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Future scenarios for climate mitigation of new construction in Sweden: Effects of different technological pathways

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ABSTRACT

A variety of climate mitigation strategies is available to mitigate climate impacts of buildings. Several studies evaluating the effectiveness of these strategies have been performed at the building stock level, but do not consider the technological change in building material manufacturing. The objective of this study is to evaluate the climate mitigation effects of increasing the use of biobased materials in the construction of new residential dwellings in Sweden under future scenarios related to technological change. A model to estimate the climate impact from Swedish new dwellings has been proposed combining official statistics and life cycle assessment data of seven different dwelling typologies. Eight future scenarios for increased use of harvested wood products are explored under different pathways for changes in the market share of typologies and in energy generation. The results show that an increased use of harvested wood products results in lower climate impacts in all scenarios evaluated, but reductions decrease if the use of low-impact concrete expands more rapidly or under optimistic energy scenarios. Results are highly sensitive to the choice of climate impact metric. The Swedish construction sector can only reach maximum climate change mitigation scenarios if the low-impact building typologies are implemented together and rapidly.

1. Introduction

Further increases in the global anthropogenic greenhouse gas (GHG) emissions as in current patterns will most likely cause irreversible environmental impacts (Field et al., 2014). The construction sector is responsible for nearly 19% of the global GHG emissions, making it a climate hot-spot that requires urgent mitigation measures (Edenhofer et al., 2014). It is estimated that about 8% of the global GHG are caused solely by the production of cement, the main component of concrete (Olivier et al., 2016). The concrete and cement industry contribute to a significant share of the global greenhouse gas emissions, but still are not expected to reduce significantly their climate impact intensity (Science Based Targets Initiative [SBT], 2015). The substitution of concrete with wood and harvested wood products (HWP) has been considered as a strategy to reduce the climate impacts of buildings, showing significant potential for mitigation (Weiss et al., 2012). This is specially the case for Sweden, where in contrast to most other countries there is an extensive amount of forest area with steady growth, available for harvesting. Life cycle assessment (LCA) has been extensively used for the evaluation of the climate mitigation potential from this and other strategies at the material and building level (Buyle et al., 2013). However, the inconsistency of LCA practice in the building sector suggests that additional approaches are needed to support decision-making (Säynäjoki et al., 2017). What is more, few studies have investigated the effects of mitigation alternatives at a broader level, or taken into account future variations in the climate impact of processes.

The environmental performance of building stocks has been increasingly studied in several publications, but mostly with a focus on energy aspects and lacking a life cycle perspective (Mastrucci et al., 2017). Still, some interesting efforts exist, such as the

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Abbreviations

GHG	Greenhouse gas
LCA	Life cycle assessment
HWP	Harvested wood product
MFA	Material flow analysis
HFA	Heated floor area
IPCC	Intergovernmental panel for climate change
GWP	Global warming potential
GTP	Global temperature potential

review carried out by Condeixa et al. (2017) illustrates. The present and future material flows in the Norwegian building stock have been estimated to identify future developments and challenges concerning the fate of PCBs in building materials (Bergsdal et al., 2014). Using dynamic material flow analysis, Holck-Sandberg and Brattebø (2012) calculated the energy intensity and carbon emissions of the Norwegian dwelling stock for the coming 50 years. Pauliuk, Sjöstrand & Müller (2013) combined Material Flow Analysis (MFA) and LCA to assess potential pathways for reaching 50-year climate targets in the residential dwelling stock in Norway. A more recent study combined bottom-up and top-down approaches to model the embodied energy and GHG implications of different retrofitting pathways, and suggest that material manufacturing will become more relevant with the surge of energy efficient dwellings (Seo et al., 2018). Condeixa et al. (2017) proposed a static framework to estimate future waste flows from the building stock of Rio de Janeiro, aiming to support decision-makers. Finally, Reyna and Chester (2014) have proposed a framework to model the current building stock of Los Angeles based on past trends, and warn on path dependency and risk of lock-ins with long-lasting building types. No study to date focused on the Swedish dwelling stock has estimated the long-term climate impacts using similar approaches.

The climate long-term effects of increased use of HWPs in construction and other sectors have been somewhat studied. For example, Lundmark et al. (2014) assessed the net carbon emissions of biomass harvesting for forest products in Sweden under different forest management scenarios, concluding that increasing the intensity of harvesting practices to substitute non-biobased products would result in net climate benefits. Cintas et al. (2015) explored the long-term effects of increasing the harvest of forest biomass in Sweden to obtain higher output of products, and concluded that methodological choices such as spatial perspective, reference situation, location, harvesting practices and displaced technology have significant influence in this type of analysis. Suter et al. (2016) assessed the environmental benefits of wood product use in Switzerland through a model that also combines MFA and LCA. Nepal et al. (2016) estimated the carbon savings in the coming 50 years from increased use of wood products in the United States and found out that increasing the use of wood would lead to net long-term carbon savings. Among all similar studies concerning the effects of increased use of HWPs, none has accounted for the effects of technological change in GHG emissions from manufacturing processes in the long-term. These effects should not be underestimated, since the GHG emissions from energy generation and material manufacturing are expected to decrease in Sweden in the coming twenty years (Swedish Environmental Protection Agency [EPA], 2017).

The objective of this study is to evaluate the climate change mitigation effects of an increased use of HWPs in the Swedish dwelling stock under different future scenarios analysing the material consumption. A scenario-based model is used to estimate the amount of building materials for construction of new residential dwellings. The operational energy use is not accounted for, but the energy use for material manufacturing is widely studied in the study. Using these amounts and dynamic factors for GHG emissions from LCA studies, the climate impact of material production for the Swedish dwelling stock is estimated for the coming 100 years. The scenarios investigated explore how different pathways for technological change in material manufacturing and energy production affect the climate impact of new residential construction in Sweden.

2. Methods

A combination of scenario-based modelling and LCA was used to forecast the climate impact from the construction of new residential dwellings in Sweden for the coming one hundred years (2017–2117). This time period was selected in order to capture long-term impacts of sustained changes in the building stock. To handle the different plausible directions of societal and market development, a number of scenarios were constructed following different levels of increase in the use of biobased materials in new dwellings and different development pathways for energy and material manufacturing. The impacts from the operational energy use of the buildings have been excluded from this study in order to focus on aspects that are related to the material choice in buildings.

2.1. Estimating the material flows for new dwellings

A scenario-based stock model of the heated floor area (HFA) of new residential dwellings per year is suggested (Fig. 1). The starting point of the model is to forecast the yearly amount of new heated floor area that will be required in Sweden (in m^2/cap.yr), based on historical trends for the last 20 years. These trends were obtained using values for population growth (Statistics Sweden [SCB], 2016a) and new built heated floor area (SCB, 2013) from official Swedish statistics. Based on this data, an average yearly decline rate for HFA per capita of 0.22% was estimated, which was then used to estimate a yearly HFA per capita factor for the studied period. Based on this factor and the population size projections from the official Swedish statistics (SCB, 2016b), a projection was made for the annual growth of HFA in Sweden. The historical data from statistics used is illustrated in Fig. 2; with Fig. 2a showing population growth and Fig. 2b displaying the growth of HFA in Sweden.

The next step was to estimate the amount of new dwellings that would be required to provide this additional yearly HFA and the flows of materials for this. The HFA output and material input per dwelling depends greatly on the construction system used, so it was necessary to establish dwelling typologies. These typologies were selected using two criteria; the typologies in available statistical data for new construction of dwellings in Sweden and the availability of LCA data for each typology. The parameters that differ between typologies are the dwelling size, the building materials and the building concept. The dwelling typologies used in this study are 1–2 family house, three types of timber-based multi-family dwellings (prefabricated volume elements, massive elements and column-beam), three types of multi-family dwellings with concrete structure (on-site casted, VST and low-impact) and one type of steel structure. More detailed descriptions can be found in Table 1, including the literature reference used to estimate the material amounts. Each of these references used different system boundaries, thus different exclusions that affect the comparability of their LCI data. Therefore, adjustments to the data were necessary so the same exclusions are applied to each typology in the present article. As a result, the only building components included here are the foundations, building structure, internal walls and floor