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Using a dynamic segmented model to examine future renovation activities in the Norwegian dwelling stock

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ABSTRACT

Roadmaps and action plans for energy savings in building stocks commonly assume strong increases in the renovation rates to obtain future energy savings. This study presents a segmented dynamic dwelling stock model for understanding the nature of the long-term development in stocks, their turn-over and need for maintenance, including a case study for Norway. Segments are defined by dwelling type and construction period. Based on the underlying drivers in the system, population size and number of persons per dwelling, the dwelling stock demand and construction, demolition and renovation activity are estimated for each year towards 2050. Demolition and renovation activity is modeled using probability functions of different characteristics.

The dynamic and segmented model gives useful insight to what segments of the dwelling stock that are expected to be exposed to renovation in the future. This is important for proper tailoring of building renovation and energy policies today and in future. In Norway, detached houses constructed between 1945 and 2011 will dominate the renovation activity in the coming decades. Although the renovation rate is expected to increase in the future, we have found that the rates commonly assumed in roadmaps and action plans in Europe do not seem to be realistic.

1. Introduction

Buildings account for 40% of the energy consumption in the European Union [1], and the building sector is important for future mitigations of greenhouse gases (GHG) as reductions in energy demand and changes to renewable energy sources can be done more easily than in many other sectors. The total energy demand of the dwelling stock is equal to the total stock size multiplied with the average energy intensity per dwelling or per square meter floor area. This multiplied with the average GHG emission intensity gives the total GHG emissions from the stock. The energy demand and GHG emissions change over time due to changes in stock size, energy intensity or GHG emission intensity.

Roadmaps and other analyses of future development in energy demand or GHG emissions commonly use very detailed analyses of energy and emission intensities, whereas the development in the dwelling stock itself is modeled using simple linear models with fixed rates for construction, demolition and renovation. Construction and demolition rates are commonly based on recent trends, whereas renovation rates are often assumed to be increased to reach levels needed to reach the energy efficiency goals for the stock. When forecasting future development in energy demand or GHG emissions from the dwelling stock, it is important to use a good model for the development of the dwelling stock itself, in addition to the analyses of future development in energy and GHG emission intensities.

The present model is a dynamic model for the long-term development in a dwelling stock using the development in the input parameters population and number of persons per dwelling, as well as lifetime and renovation probability functions. Further, the dwelling stock is segmented in dwelling types and construction periods. The model output is the long-term development in demand for dwellings as well as construction, renovation and demolition activity for the total dwelling stock and for each of the segments. Results from a detailed dynamic model like this can be used to indicate the natural turn-over and renovation cycles in the dwelling stock.

Many energy-efficiency measures are only cost efficient to introduce when a building is going through a deep renovation in any case. The present model aims at describing what renovation rates

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can be expected based on the characteristics of the dwelling stock and the dwellings' need for maintenance. The model results can be used for proper tailoring of policies to make sure that renovations that are already taking place are as energy efficient as possible. The model is general and could be used for any dwelling stock. The present paper includes a case study for the Norwegian dwelling stock segmented in two dwelling types and five construction periods. The present paper does not include an energy analysis per se, as this would require the inclusion of a large amount of additional data, technical descriptions and calculated results, beyond what is possible to cover in one well-focused journal article of acceptable size. This is left for later publications, but the opportunities for such a use of the model are indicated by including renovation cycles of 20, 30 and 40 years. The 20-year cycle is exemplified by replacement of appliances (e.g. boilers), the 30-year cycle by replacement of building components (e.g. windows, roof) and the 40-year cycle represents deep renovation of facades. The full energy analysis would include estimations of energy savings in different types of renovations and hence the total expected or possible energy savings in the dwelling stock.

2. Context and literature review

2.1. Political context

The Energy Performance of Buildings Directive (EPBD) [1] provides detailed regulation of the requirement for energy performance of new and renovated buildings in Europe. The directive applies for all new construction and for existing buildings that are already subject to major renovations, as far as it is technically, functionally and economically feasible. In Norway, the energy requirements in the EPBD are implemented in the Regulation of Technical Requirements of Buildings (TEK) [2] for new buildings, but there is no specific energy-related regulation for renovated buildings.

As the EU was not on track to reach its target of 20% energy efficiency by 2020, the Energy Efficiency Directive (EED) [3] was introduced in 2012 to increase energy efficiency measures in the Member States. According to the EED, the renovation rate for public buildings occupied by central government should be 3%. By April 2014, Member States will have to deliver a strategy for cost-effective deep renovations of buildings. Further, according to the EU Energy-Efficiency Plan [4] binding targets for renovation rates will be set in 2013.

2.2. Standard building stock models

There is a wide range of literature on building stocks and energy use, and a complete literature review is beyond the scope of this study. The following references serves as examples of studies using standard methodology. Most standard dwelling stock models assume future construction and demolition rates to follow recent trends, with no regard to changes in underlying driving forces in the system [5–8]. For instance, the evaluation report of the Norwegian political instruments and action to reach the GHG emission reduction goals by 2020, Klimakur 2020 [6], predicted a minor increase in energy consumption in the Norwegian dwelling stock from 2007 to 2020, based on a building stock model assuming a fixed number of square meters of new construction each year.

Some studies seem not to consider changes in the stock composition at all, e.g. the report on energy demand in Danish buildings in 2050 [9]. This study does not include any considerations regarding changing demand for dwellings, construction or demolition activity. Hence, this is a study showing the potential for energy reductions in the existing building stock rather than an estimation of the total energy demand in the dwelling stock in 2050.

Other studies make use of population forecasts to estimate the future need for dwellings, but make use recent trends for estimating demolition and renovation activity [10–12]. In the Global Buildings Performance Network study on global building energy-related GHG emission mitigation delivered by best-practice policies [10] the mitigation potential by 2020, 2030 and 2050 was estimated concluding that global building final energy use can be reduced by about one-third by 2050, as compared to the 2005 values.

Some models are bottom-up models with high number of dwelling types [13], whereas other models are top-down model analyzing the aggregated building stock as a total or divided into few construction periods [10].

The study *Europe's buildings under the microscope* [14] is a country-by-country review of the energy performance of European buildings, including a roadmap for future development towards 2050. The renovation model assumes fixed rates for construction and demolition, 0.5% and 0.2% of the building stock, respectively. Further, there are scenarios for the future development in renovation rates. The baseline scenario assumes a fixed renovation rate of 1%, and the other scenarios assume different patterns of increase, all with the ambition of all EU buildings to be renovated before 2050. The conclusion is that the level of renovation activity needs to more than double. In the most ambitious scenario the energy saving in 2050 is 71%, and the CO_2 emissions are reduced by 91%.

2.3. Dynamic building stock models

A dynamic stock model for the Dutch dwelling stock was developed by Müller [15]. Based on dynamic material flow analysis principles and the underlying drivers in the dwelling stock system (population, service stock per capita, lifetime distribution and material intensity per service unit), the floor area demand was estimated for each year. The demolition activity was estimated based on historical construction activity and a lifetime probability function, and the construction activity needed was calculated using mass balancing principles. Material flows were estimated using material intensities. The model was modified and applied to the Norwegian case by Bergsdal et al. [16] and further developed for the renovation activity by Sartori et al. [17]. Similar dynamic dwelling stock models have also been used for studies of the Chinese dwelling stock [18–20].

Energy and carbon intensities were introduced to analyze the long-term development in energy demand and GHG emissions in the Norwegian dwelling stock [21,22]. Although these studies clearly showed the need for good dwelling stock models when trying to understand long-term development in energy demand from the dwelling stock, they also revealed the need for disaggregation of the stock in the dynamic model to better understand the role of different dwellings types and to explore the potential for future energy savings in the dwelling stock. To the knowledge of the authors, no such segmented dynamic dwelling stock models exist.

The present study is based on the work previously done in the field [15–17]. In contrast to the previous studies, the present one models the dynamics of the dwelling stock measured in number of dwellings rather than in floor area. This way, one of the most uncertain input parameters, the average floor area per dwelling [16], is removed from the core of the model. At later stages, the stock and flows of floor area can easily be included in an additional layer of the model.

Further, there has been a thorough revision of the input data, and a more appropriate probability function is used for the demolition activity. Finally, the present model describes the dwelling stock demand and activities for the dwelling stock segmented in types and construction periods. This allows for a wide range of