Sheltering 10 billion people in a warming and resource-scarce world: challenges and opportunities
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Summary

Sheltering is an immediate human need and determines well-being and health. However, we face many challenges in providing homes and offices for all on this rapidly changing planet. In the 21st century, climate change, resource crises, and population expansion will combine to exacerbate existing challenges. We need to better understand and tackle these issues. Therefore, the overarching research question of this thesis is:

What are the main challenges and opportunities in delivering decent shelters for nearly 10 billion people in a warming and resource-scarce world?

To this end, this thesis makes the first steps in exploring several key intersecting challenges related to resources scarcity, global warming, and natural hazards. Specifically, four sub-questions are investigated in Chapter 2 to 5, respectively.

SQ1. In the face of an unfolding sand crisis, how might demand for building sand develop in the future and how can we reduce this demand to secure the shelter needed and limit sand-related environmental impacts?

Chapter 2 explores future trends of building sand use in the face of the unfolding global sand crisis. A dynamic building sand model is developed and a set of different scenarios are discussed. Results show that under a middle-of-the-road baseline scenario, global building sand use (for making concrete and glass) sees a 45% increase from 2020 to 2060. Regional trends vary significantly with a nearly 300% increase in low-and-lower-middle-income regions and a slight decrease across higher-income regions. Increasing efficiencies of building and material use could nearly halve the cumulative building sand requirements globally. However, even under high efficiencies, the lowest-income African regions will still need to double their demand for building sand in 2060 compared to 2020. International cooperation on investment, technology, and resources are of great importance to address vulnerabilities and inequalities.

SQ2. How might greenhouse gas emissions related to building materials develop in the future with socioeconomic developments, how can we reduce these emissions by material efficiency strategies, and what does this mean for global climate targets?

Chapter 3 investigates the hard-to-decarbonize emissions from building material production. It assesses the changes in greenhouse gas (GHG) emissions from the production of several building materials (steel, concrete, brick, aluminum, copper, glass, and wood) in residential and commercial buildings in 26 global regions. Results shows a continuous emission increase from 3.5 to 4.6 Gt CO_2eq yr^{-1} between 2020–2060 under a baseline scenario, with a shift from high-and upper-middle-income to low- and lower-middle-income regions driven by economic, population, and urbanization trends. Nearly half these emissions may be avoided through scaling up material efficiency strategies on a global level in a high efficiency scenario. However, even under this scenario, the expected emissions from building materials are still higher than what would be compatible with the 1.5 °C climate target (if the remaining global carbon budget is allocated proportionally across sectors). In the absence of fundamental changes in manufacturing processes, negative emissions technologies are likely necessary in the second half of the century to offset process-related emissions that are challenging to avoid.

SQ3. What are the trends in the energy intensity of residential and commercial buildings, their relationship with economic development, and their future role in energy savings around the world?

Chapter 4 examines the trends of energy intensity (energy use per floor area) in global building stocks. Results show that residential energy intensity has significantly reduced on a global level (from 897 to 476 MJ/m^2 between 1971 and 2014) with clear difference across regions and income groups. While most high-income and upper-middle-income regions see decreasing energy intensities and strong decoupling from economic development, the potential for further efficiency improvement is limited in the absence of significant socioeconomic and technological shifts. Lower-middle-income regions, often overlooked in analyses, will see large potential future residential energy savings from energy intensity reductions. Commercial building energy intensity, while much higher than residential buildings, also demonstrated dramatic declines globally, with larger differences observed across regions with different income levels than those in the residential sector. Given the large energy intensity reduction potential and rapid floor area growth, commercial buildings are increasingly important for energy saving in the future.

SQ4. Under current and future climatic conditions, what are the building stocks and materials at risk of riverine and coastal flooding hazards and embodied emissions of material losses?

Chapter 5 maps how several types of building materials (concrete, steel, copper, aluminium, wood, and glass) are at risk of riverine and coastal flooding hazards in 49 European countries / regions. Results show that currently nearly 11.7 Gt building materials (~11.6% of total building material stocks) are at risk from a 1-in-100-year riverine or coastal flooding events. Countries facing the highest risk are Italy, France, and the Netherlands, generally having accumulated large building stocks along long coastal lines and river banks or in low-lying areas. Climate and land-use changes may have significant impacts on the flooding risks. Expected annual damage (EAD) is ~329 Mt in the absence of flood protection. The replacement of these materials would be ~106 Mt CO_2eq of GHG emissions. Introducing potential flood protection standards could reduce these embodied emissions by ~92% or ~100 MtCO_2eq, nearly 20% of the current annual building-material-related emissions in Europe. The EAD-related embodied emissions, not considering any flood protection, see an increase of 71% to 180 Mt CO_2eq per year in 2080 under a high-emission climate scenario (RCP 8.5, including land subsidence). Climate mitigation from RCP 8.5 to RCP 4.5 reduces these embodied emissions by 25 Mt CO2eq (14%) to 147 MtCO_2eq per year. Overall, climate mitigation and flood protection are critical to reducing building material losses and embodied emissions.

We can now reflect on the above overall research question on the basis of the exploration of the sub-questions. Continued growth in population and wealth means we will need more homes and offices. The overexploitation of natural resources, reduction of emission allowance and exacerbation of natural disasters, among others, may increasingly reduce the operating space in which we provide and maintain buildings. We need to produce materials, build and maintain buildings more efficiently and wisely. We need to do this urgently. To this end, we first need to map the key challenges that may impact our future shelter security on global and regional scales. We should then explore the available and emerging solutions to each of these challenges, the cost and barriers of implementing these solutions, the trade-offs across solutions, as well as the priority areas needing urgent investment.

This thesis makes a step in understanding a few key global challenges and promising solutions. In general, global housing presents a significant challenge in a warming and resource-scarce world. Lower-income regions face larger problems, from today's housing shortages to mounting pressures from a stock expansion driven by economic and population growth including resource and investment issues combined with increasing climate damages. Higher-income countries will experience some of these pressures but probably to a lesser extent. Improving the efficiencies of material supply and use in building construction and operation has a substantial potential in both resource conservation and emission mitigation across the globe. Negative emission technologies (NETs) may be necessary in the longer term to achieve a global net-emission building construction industry. Buildings should be designed and constructed in a more resilient manner for longer longevity against the extreme weather and natural disasters that increase with climate change. Flood protection standards are critical to ensuring the safety of buildings against flooding events and need to be broadly strengthened. A multifaceted global strategy integrating environmental, economic and social dimensions is needed to ensure sustainable and equitable shelter security around the world.

This thesis provides several scientific and policy implications. Scientifically, we first showcase an integrated framework to systematically model global shelter security and connect it to environmental challenges. Second, we make multiple modelling advances. The models we present can be easily applied for a broad range of research purposes. As an example, the dynamic building sand model (Chapter 2), as the first of its kind, can be used to understand the development of sand crisis and other resource scarcity issues across different global regions and sectors. This thesis also provides important policy messages from regional and global perspectives. Starting with regional policy, policy makers need to incorporate sustainability holistically into the overall process of building stock development, from investment decisions in urban development to building design and construction, from maintenance and renovation to end-of-life management of buildings and components. From a global perspective, we first show that deploying negative emission technologies are likely needed to compensate emission reductions in the hard-to-decarbonize material sector to achieve the 1.5 °C-compatible climate target. We then show the need for a rise in international cooperation in technology, investment, and resources. in addressing regional inequalities, where trade agreements may play an important role in lowering barriers and increasing efficiency.

Extensions of this research could integrate more resources (such as land use and labor forces) and challenges (such as climate migrations and biodiversity issues). Other improvements may be related to modelling and data. For example, future models could integrate renovation into dynamic building models against the renovation wave of existing buildings that can be expected in the next decades and include a larger number of scenarios to explore a broader spectrum of potential futures. Dedicated efforts are needed to improve data availability and robustness for global and regional analysis.