Cost-optimal integration of Zero Energy Buildings in the Scandinavian energy system

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Overview

Zero Energy Buildings (ZEBs) are considered as one of the key elements to meet the Energy Strategy of the European Union. According to the Energy Performance of Buildings Directive (EPBD), all new buildings are to be nearly ZEB from 2020. A ZEB is a building with low energy demand, and which produces on an annual basis, as much renewable energy as its energy consumption. Photovoltaics (PV) power is considered a favourable technology to generate energy in ZEBs, as solar panels are easily integrated into the façade and roof of the building. However for the Scandinavian countries, an implementation of ZEBs with PV causes a temporal mismatch between the electricity demand and PV production, as the demand is highest in winter when the solar radiation is poor. ZEBs can consequently affect the cost-optimal energy investments and operation of the overall energy system.

We analyse the effect of a large-scale implementation of nearly ZEBs, gradually introduced towards 2050, on the Scandinavian energy system with a stochastic TIMES model (The Integrated MARKAL-EFOM System). Here, a nearly ZEB is defined to be a passive building with on-site PV production, and no local energy storage. To satisfy the energy production requirement, the annual PV production is set equal to the annual electric specific demand of the building. The mismatch between electricity supply and demand in a ZEB is handled by trade with the electricity grid. The building can export electricity to the grid in periods with excess production and import in periods with shortage of supply. To take into account the uncertainty of PV production, wind production, hydropower production, heat demand in buildings and the electricity prices outside Scandinavia, they are modelled as stochastic parameters.

Methods

TIMES is a long-term modelling framework that captures the interaction between different energy sectors, including the competition between technologies and energy carriers. The model minimizes the discounted cost of the energy system from 2010 to 2050, to meet the demand for energy services in all the Scandinavian Nord Pool price regions. We apply a two-stage stochastic modelling approach, that is described in detail in (Seljom and Tomasgard, 2015). The stochastic optimisation makes the investment decision dependent on the possible outcomes of the uncertain parameters (Higle, 2005). The uncertain parameters; PV production, wind production, hydropower production, heat demand in buildings and the electricity prices outside Scandinavia are represented by 21 possible realisations with the same probability, called scenarios. The model is constrained such that the investments in new capacity, for all periods, are identical for all scenarios. However, the operational decisions are scenario dependent, including the activity level of each installed capacity type, fuel consumption and electricity trade. The objective function minimises the sum of the investment costs and the expected operational costs. This gives investment decisions that recognize the expected operational cost, and that are feasible for all the model specified realisations of the uncertain parameters.

We use historical information as a basis to generate the stochastic scenarios. As an example, the heat demand scenarios are based on hourly outside temperatures for representative locations in the Nord Pool regions from 2001 – 2014. Based on a methodology described in (Pedersen, 2007) and (Lindberg and Doorman, 2013), the corresponding heat demand is derived by using regression models of the residential and non-residential buildings that detect the temperature dependency of a building's heat demand. The scenarios are created by random sampling from a data set that represents the characteristics of each parameter. The sampling procedure is designed such that each scenario explicitly considers the correlation between the Nord Pool regions and the appropriate correlation in time.

Two model cases are performed. The reference case includes assumptions on future energy demand of a 'normal' development of the building stock. In the ZEB case, all new buildings and part of rehabilitated buildings are assumed to become ZEBs, which reduces the total heat demand of buildings in Scandinavia with 20 % compared to the reference case. Further, the assumption that PV is the only way the ZEB buildings can generate on-site energy, results in 62 GW of PV installed in 2050, if oriented and inclined optimally. In the ZEB case, we also assume that ZEBs are implemented in the surrounding countries (in e.g. UK and Germany), which is assumed to make the exogenous price profiles towards these countries more volatile (lower at daytime and higher at night, but the average is kept constant).

Results

The ZEBs influence the optimal energy investments strategy in Scandinavia in two main ways, 1) through their lower heat demand due to the higher building standard, and 2) through their on-site PV production.

The results show that with a large implementation of ZEBs, the total electricity production in the Scandinavian countries increases, which again reduces the power prices. Consequently, the profitability of investments in both non-flexible hydro, CHP and wind capacity are reduced. With a large implementation of ZEBs, the wind capacity in 2050 is 9 GW, which is about 50 % of the capacity in the reference case, and the capacity is considerably larger in Denmark at 6 GW than compared to Norway and Sweden. This can be explained by the available hydro reservoirs in Norway and Sweden which provide electricity in absence of solar radiation, while Denmark, who has no flexible hydropower, mainly uses wind power to meet the electricity demand in periods with poor solar conditions.

Because of the lower heat demand of ZEBs, the installed capacity of all heat technologies in the building stock are reduced, especially heat pumps, gas and biomass technologies. However, due to the lower electricity prices, the capacity of electric boilers and direct electric heating with poor efficiency, is slightly increased. Hence, despite the lower heat demand, the total electricity consumption in Scandinavia is only slightly reduced.

Due to constraints in the electricity grid, there are periods when it is not feasible to utilise all the PV production from ZEBs. In 2050 the expected curtailed PV production corresponds to 0,4 % of the Scandinavian electricity consumption, which corresponds to 2,4 % of the PV production. This indicates that the Scandinavian energy system is highly flexible and capable of integrating a large share of intermittent electricity production.

Further, the results demonstrate that the electricity trade pattern with Europe is changed with ZEBs. For example in spring at day-time, Scandinavia is normally a net exporter, however in the ZEB case, Scandinaiva is net importing, due to the lower electricity prices of the surrounding European countries in these hours. Finally, the results asserts that increased electricity price variability in Europe, caused by more PV, is beneficial for Scandinavia. Because of the flexibility that the hydro reservoirs offers, which enbles export of electricity when the prices are high, and import of electricity when the prices are low.

Conclusions

A large introduction of ZEBs results in lower heat demand and increased electricity generation, which leads to lower electricity prices. The lower electricity prices increases the use of direct electric heating, and hence there is little effect on the total electricity consumption. Consequently, when production increases and consumption is almost unaffected, the export to the surrounding countries outside of Scandinavia is increased.

This study shows that when deploying a considerable share of ZEBs, it is important to understand the impact on the surrounding energy system. Consequently, a holistic evaluation of the entire energy system is required for a for a cost-optimal implementation of ZEBs.

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