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Equation for zero emissions -achieving carbon-neutrality in building sector

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Abstract. Energy has a central role in people's lives. However, access to affordable, clean and reliable energy is not the case yet for all. As more people have access to energy, the global energy consumption is set to rise, along with the global greenhouse gas emissions.

The building sector is one of the most significant ones in terms of energy consumption and GHG emissions (Ruuska, 2018). Buildings consume vast share of global energy and produce significant share of greenhouse gas emissions. Thus far the improvements in energy efficiency have not been able to offset the increase in energy use due to increased amount of buildings. In order to cap the global warming to 1.5 °C (IPCC), thorough changes are needed in the way we consume and produce energy. For the building sector, it is suggested that the whole of the building sector should decarbonize by 2050 (WGBC, 2018). This paper assumes that the building sector can decarbonize by 2050 and looks for ways to make it happen.

Technological means to move towards clean, low-carbon energy in buildings are many. On the supply side, moving away from fossil fuels and increasing the share of renewable energy are the big goals. On the demand side, energy use can be reduced through better energy efficiency in buildings. Furthermore, smart energy management can help to operate buildings optimally, and to shift and reduce peak loads. There are also opportunities related to, for example, energy storages. However, this paper assumes that the key towards broader implementation of the technological means may lie in user-friendly services and business models.

This paper further assumes that decarbonizing construction industry is not a technological problem as such, but more of a systemic problem. Therefore, this paper seeks to understand the interactions and feedback loops in the sector, by focusing on the level of a single building and its owner/user. This paper shows the general dynamics of the energy systems around a single building, and the connections they have to the broader energy system. Furthermore, this paper presents a simple equation for zero emission building stock and links this equation to system dynamics around single building's energy systems.

All of this is done from the viewpoint of a single building and its owner/user to illustrate how the situation looks from the user/owner perspective and to see if some factors arise that could speed up the transformation towards decarbonized building sector.

1. Background and problem formulation

The equation for zero emissions from building sector is mathematically very simple. We can either zero the operational energy consumption from the sector, or we make the consumed energy emission-free. At the same time, we need to look at the building life-cycle to make sure that the embodied carbon

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from material production, construction, renovations and other life-cycle activities are zero. You can write the equation in the form:

$$GHG = E_E * E_A + GHG_M = 0 \qquad \text{(Equation 1)}$$

GHG = Greenhouse gas emissions
E_E = Emissions from energy production
E_A = Amount of energy use
GHG_M = GHGs from material-related sources, or embodied carbon.

Equation 1 is very simplified version of the work by Ruuska (2018) [1], but serves the purpose of this paper. In principle, almost any building owner could zero their emissions already today. Theoretically, moving to use clean and green energy is a choice that a building owner/user could make any given day. Likewise, energy efficiency improvements are available at the markets and the owners can choose to select low-carbon materials in their new construction and renovations. The building owners and users can also compensate any occurring emissions with different means, for example by purchasing emission allowances through the EU ETS and keeping them off the market [2]. This paper understands that in practice, the options for building owners and users may be only limited and those available may not be cost-efficient.

At the same time, this paper understands that on global and societal levels the building sector is one of the most significant GHG emission producers and global energy consumers [1]. Thus far, sector's energy efficiency improvements have not been able to offset the increase of energy use due to increased amount of buildings. In order to cap the global warming to 1.5 °C [3], thorough changes are needed in the way we consume and produce energy. There's also viewpoints that the whole building sector should decarbonize by 2050 [4] to keep us on track towards 1.5 °C. At the moment, the progress on sectoral level is not fast enough as we are falling behind even from the 2.0 °C goals in this sector [5, 6].

In order to catch up and reach the challenges of 1.5 °C, we need to find new ways to rapidly take action in the built environment. Furthermore, massive investments on global scale will be needed to boost these actions. This paper assumes that the building sector can decarbonize by 2050 and looks for ways to make it happen. It hypothesizes that system-level impacts and their value could offer a way to speed up the progress in the sector and actions at the level of single buildings.

2. Research methods

2.1. System dynamics of building energy ecosystems

This paper builds on earlier research by Nieminen, Åkerman and Mäkinen, 2018 [7] and focuses on the viewpoint of a single building owner as part of the energy system. In their work, the authors developed system dynamics for 'evolving building energy ecosystems' and studied the prerequisites and dynamics of such as system in Finland. The authors' model was based on expert review of different stakeholder's strategies in the sector. The authors also conducted a total of 36 interviews of various actors in the field of energy and construction (public authorities, big and small energy companies, construction companies, solution providers and users/dwellers). The interpretations and the system dynamics were validated in two separate expert workshops, held with relevant stakeholders (Nieminen, Åkerman and Mäkinen, 2018).

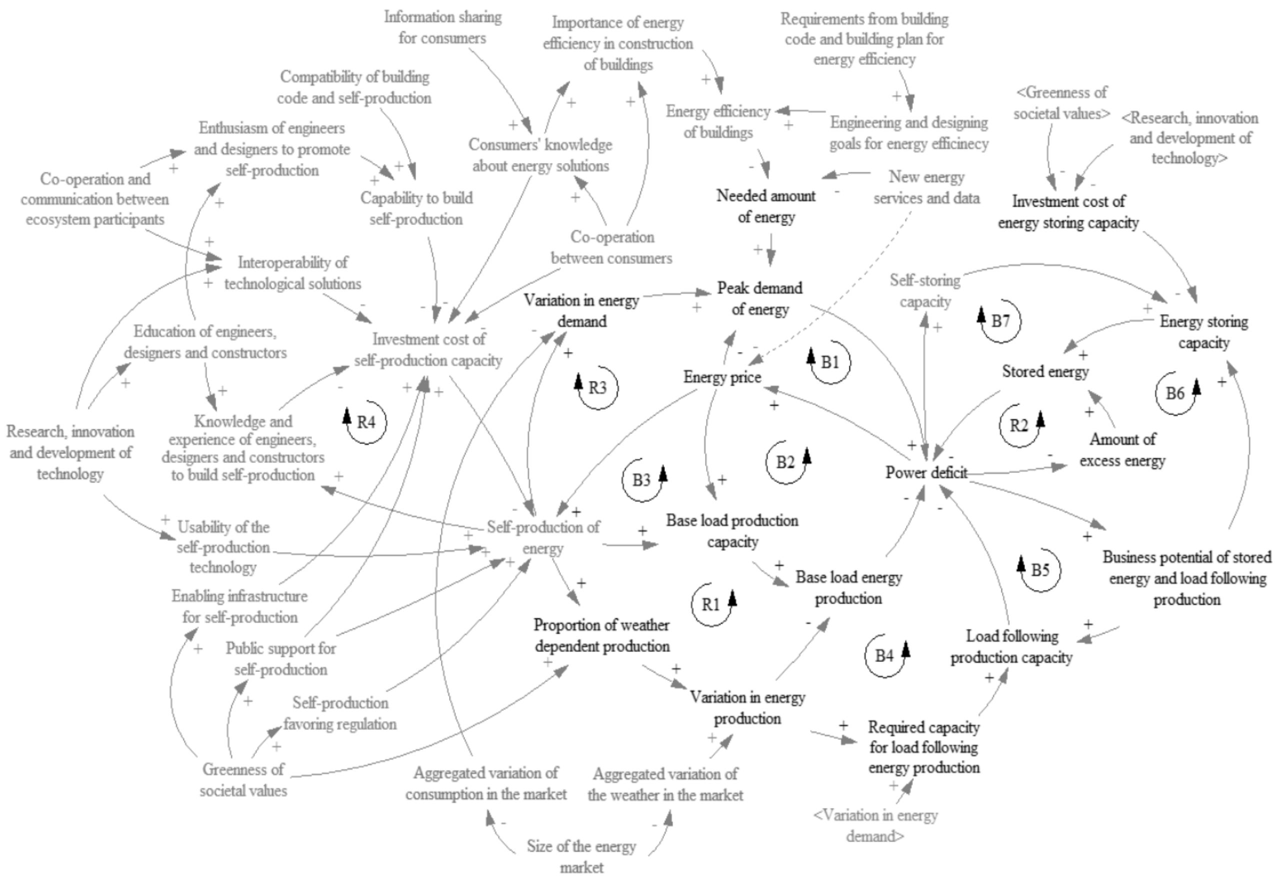
In their work the authors:

- showed various interactions and feedback loops in the system
- defined the general dynamics which makes possible the emergence of new energy regime and ecosystems

- indicated how number of actions & actors affect the transition.

Figure 1 illustrates the system dynamics of the evolving building energy ecosystems (Nieminen, Åkerman and Mäkinen, 2018)

Figure 1. System dynamics of the evolving building energy ecosystems (Nieminen, Åkerman and Mäkinen, 2018).



2.2. System dynamics of the energy systems of a building

This paper utilizes a system dynamic model from past research [8] and develops it to focus around the owner/user of a single building. This paper looks to:

- show interactions and feedback loops of an energy system that is centered around a single building and its owner/user
- define general dynamics that could make it possible to move towards carbon-neutral building sector by connecting the system dynamics to the different factors in *Equation for zero emissions*, shown in Equation 1
- draw conclusions about what could speed up the transition towards carbon-neutral building sector, focusing on the owner/user perspective

The modelling work in this paper was done as expert work and its interpretations have been validated through expert discussions. The model does not aim to be a complete presentation of the system dynamics in this field, but it aims to serve in focusing future efforts in the field. The model, along with

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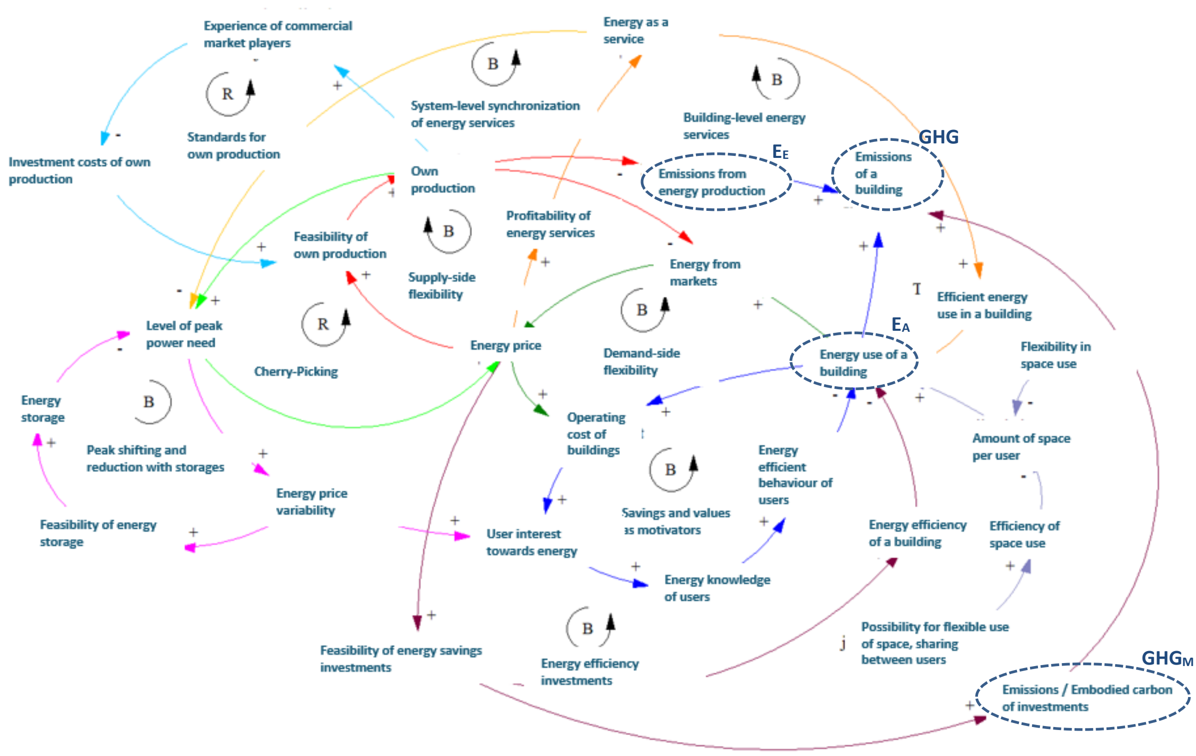
most relevant interactions and the feedback loops in the system are described in more detail under the 'Results' section.

3. Results

3.1. System dynamics around the energy system of a single building

The work of this paper is largely based around the system dynamics of energy systems of a single building that is presented in Figure 2. The model also shows how different factors of Equation 1 are linked to model. The figure gives a visualization of how different feedback loops impact the emissions of a single building.

Figure 2. System dynamics of energy systems of a single building, along with linkages to Equation 1. *GHG= Greenhouse gas emissions of a building,* E_E *= Emissions from energy production,* E_A *= Amount of energy use and* GHG_M *= GHGs from material-related sources, or embodied carbon*



As Figure 2 illustrates, system dynamics around the energy system of a single building form a complex model with multiple interlinked feedback loops. Based on the modelling results and expert assessment, a total of nine feedback loops were identified. The following goes through the key loops, while the remainder are discussed in the *discussion*-section.

The key loop for making things happen on building level is the one centred on the owner/user of a building. This is called *Savings and values as motivators.* In short, values and savings are strong drivers for this loop, as every action on building level requires motivated actions from the owner/user. This loop can activate or deactivate any of the other loops that impact the emissions of a building (here, we mean loops impacting Equation 1 factors E_E, E_A and GHG_M).

The other two key loops in the system are: *demand side flexibility* and *energy efficiency investments.* First of these loops, *demand side flexibility,* along its related sub-loops, has an impact on the energy need (or supply) of a building (E_A), and the timing of any such need / supply. This loop also impacts emissions from energy production, $E_{E,}$ although this link is not as apparent. Demand side-flexibility can help to shift energy consumption to more favourable times from the energy system perspective, for example, away from the morning peak hours. Likewise, it can supply clean energy to the grid, for example, through solar panels.

The second of these loops, *energy efficiency investments,* can lower the energy consumption of a building, but also result in material-related carbon emissions. This means that the benefits of energy savings (lower E_A) need to exceed the negative impacts (GHG_M) in order for energy efficiency improvements to be beneficial from the viewpoint of decarbonisation efforts of the sector.

These feedback loops are discussed in more detail in the discussions section. It is understood here that their naming of the loops could be different, some of the loops could be combined with each other and some of the relationships could be modelled in a different way. However, this paper sees this modelling work is sufficient for the purpose of this paper.

4. Discussion

This paper utilized a system dynamic model from past research and developed it to focus around the owner/user of a single building. This paper aimed to: 1) show interactions and feedback loops of an energy system that is centred around a single building and its owner/user, 2) define general dynamics that could make it possible to move towards carbon-neutral building sector by connecting the system dynamics to the different factors in Equation for zero emissions, shown in Equation 1, 3) draw conclusions about what could speed up the transition towards carbon-neutral building sector, focusing on the owner/user perspective.

4.1. Savings and values as motivators

The key loop for making a change happen on building level is the one that's focusing on the owner/user of a building. This is called *Savings and values as motivators.* In short, nothing will happen at the level of a single building without some actions from the owner/user.

While the single building is the focus of this paper, it is in principle possible that the whole building sector could decarbonize without any actions from the owner/user. This would require that the energy in the broader system would become clean. In other words, if E_E could be zeroed, used energy would be emissions-free.

This would require that the GHG_M should also become zero, meaning that the building material industry, construction industry, transportation sector, etc. would also need to decarbonize. Were these things to happen, the owner/user would not have to take any action, as the building sector could decarbonize.

However, this paper sees that user/owner actions, such as *demand-side flexibility* and *energy efficiency investments* can help to decarbonize the broader system through their connection to the broader energy system.

4.2. Demand-side flexibility

Demand side flexibility is a linked to the operating costs of a building. In practice this means that the buildings could offer flexibility towards the energy networks in terms of lowering their demand temporarily. In order for such a feedback loop to form, the building users/owners should be rewarded for offering flexibility. At the moment, such rewards are not commonplace for the users/owners. In order to boost this loop, the user/owner should be rewarded for such activities. Furthermore, as the technologies that are related to the demand-side flexibility are many, it is seen here that there is a space for service providers who could combine for example: *building-level energy services* (such as smart control of indoor air conditions), *supply-side flexibility* (or production of on-site renewable energy), and *peak shifting and shaving with storages* (for example batteries) into meaningful and beneficial services for the building users/owners.

It is also seen here, that whereas the user/owner may benefit from some actions, there may also be system-level benefits through *system-level synchronization of energy services.* Aggregating loads from multiple buildings into larger loads that can be connected to the energy markets is a concrete example of this[1]. Another example is bundling demand-side flexibility of heating loads from multiple buildings into larger entities that can help district heat companies decrease use of peak power plants[2]. It is understood that some things, such as *standards for own production* could boost up the uptake of all of these solutions. However, a more contradictory aspect is that some of the building-level actions may be seen as *cherry-picking.* Some solutions, like heat pumps replacing district heating, may lead to unwanted results on system-level, regardless of being more beneficial for the building owners/users.

4.3. Energy efficiency investments

Energy efficiency investments are investments into, for example, better insulation, more effective building heating, ventilation and air conditioning systems, or in smart control. However, any investments in energy efficiency also result in embodied energy and carbon, meaning that the amount of such emissions needs to be calculated with life cycle assessment to ensure that such investments actually result in payback in terms of energy and emissions.

The system dynamics of Figure 2 also show that one aspect of emissions from buildings is the amount of space per user. This is also a contradictory feedback loop, as it may actually increase the energy consumption and emissions on building level but decrease them on the system level. Fitting more people, or utilizing buildings more effectively increase their energy consumption and emissions, but bring benefits through decreased overall need of buildings.

5. Conclusions

In order to catch up and reach the challenges of 1.5C, we need to find new ways to rapidly take action in the built environment. This paper assumes that this can be done and shows how the different feedback loops on building-level can help achieve this. This paper sees that the complexity needs to be decreased towards the users/owners of the buildings with services that improve the indoor conditions and bring value for them. Technologies on building-level are many, but their benefits and/or pitfalls from greenhouse gas emissions may be apparent only on the system-level.

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[1] For commercial example, see [8]
[2] For commercial example, see [9, 10]

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