however there will be an impact on both future energy production and energy demand. Increased hydro production, due to increased precipitation is partly taken into account in the analysis as the hydro production in a normal year has increased. Future increase in hydro power production is not included, neither is reduced energy demand due to increased average temperature included. (According to previous work [17], the future heating demand in buildings can be reduced by approximately 15% in 2050 compared to a development without climate change.)

Model imperfections
In this work the energy system model TIMES-Norway is used to analyse the future energy consumption. TIMES assumes perfect competition and perfect foresight, and the model aims to supply energy services at minimum cost, thus the model will utilize the whole potential of the low-cost options with respect to technology and energy carrier. This may result in too high utilization of certain technologies, while the actual technology mix is more diversified. TIMES-Norway depends on various assumptions, ranging from technology development, to energy prices and population projections. A huge effort to improve input assumption has been done, however considerable uncertainty exists in the development towards 2050. The use of sensitivity analysis for selected parameters contributes to an increased understanding of the robustness of the analysis results.

The demand for energy is dependent on people's behaviour. Examples are in choice of vehicle, as small or large vehicles have a huge impact of the vehicle efficiency and in shift from use of private car to public transport, walking or cycling. This kind of behavioural aspects is not included in TIMES-Norway, however it is an important area of future energy use that has to be analysed beyond the work presented here.

Concluding remarks
Some of the analysed uncertainties are compared in Figure 27 as changes compared to the reference path in 2050. The activity level of Norwegian industry as described in the LOW and HIGH activity scenarios results in a variation from -15 TWh to +17 TWh in 2050. If the population projection follows the high or low path of Statistics Norway [5], the energy use of the building sector increase by about 25 TWh or decrease with about 13 TWh, an outcome difference of 39 TWh. Another development of huge impact is if the transportation demand increase as much as described in the National Transport Plan [18] or if it can be reduced to the same growth as the population ("lower transportation" in Figure 27). The energy demand for transport also decreases; however to a smaller degree, if there is no restriction on the use of battery electric vehicles. Increased building regulation requirements may have an important impact on the future energy demand. If the heating demand is restricted to 15 kWh/m^2 for space heating in new buildings from 2020, in accordance with the passive house requirements, the energy use of buildings can be reduced by about 9 TWh in 2050,

compared to the development in the reference path ("passive house" in Figure 27).

The outcome of the analysed scenarios points at some interesting pathways of Norwegian energy use. In the low activity scenario the Norwegian industry will be less important from an energy point of view and Norway will be a major exporter of clean, renewable energy to Europe. The net electricity export in the low activity scenario is calculated to more than 60 TWh in 2030, compared to the high export year 2012 of 18 TWh, and this could be even higher in years with high precipitation. Another example of Norway as a commodity exporter is the export of timber that has increased considerable due to the closing down of many pulp and paper plants and if no alternative Norwegian use is developed, this effect will be enforced in the low activity scenario.

The opposite is the result of the high activity scenario, where the electricity export is low and the Norwegian industry has a significant growth. A combination of implementation of energy efficiency measures, improved transportation and a higher Norwegian industry activity, will make it possible to combine a high national activity with an important contribution to balancing intermittent power production in Europe through power connections. Strong business policies with stable framework conditions will probably be necessary to develop Norwegian industry along the high activity pathway. If energy efficiency measures are implemented along with promoting activities such as energy labelling, building regulations, energy monitoring including advanced monitoring and control systems, the Norwegian energy use can be efficient yet on a high activity level, letting Norway act as a balancing partner of European power production.

Within CenSES a common interest for energy demand projections has been identified, and the common projection for Norway, presented in this paper, is meant to form a basis for new analysis and studies. The assumptions are available in the project report [4]. Even though the future is unsure, and despite the many uncertainties in the assumptions, the presented reference path for energy demand towards 2050, and the alternative scenarios, represent a possible range for development of future energy demand.

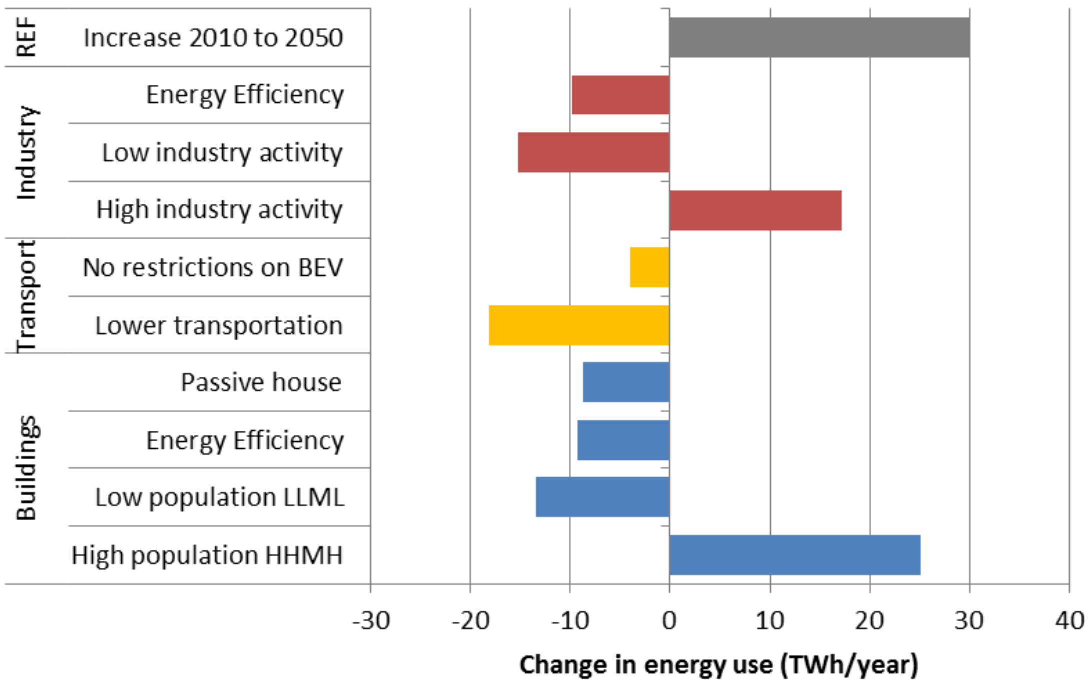


Figure 27 *Illustration of the impact of some assumptions compared to the energy use of 250 TWh in the reference path in 2050 (TWh/year)*

7. References

1. Minisitry of Environment, NOU 2006:18 A climate-friendly Norway (In Norwegian: Et klimavennlig Norge), 2006
2. Ministry of Petroleum and Energy, In Norwegian: Bakgrunnsnotat om beregninger til Energiutvalget, 2012
3. Institute for energy technology, Energiscenarioanalyser Enova-IFE, IFE/KR/E-2009/006, 2009
4. Institute for energy technology, CenSES-energiframskrivninger mot 2050, IFE/KR/E-2014/003, 2014
5. Statistics Norway, Befolkningsframskrivninger 2012-2100, 2012, Available from: http://www.ssb.no/befolkning/statistikker/folkfram/aar/2012-06-20
6. Lind, A., et al., Analysis of the EU renewable energy directive by a techno-economic optimisation model, Energy Policy, 2013. 60(0): p. 364-377
7. Institute for energy technology, TIMES-Norway Model Documentation, IFE/KR/E-2013/001, 2013
8. IEA, World Energy Outlook 2013, 2013
9. Energinet.dk, Energinet.dk's analyseforudsætninger 2014-2035, 2014
10. Statistics Norway, Statistikkbanken, 2015, Available from: www.ssb.no/statistikkbanken
11. Institute of Transport Economics, Grunnprognoser for persontransport 2010-2060, 2011, Transportøkonomisk institutt, Oslo
12. Institute of Transport Economics, Grunnprognoser for godtransport til NTP 2014-2023, 2011, Transportøkonomisk Institutt, Oslo
13. Joint Research Centre, The JRC-EU-TIMES model, Assessing the long-term role of the SET Plan Energy technologies, 2013, JRC, Petten
14. Eurostat, Database Energy statistics, Final energy consumption. 2015, Available from: http://ec.europa.eu/eurostat/data/database
15. Ministry of Finance, White Paper No. 12 2012-2013 Long Term Perspectives on the Norwegian Economy (In Norwegian St.Meld. 12 2012-2013 Perspektivmeldingen 2013), 2013
16. Ministry of Petroleum and Energy, Energy report - Value added, energy security and environment (In Norwegian: Energiutredningen - Verdiskaping, forsyningssikkerhet og miljø), 2012
17. Seljom, P., et al., Modelling the effects of climate change on the energy system—A case study of Norway, Energy Policy, 2011. 39(11): p. 7310-7321
18. Ministry of Transport and Communications, White Paper No. 16 (2008-2009) National Plan of Transport 2010-2019 (In Norwegian: St.meld. nr. 16 (2008-2009) Nasjonal transportplan 2010-2019), 2009

CenSES — Centre for Sustainable Energy Studies
Faculty of Humanities
Norwegian University of Science and Technology (NTNU)
7491 Trondheim
Norway

www.censes.no
censes@ntnu.no

Eva Rosenberg
eva.rosenberg@ife.no

Kari Aamodt Espegren
kari.espegren@ife.no

Erling Holden
erling.holden@hisf.no

Olav Wicken
olav.wicken@tik.uio.no

Marianne Ryghaug
marianne.ryghaug@ntnu.no

Knut Holtan Sørensen
knut.sorensen@ntnu.no

View the report online: www.censes.no/publikasjoner
Order a copy of the report: censes@ntnu.no

Photo front cover © istockphoto
ISBN 978-82-93198-09-3