Energy Pathways for Future Residential Building Areas in Norway

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Abstract. Due to stricter building energy requirements, future buildings will be characterized with low base loads and occasional high peaks. However, future building areas will still contain existing and historical buildings with high energy use. Additionally, there is a requirement that future building areas have to get energy from renewable energy sources, while existing buildings need to make transition to the renewables. The aim was to analyze different energy systems and technologies that can help to reduce CO_2 emissions in the future building areas in Norway. In this study, different methods were combined: detailed building simulation, energy supply technology simulation, heat demand aggregation, and data post-processing. The results showed that the energy pathways would be very dependent on the CO_2-factors for the energy sources and it is hard to tell which CO_2-factor is correct. An increasing housing stock development would slightly increase the CO_2 emission towards 2050, even though the new buildings used half the energy than the existing buildings and the existing buildings undergone energy efficiency improvements. A constant housing stock would decrease the CO_2 emission by around 22-27 % depending on energy supply systems. The results showed that the influence of implementing stricter building codes had a lower impact on the total CO_2 emissions, compared to the influence of the CO_2-factors and energy supply technologies. Regarding the existing buildings, the requirements such as: limited use of direct electric heating, requirements on the service systems, and definition on hot tap water use should be emphasized.

Keywords: Energy planning, Building stock, Residential buildings, Energy supply, Building requirements.

1 Introduction

Energy planning of the building stock is a highly important topic and highly relevant for energy policy, requirements, and standards development, see Fig. 1. Regardless of its importance, this research topic is still in its infancy. Different tools have been developed, but they have only partially succeeded due to sectional and particular interests when developing the tools [1, 2]. There are several reasons for this such as a fragmented building industry, complex building ownership, divergent interests regarding energy use and supply.

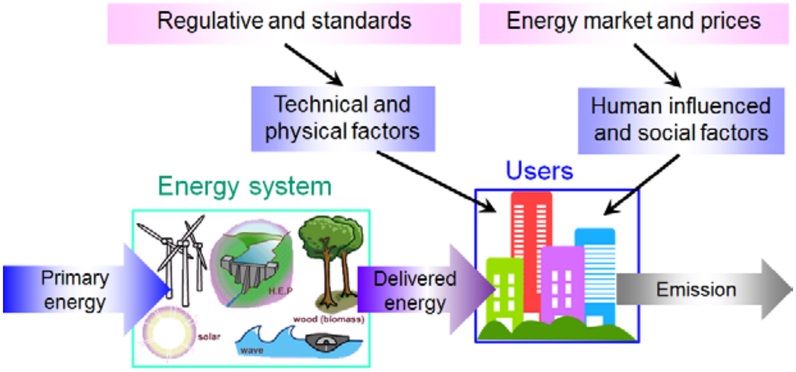

Fig. 1. Big picture of building energy planning

Currently, there are only a few transparent tools internationally with limitations for developing building energy requirements, which links building stock characteristics to aggregate energy demand and the associated greenhouse gas emissions. For example, the discussion on the last Norwegian building technical requirement, TEK17, showed this problem when the requirement on energy flexibility for building energy supply was removed, due to government promise to enable cheaper housing. The requirement on energy flexibility that implied possibility for the water based heating and connection to the district heating was diminished: 1) by decreasing the share of energy that should be delivered by the flexible solutions, and 2) by increasing the building area with the energy supply requirement. All these meant that requirement for the implementation of the renewable sources was weakened. This example from Norway showed that the development of building energy requirements was not performed neither by considering energy analysis of the building stock nor estimation of the effect of the decisions on the future energy demand of the building stock. Current building energy requirements do not guarantee that buildings and building stocks will achieve global environmental requirements, because there are few organizational and institutional structures to support these changes and no sufficiently useful and transparent energy planning methodology [3]. Hence, there is a lack of tools for energy planning on different levels for different decision makers. To achieve global emission requirements, policy developers, energy planners, energy supply companies, and city planners need a transparent tool and methodology to analyze the possibilities, so that their requirements and ideas would provide a renewable society with very low emissions.

Different methods are suggested to model energy use and emissions of the building stocks. The extrapolation method considering the occupant behavior is done by many researchers in Japan. Energy Solar Planning (ESP) tool is a simple tool for municipalities' district planning based on a steady-state monthly energy balance method [1]. Monte Carlo simulation has been used to predict space heating energy use of housing stocks in a bottom-up approach [4], but the model shows to have uncertainties in prediction. At present the only software to deal with this topic is the Sustainable Urban

Neighborhood modeling tool (SUNtool) and its recent successor CitySim. Even though these tools are dealing with occupant behavior, they are not treating energy storage associated with buildings or district energy systems. Even though the research field on energy flow modeling of the urban built environment has been growing, it is still in its infancy. Only limited progress has been made with respect to modeling of supply from energy conversion systems [1]. The simulation tool for energy planning called EnergyPLAN treats the supply side, while the heating and electricity load of an urban area are inputs [5]. Therefore, one of the aims of this study was to develop approach for modelling the building area together with the energy supply system.

The aim of the study was to develop energy pathways for residential building areas, taking into account different structure of the building area, implementation of the new requirements for buildings, and energy supply systems. For this purpose, different calculation methods were combined: detailed building simulation, energy supply technology simulation, heat demand aggregation, and data post-processing. Building models covering different building codes were developed in IDA ICE. An imaginary area connected to district heating representing in a well way the Norwegian residential statistic was analyzed.

The paper is organized as follows. Methodology is introduced in brief by presenting the main calculation steps. In the result section, energy use of residential buildings at different standard are firstly introduced. Based on the linear projection of the building development, total energy demand until 2050 was presented. The most important performance data of the energy supply plants were introduced. Finally, the CO_2 emission development of the building area over the years is given. This was a big study. Due to effectiveness of the paper, only the main results are introduced. The sensitivity analysis and criticism on the results is given as comment when relevant.

2 Methodology

This study was combining the methods from building energy use analysis and energy supply system analysis.

2.1 Main information flow for the study

The main information flow for the study is introduced in Fig. 2.

Firstly, the study focused on energy use in buildings and the purpose was to create different simulation models that presented households according to different standards, thus representing all the building energy classes in Norway. The first part of the method is given at the left side in Fig. 2. The input data are placed in trapezoids. The building models were developed in the IDA ICE simulation tool, and were based on historical and current standards. The models were simulated separately and then aggregated to achieve an imaginary housing area with 72 MW of heat demand and 28 MW of electricity demand.

In the second part of the study, the right part in Fig. 2 - dealt with the energy supply technologies and thereby the power and energy requirements of the housing stock were used as the input for evaluating different energy supply technologies.

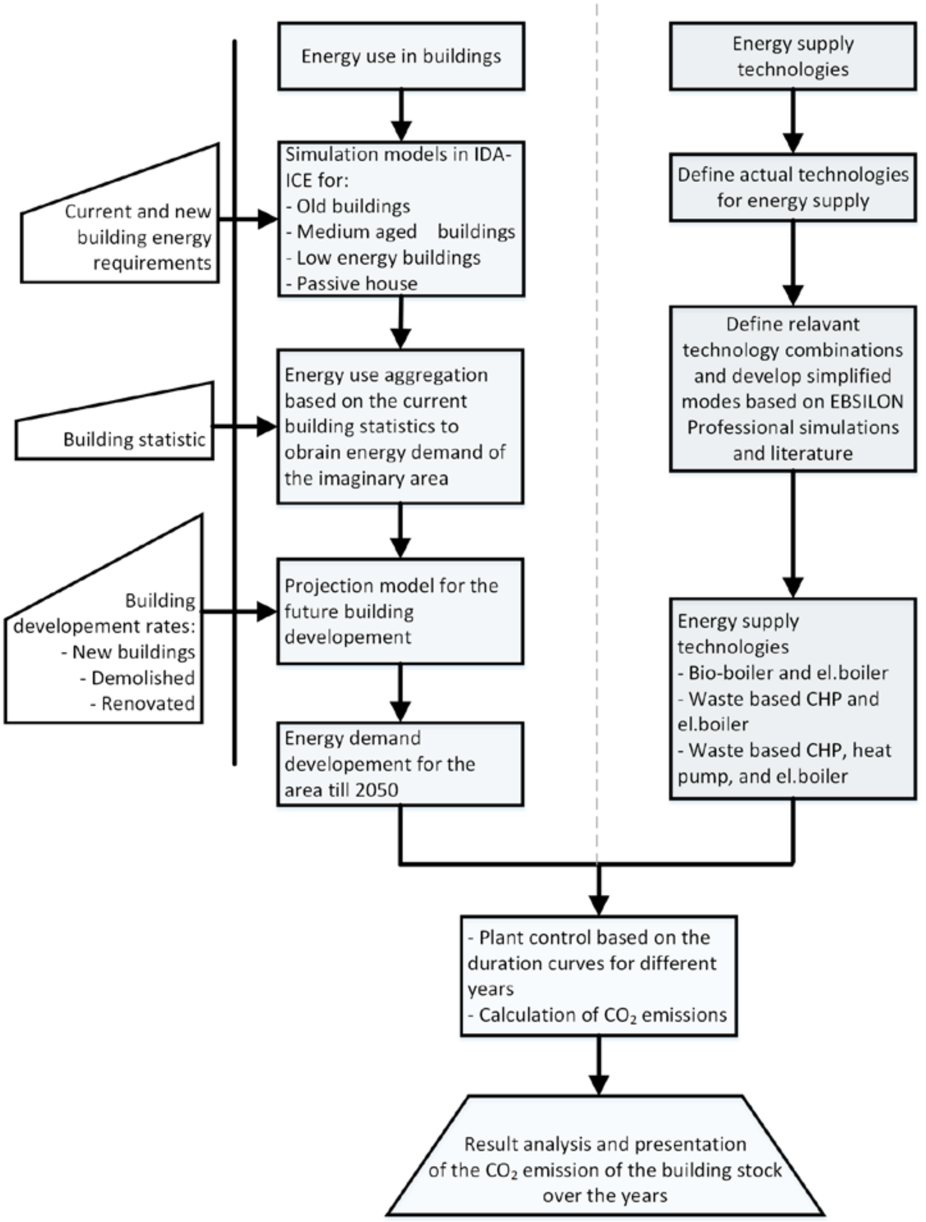

Fig. 2. Main information flow for the methodology combining building energy use and energy supply

Energy supply technologies were determined through a literature study that deals with current renewable energy sources and associated CO_2 factors [6, 7]. Combinations of energy supply technologies, as well as power distribution between technologies, were based on experience from other facilities. Simplified simulation models based on EBSILON Professional simulations were calibrated with the corresponding real plant data. With the simplified models, it is meant parametric models giving relationship between the heat and power output and fuel input. By combining the parametric models and the load of the building stock, a method has been developed to control input of the energy supply technologies based on the energy requirements. Finally, CO_2 emissions were calculated for today and future years. The technologies were further evaluated against each other to find the most optimal solution.

2.2 Building energy demand

In this study, a reference building that is a typical two-storey, three-bedroom. single-family house built before 1980, with an area of 122.2 m^2 was chosen, see Fig. 3. The unit is located at the end of a terraced building to represent the worst-case scenario. A multi-zone model of the building was developed in IDA-ICE [8], and Climate data for Oslo, Norway, were used.

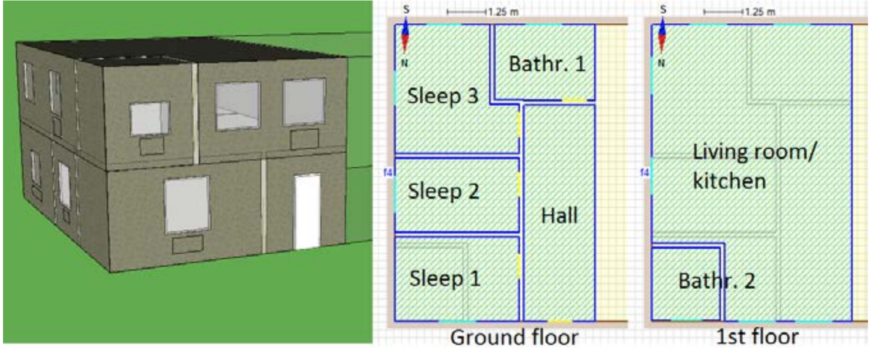

Fig. 3. Residential building model

To calibrate the energy use of the reference building in Fig. 3, data from both the Norwegian Energy Efficiency Agency, Enova [9], statistical data, and standards were used. For buildings built around 1969, the average total specific energy use was 178 kWh/m^2. Radiators were chosen as the heating system. Based on NS3031[10], the space heating system was designed for an desired temperature of 21/19°C in occupied/non-occupied hours during the coldest period of the year. The internal gains and electrical appliances were modelled based on the standard values [11] and to achieve an average energy use for electrical appliances of 25 kWh/m^2 [12].

After the building simulation model was calibrated based on the national statistics, different measures were introduced to model medium aged buildings, low energy, and passive house buildings. The medium aged buildings presented the existing buildings that have passed some energy efficiency measures. In this study, detail hourly values on the heat and electricity demand were used. Such high quality and high resolution data were difficult to find in the national statistic data. In general, it was only possible to find specific total building energy use per m^2. A summary of all the relevant input data for modelling of the single residential building are given in Table 1.

Table 1. Summary of the input data for the building simulation

Description	Old building	Medium aged building	Low energy building	Passive house
U-value for roof [W/m^{2}K]	0.40	0.20	0.13	0.09
U-value for floor on ground [W/m^{2}K]	0.40	0.299	0.15	0.08
U- value for external wall [W/m^{2}K]	0.50	0.299	0.18	0.12
U-value for windows [W/m^{2}K]	2.889	2.40	1.145	0.78
U-value for doors [W/m^{2}K]	2.00	2.00	1.20	0.80
U-value averaged [W/m^{2}K]	0.548	0.380	0.2723	0.1922
Normalized cold bridges [W/m^{2}K]	-	-	0.03	0.03
Air change at 50 Pa pressure difference [h^{-1}]	4.0	4.0	2.50	0.60

From Table 1, it can be noted that there is a large decline in average U-value, from older buildings to passive houses. Further, it can be noted that the average U-value has a declining tendency in recent years, which indicates that the development of dense and compact building bodies has come a long way and that the improvement potential is not as great as before. For the building given in Fig. 3 and the input data given in Table 1, the total specific energy use considering different building standards is given in Fig. 4.

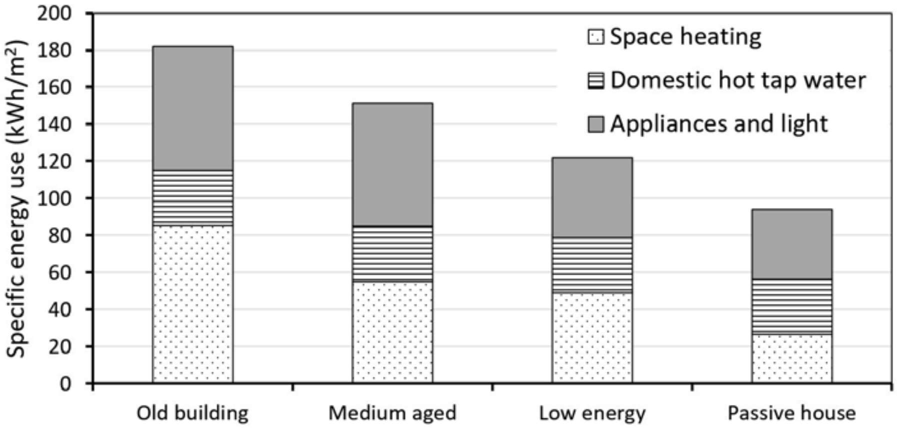

Fig. 4. Total specific single building energy use

From Fig. 4 it can be noted that energy use was almost halved from the older building for the passive house. The biggest contribution to the reduction came from a significantly lower heating requirement through better insulated building body. The heating requirement for tap water is unchanged, while electricity use was reduced due to more energy-efficient equipment and lighting. The results in Fig. 4 were also compared with the real measurements and statistics and were found to fit well with the energy measurements. Hence they were treated as reliable for further analysis.

For the developed building models, influence of occupant behavior on the building stock energy demand was also analyzed by considering differences in light, appliances, and domestic hot tap water use. Different schedules and demand were implemented for the domestic hot tap water. Different operation schedules and installed power for the appliances and light were treated, too.

2.3 Building stock model

Energy demand aggregation was based on housing statistics and statistics from the energy labeling system to get accurate weighting of the housing stock. Furthermore, the housing stock was projected with linear growth rates, so that an overview of the power and energy requirements today and in the future was provided. Three different scenarios were made for the projection of housing stock in order to capture the uncertainty associated with housing growth. A summary of the projection rates for the building stock is given in Table 2.

Table 2. Projection rates for building stock

Projection rates (% per year)	Normal	Conservative	Ambitious
New building rate	1.33	1.06 (-20 %)*	1.66 (+20 %)*
Rehabilitation rate	1.50	1.20 (-20 %)*	1.80 (+20 %)*
Demolition rate	0.60	0.48 (-20 %)*	0.72 (+20 %)*

The projection rate in Table 2 were assumed based on a report on future development. Please note that these projection rate are based on a possible economical development, rather than on achieving certain energy demand decrease of the building stock. Based on the Norwegian building statistics of the building stock and forecasts for the residential building development given in Table 2, an analysis on development of the energy demand until 2050 was made.

2.4 Energy supply system and CO_2 emission

To combine hourly heat and electricity demand with the energy supply technologies, parametric models were used as explained in Section 2.1. The parametric model included performance data under the part load. Depending on the energy supply scenario, see Table 3, the plants were controlled in the following way. The plant were organized as base and peak load plant. The plant with high investment cost and low energy cost were treated as the base load plants, while the plants with the low investment and high energy cost were considered as peak load plants. The sizes of the plants in Table 3 were obtained based on the cost-optimal approach explained in [7, 13].

The control of the plant were organized as: if the heat load at an observed moment was lower than the full base load plant, then that plant was operating under the part load. If the observed load was higher than the full base load plant, the second plant was started. Based on the rest load, the second or the peak load plant was operating on part load. The hourly calculation for each year considering change in the duration curves and thereby energy demand due to building stock change was calculated.

Table 3. Energy supply scenarios

Scenario	Energy production (heat demand)	Required rate (MW)
F1	90 % Bio-boiler	33.1
	10 % Electrical boiler	-
F2	90 % Waste based CHP	33.1
	10 % Electrical boiler	-
F3	80 % Waste based CHP	25.6
	20 % Electrical boiler	-
F4	67,7 % Waste based CHP	19.0
	22,3 % Heat pump	14.3
	10 % Electrical boiler	-

After the fuel and energy input were calculated over different years, the CO_2 emission was estimated. The CO_2 emission was estimated by using the factors given in Table 4 based on [14]. There have been lots of discussion about the values on the CO_2 emission factors. Depending on the institution, the values from 3 gCO_2e/kWh [15], if only the Norwegian hydro power is considered, up to 493 gCO_2e/kWh [16], if the guarantee of origin for the renewable electricity were treated. Regarding the CHP plant, the CO_2 emission related to the heat and electricity production, was allocated by using the energy method [6].

Table 4. Recommended CO_2 emissions factors [14]

Energy soures	Total (gCO_2e/kWh)
Electricity (Nordic production mix)	110
Municipal waste (with sustainable criteria)	11
Municipal waste (without sustainable criteria)*	175
Wood chips	18
Pellets and wood powder	19
Heat pump	110

In Table 4, for the municipal waste with sustainable criteria, it was meant waste without fossil waste and this value was used in the study. With the CO_2 emission of the heat pumps, it is meant CO_2 emission of the electricity used by the heat pump. All the values may change over the years, but this was not treated in this study. For analysis purpose, different values for the CO_2 emission were considered and commented.

3 Results

A brief summary of the most relevant results giving the main idea how to decrease the CO_2 emission of the building stock and what are the main issues is given in this Section.

3.1 Energy demand of the building stock and future development

Based on the method introduced in Fig. 2 and combining the data on development of building energy use in Fig. 4 and the building stock development in Table 2, the total energy use of the observed building area is obtained as in Fig. 5. Please note that when the structure of the area was defined, the national building stock was considered. Therefore, the results in Fig. 5 may be treated to present national trend in building energy demand. As input on the building stock development, an increased building stock with normal development rate was assumed.

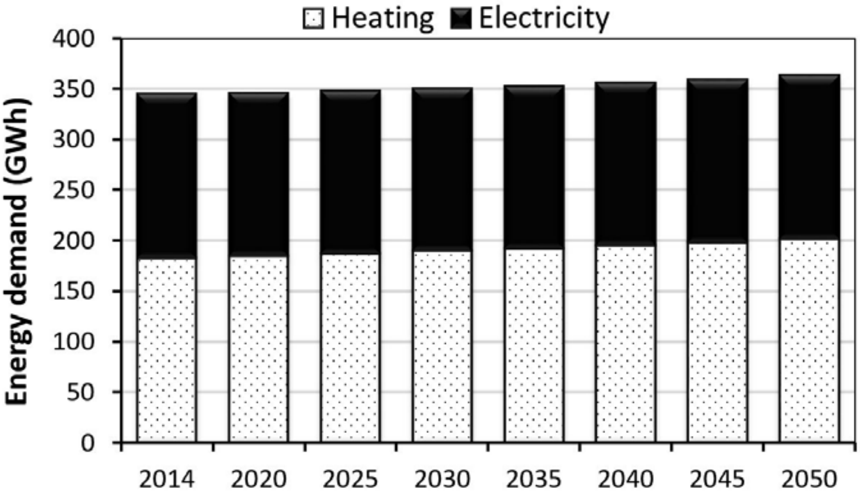

Fig. 5. Total energy demand of the building stock for increased building stock with normal development rate

The results in Fig. 5 show that the total energy demand of the building stock will increase in the future in the case of the increased building stock, regardless of a significant decrease in single building energy demand, see Fig. 4. By performing a sensitivity analysis considering occupant behavior, it was found that the results in Fig. 5 may vary for up to 10 %. In the case that the building stock was kept constant without new development, the total energy demand would decrease.

3.2 CO_2 emission of the building stock

Based on the heat demand and energy supply scenarios defined in Table 3, the CO_2 emission for increased building stock was obtained as in Fig. 6. The shortcuts are used to mark each energy supply scenario. For the reference and easy reading of Fig. 6, please see Table 3. Finally, allocation of the CO_2 emission for the different energy supply scenario is given in Fig. 7.

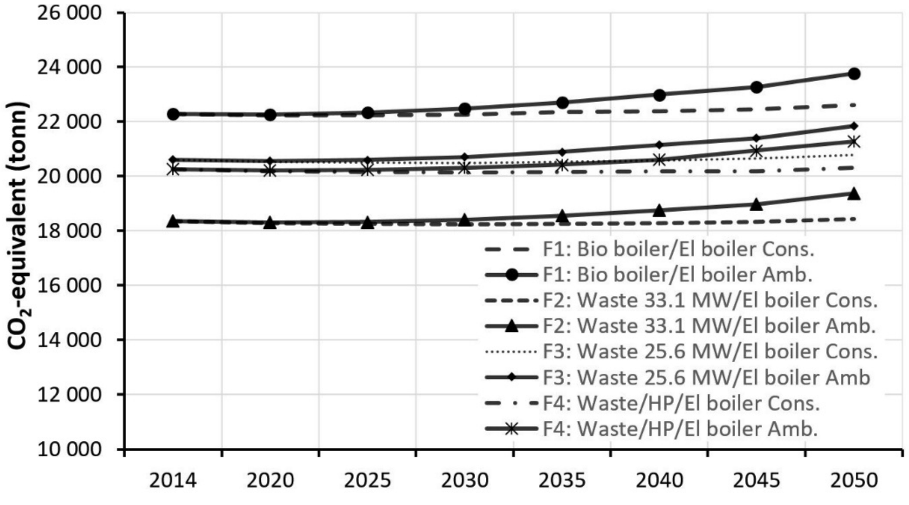

Fig. 6. CO2 emission of the increasing building stock considering different development rates

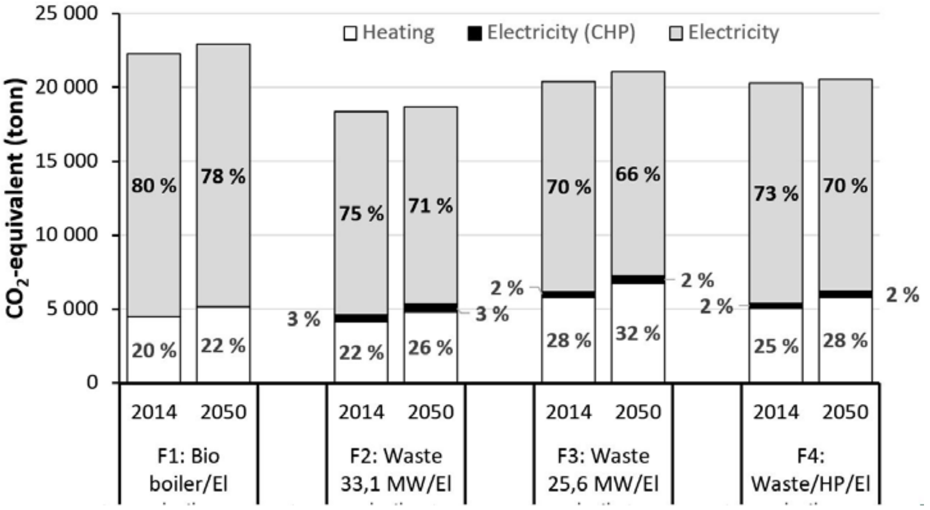

Fig. 7. Allocation of the CO_2 emission for the different energy supply technologies for the increased building stock

In Fig. 7, 2014 was consider as a reference year, since the building stock model was developed based on the building stock structure in 2014. The results in Fig. 6 and Fig. 7 show an increasing trend in the CO_2 emission. However, depending on the technology choice, the CO_2 emission may be decreased. For example, the CO_2 emission is the lowest in the case of the waste based CHP plant in combination with the electric boiler, scenario F2. In general, it might be noted that the scenarios including CHP provided lower CO_2 emission.

Finally, to show what may give the biggest decrease of the CO_2 emission of the residential building stock in Norway, a comparison of the results for the stock without increase in the building number and with the increasing of the buildings is given in Fig. 8. The results show that the constant building stock would show a higher decrease in the CO_2 emission. This means that the implemented energy-efficiency renovation rates and penetration of the new houses would not be enough to give a significant decrease in the CO_2 emission of the building stock.

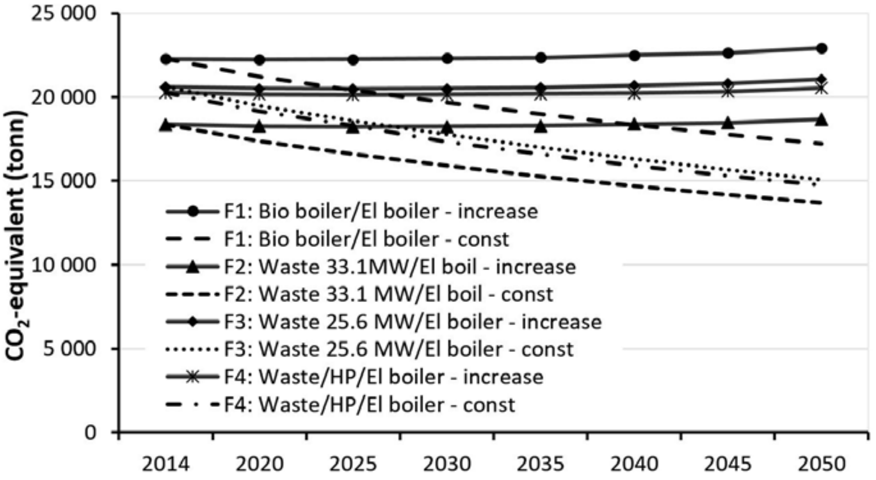

Fig. 8. Comparison of the CO_2 emissions for the increasing and constant building stock

4 Conclusions

The aim of the study was to analyze energy supply systems and technologies for buildings for future building areas. To answer the task, building energy performance models were developed in IDA-ICE with different building standards, which presented different building categories in a housing stock. In addition, four energy supply technologies for the base and peak load solutions were developed in EBSILON Professional, where the goal was to look at which solutions gave the lowest CO_2 emissions by 2050. Using the CO_2 emission factors recommended in [14], the waste based CHP in combination with the electric boiler gave the lowest CO_2 emission with a margin of 10.3% in 2014. Furthermore, the energy supply system with the waste based CHP in combination with the heat pump and the electric boiler gave good results. The poorest results were obtained for the energy supply system with bio boiler and electric boiler that had CO_2 emission 21.3% higher than the best one. When using the CO_2 factors from other sources, the results would change. If other CO_2 emission factors than that in [14], the solution with the waste based CHP in combination with a heat pump and electric boiler that would be the best. This shows that the choice of CO_2 factor is very important for the result, especially the CO_2 factor for electricity. Different companies and organizations often operate with different CO_2 factors to substantiate their own interests, so it can be difficult to assess which CO_2factors are provided on the most objective basis.

In the scenario of increasing housing building stock, it is apparent from the results that CO_2 emissions increase slightly by 2050 for all energy supply systems, despite the fact that the passive houses that were being built use only half the energy of the existing buildings being demolished. This is a good indication that much stronger activities on the building renovation are highly necessary. The renovation rates used in this study seems to be not enough, even though they are higher than in rest of the world. In a scenario with a constant housing stock, CO_2 emissions were estimated to be reduced by between 22-27% depending on which energy supply system were analyzed. This shows that implementation of stricter construction regulations has a positive impact on CO_2 emissions, but that it has less impact on emissions than the choice of energy sources, because the energy sources gave bigger reduction of the CO_2 emissions. The results and conclusions in this study might have some limitations due to all the assumptions made. However, the results might give some recommendations on building energy planning and choosing energy supply sources.

References

1. D. Robinson, Integrated resource flow modelling of the urban built environment, in: Building Performance Simulating for Design and Operation, 2012, pp. 441-468.
2. Y. Chen, T. Hong, M.A. Piette, Automatic generation and simulation of urban building energy models based on city datasets for city-scale building retrofit analysis, Applied Energy, 205 (2017) 323-335. 10.1016/j.apenergy.2017.07.128
3. D.B. Crawley, Building simulation for policy support, in: Building Performance Simulating for Design and Operation, 2012, pp. 469-480.
4. M. Kavgic, A. Summerfield, D. Mumovic, Z. Stevanovic, Application of a Monte Carlo model to predict space heating energy use of Belgrade's housing stock, Journal of Building Performance Simulation, (2014). 10.1080/19401493.2014.961031
5. H. Lund, Renewable energy systems: the choice and modeling of 100% renewable solutions, Academic, London, 2010.
6. T. Tereshchenko, N. Nord, Uncertainty of the allocation factors of heat and electricity production of combined cycle power plant, Applied Thermal Engineering, 76 (2015) 410-422. http://dx.doi.org/10.1016/j.applthermaleng.2014.11.019
7. T. Tereshchenko, N. Nord, Energy planning of district heating for future building stock based on renewable energies and increasing supply flexibility, Energy, 112 (2016) 1227-1244. 10.1016/j.energy.2016.04.114
8. EQUA, IDA-ICE 4.6.2, in, 2015.

9. S. Frederiksen, S. Werner, Fjärrvärme: teori, teknik och funktion, Studentlitteratur, Stockholm, 1993.
10. NS 3031 - Calculation of energy performance of buildings - Method and data in, Standards Norway, 2014.
11. ISO, ISO 13790, Energy performance of buildings, in, 2008.
12. SINTEF, ENØK i bygninger, effektiv energibruk, 3. ed., Gyldendal Undervisning, Oslo, 2007.
13. S. Frederiksen, S. Werner, District heating and cooling, Studentlitteratur, Lund, 2013.
14. E. Otterlei, Climate calculation for district heating - avilable in Norwegian, in, Norsk Energi, Oslo, 2015.
15. Varedeklarasjon 2014, Utslipp av CO2 og radioaktivt avfall, in, Norges vassdrags- og energidirektorat, 2015.
16. Varedeklarasjon. , in, Norges vassdrags- og energidirektorat 2016.