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Assessment of the relevance of “embodied energy” in the building stock of the city of Zurich

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Short summary

The building stock is one of the biggest energy and resource consumers worldwide. Different building stock models have been developed in order to investigate the potentials of energy-efficiency measures and changes in energy supply systems in the building stock. In this context and on behalf of the city of Zurich a life cycle-based building stock model has been designed to assess the greenhouse gas emissions as well as the primary energy reduction potential from the building sector in order to achieve the so-called goals of the “2000 Watt society” by the year 2050. However, building stock models often have important shortcomings since they merely focus on the heating energy demand in the usage phase, neglecting the ”embodied energy” demand of construction materials, building technologies and energy carriers. The goal of the project described in this paper is to provide an estimation of the embodied energy associated to the construction and renovation activities in the building park in the city of Zurich. The embodied energy in Zurich building stock by building new construction and renovation cumulates to 1’796 TJ per year (Reference scenario), 2’270 TJ per year (Efficiency scenario) and 2’304 TJ per year (Eco-efficiency scenario) in 2050. In other words, the embodied energy is roughly 10% of the operating energy and already 190 Watt per capita. The differentiation by construction element reveals interesting findings, for instance the high importance of flat roofs, electrical appliances, heating distribution, air conditioning, sanitation and wall cladding that are often excluded in current environmental assessments.

Keywords: Building stock; modelling; grey energy; 2000 watt society; embodied energy

1. Introduction

The building stock is one of the biggest energy consumers worldwide. Different building stock models (BSM) have been developed in order to investigate the potentials of energy-efficiency measures and changes in energy supply systems in the building stock. In this context and on behalf of the city of Zurich a life cycle-based building stock model has been designed to assess the greenhouse gas emissions as well as the primary energy reduction potential from the building sector in order to achieve the so-called goals of the “2000 Watt” by the year 2050 [1]. However, building stock models often have important shortcomings since they merely focus on the heating (and sometimes cooling and other electricity) energy demand in the usage phase, neglecting the ”embodied energy” demand (called “grey energy” in the Swiss context) of construction materials, building technologies and energy carriers [2]. According to the target values of the SIA Merkblatt 2040 (Efficiency Path Energy) and the target values for 2000 Watt areas (Guidelines) not only the operating energy has to be considered but also the "embodied energy" of buildings in order to achieve the objectives of the 2000 Watt Society. The goal of the project described in this paper is to provide an estimation of the embodied energy associated to the construction and renovation activities in the building park in the city of Zurich.

2. Methodology

2.1 Background and steps

The calculations are based, both technically and in terms of model scenarios, on the parameters chosen in the "Energy Concept 2050, the Zurich City" (EC 2050) [3], [4], [5]. For three scenarios (see below) relevant construction and renovation activities have been quantified and an ecological assessment has been carried out based on the underlying construction processes and associated material flows. The results are presented as greenhouse gas emissions (GHG), non-renewable primary energy demand (PE_{nr}), total primary energy demand (PE_{tot}) and environmental impact points (UBP) (following the Swiss Ecological Scarcity concept [6]). The term " environmental impacts" is used in this report for the benefit of the reader-friendliness representative for the four outcome indicators under consideration.

In this study, the following steps have been carried out:

- A quantification of the embodied energy through new construction and refurbishment activities differentiated by constructions elements in time from 2010 to 2050 for three scenarios
  1. A reference scenario (Ref. sc.) represents a moderate development of energy efficiency.
  2. An efficiency scenario (Eff. Sc.) reflects a profound effect of strict policies promoting high energy efficiency (electricity and heat) and the use of renewable energies.
  3. An ecological efficiency scenario (Eco-eff. sc.) assumes along with improving energy efficiency also increased diffusion of design and energetic refurbishment measures and building elements as well as construction materials with lower material intensity and a lower environmental impacts (GHG, PE, UBP).
- A comparison of the environmental impacts due to construction and renovation activities compared to the cumulative energy demand (CED) for space heating, hot water and electricity based applications.
- A discussion on the feasibility of the “routine integration” of the environmental impacts into the BSM and the methodology of the temporal allocation of environmental impacts.

2.2 System boundaries

2.2.1 Time-related system boundaries

Regarding the considered “environmental impacts”, this study is limited to the newly added environmental impacts through “regular” and energetically driven “add-on” refurbishments as well as new construction from 2010 until 2050. Not considered are already in the past (before the start of the assessment period) caused environmental impacts in the existing building stock in 2010 due to new construction and retrofitting. This results to the following environmental impacts over time:

- Creation of new building space from the start of 2010. Over time from 2010 the environmental impact increases because more and more new buildings, extensions and add-ons are added. With the chosen methodical approach of allocation over time (depreciation principle), the environmental impact of a particular period of construction (for example 2011-2020) declines typically after 2050 because the environmental impacts of the components, with the shortest amortization period expires again (renewal of these components appear in the category "renewal").
- "Regular" replacement - renewal of buildings and parts of buildings made between 2010 and 2050: Depending on the life expectancy of the individual components a successively higher proportion of the components of the housing stock is in need of renewal due to end of life. A steady state has been achieved for the buildings from the early periods of construction and the renovation work is of medium intensity. In later periods of construction first the components with short, and then those with medium-length and long service life will be renewed. The latter already again overlap with the second renewal of the components with a short useful life. The steady state is reached after a few decades, i.e. during the

recent periods of construction until after 2050.
- "Add-on" investments made between 2010 and 2050: this applies particularly to measures on the opaque building envelope to increase energy efficiency (without windows, they behave like regular replacement renewals) or to solar systems.
-

2.2.2 Content-related system boundaries

At the building level, a division of the building into its components is according to the standard SIA 2032 (based on the cost of construction plan construction 2009) and the cost of construction plan construction eBKP-H [7] with the following main categories:
- B: Preparation,
- C: Construction,
- D: Technology
- E: External walls
- Q: Roofing
- G: Extension

This structuring of the building elements also shows the system boundary with respect to the building: as far as possible, the entire building is considered. Due to the presumed large heterogeneity and diversity, lack of data on quantity structure and characteristics and presumably little influence on the overall results, the following elements in this project are also not accounted for: balconies, roof installations and part of the interior (kitchen, interior wall and ceiling finishes, appliances, etc.). However, regarding the interior finishing the flooring, the heating distribution as well as electrical and plumbing installations is considered.

2.3 Temporal allocation method

The environmental impacts caused by the construction and renovation activity can be allocated on the time axis according to the following two methods:
- Investment principle: the environmental impact is fully attributed to the time of actual construction.
- Depreciation principle: the environmental impact is equally distributed over the expected life time of the construction

If only a single measure is considered in a single building, the difference of the two methodical approaches introduced above is immediately understandable:
- The first case results in a peak at the point of time when the construction is made whereas in the second case, the environmental impact is spread over the entire lifetime of the construction element. If the lifetime of a building is considered the peaks of the building construction and retrofit measures can be seen. The peaks correspond to the time associated with the environmental impacts caused by the material production (Fig. 1).
- In the second case the distributed environmental impact over the life time of the retrofit measures or new constructions is visible. This means that there is an equal distribution of the associated environmental impacts over the period of time where the relevant components and building elements provide a "service" to the users (Fig. 2).

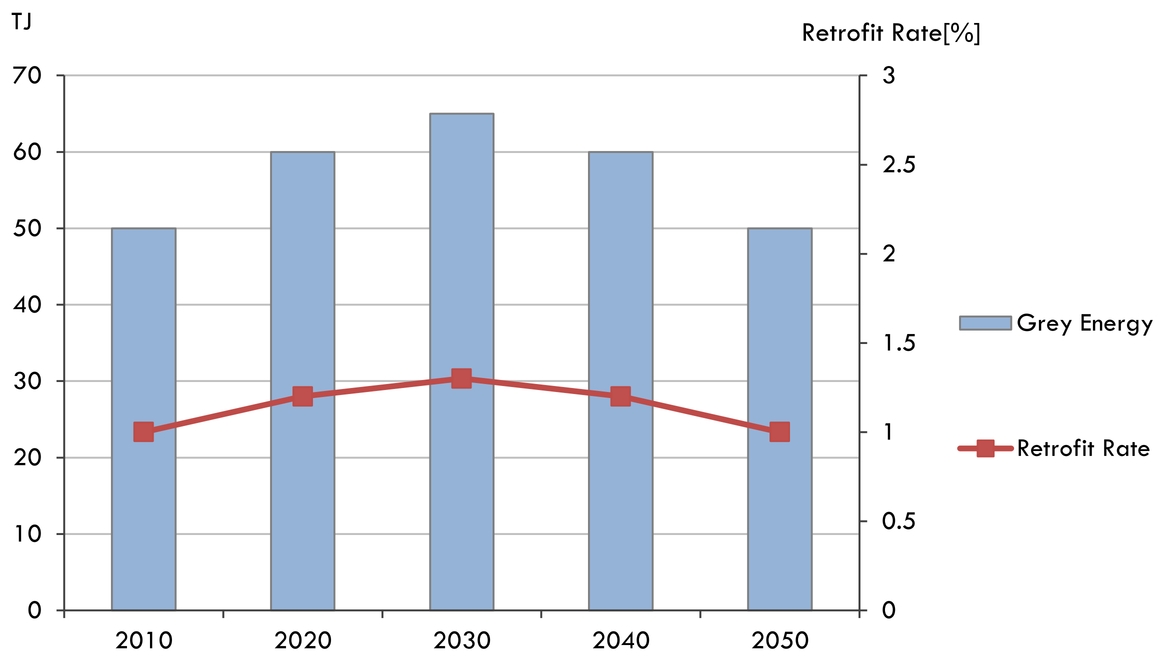

Fig. 1: Exemplary allocation of embodied energy in accordance with the allocation methodology "investment" principle (direct credit)

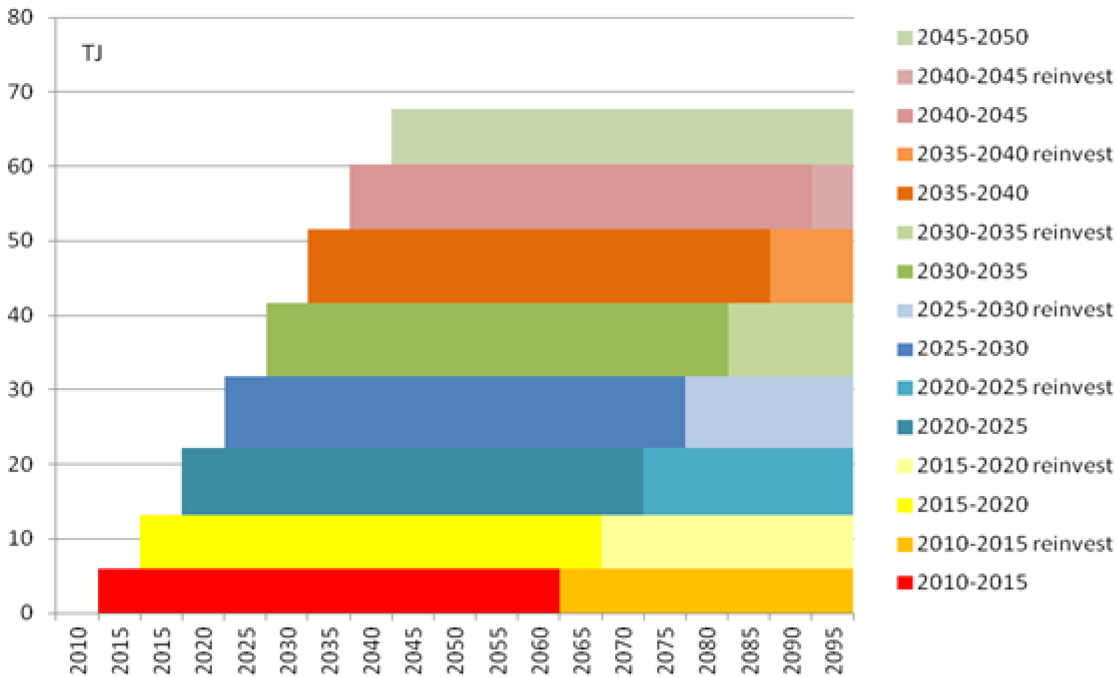

Fig. 2: Exemplary allocation of embodied energy in accordance with the allocation methodology "depreciation"

In this study, the accounting principle "depreciation" is applied, because the environmental impact is equally the time period where the building component provides a "service" to the user.

2.4 Technical model implementation

This chapter describes the technical implementation of the embodied energy calculation. Figure 3 shows an overview of all inputs and outputs of the computational model to quantify the embodied energy in the building stock of the city of Zurich. The approach is that an additional module "embodied energy" is connected to the existing quantity structure and calculation model of the EK 2050 [5]. The figure shows a diagram of the data flow and the calculation of the course module "embodied energy", and the intersection at which the consideration for the embodied energy will be connected to the existing building stock model. Each box of the flow image describes a model input or output.

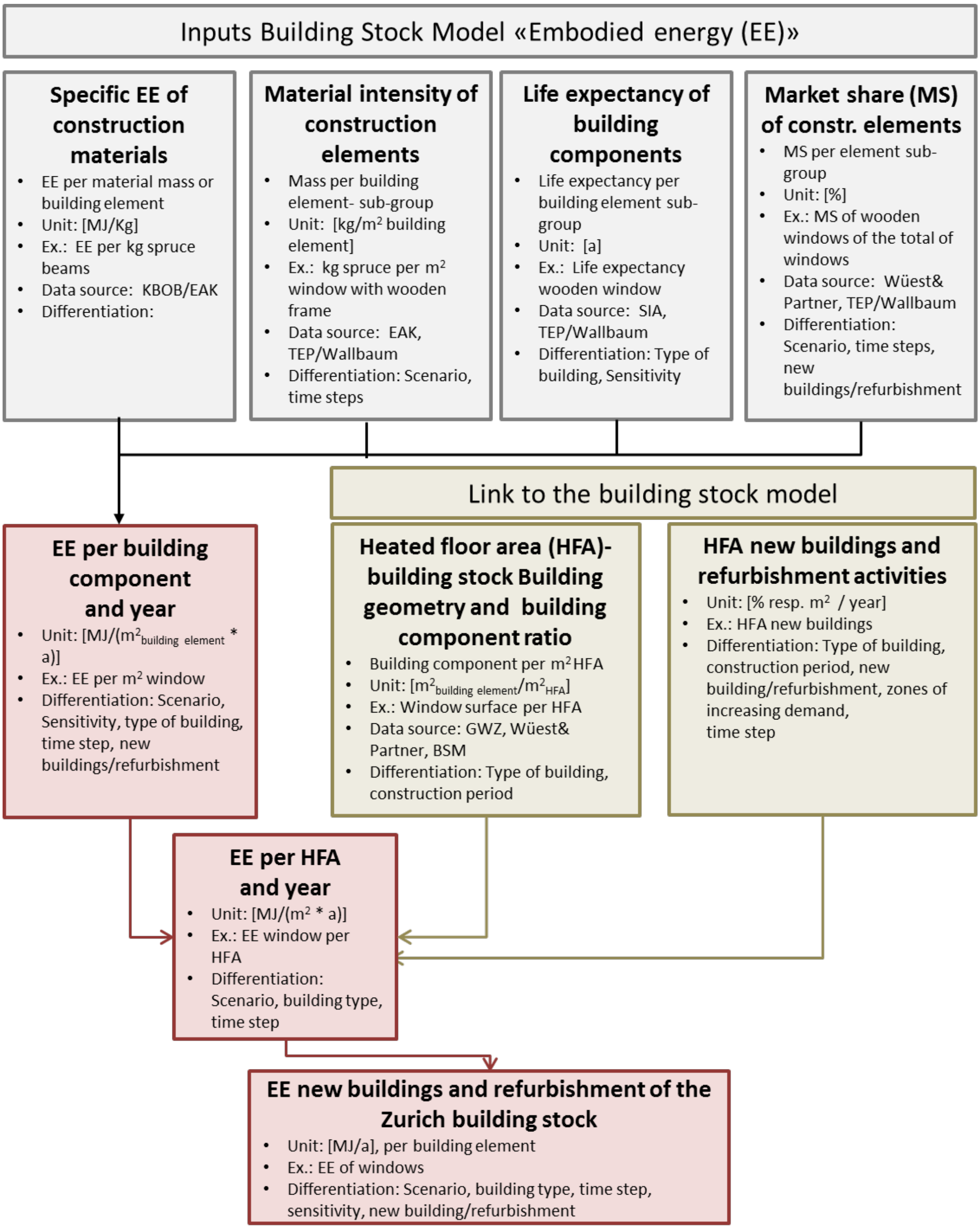

Fig. 3: Flow diagram of the model inputs (colored grey and green) and outputs (red colored)

3. Results

3.1 Scenario results

The embodied energy in the building stock of the city of Zurich through new construction and renovation is between approximately 1800 TJ / year in the reference scenario and 2,300 TJ / year in the efficiency scenarios in 2050. The greenhouse gas emissions amount to 145 thousand t-CO_2 equivalent in the reference scenario and to 180 thousand t-CO_2 eq. in the efficiency scenarios in 2050. The values of the environmental impacts of the efficiency scenarios are about a quarter higher than in the reference case. In other numbers, these are around 190 watts per person (or already appr. 10% of the target value of 2000 watts per capita in the year 2050) and 0.48 tonnes of CO_2 per person in 2050 for the efficiency scenario.

Figure 4 shows the embodied energy for three time steps to 2050 in the efficiency scenario, divided into the main categories of building elements. The values start at a very low level in 2010 and continuously increase until 2050. This results from the underlying calculation method, in which the environmental impact is distributed over the life expectancy of the different building elements (depreciation principle, see Section 2.3). The increase of the environmental impact between 2020 and 2035 is greater than the increment between 2035 and 2050. The share of the support structure decreases over time. This is due to the assumption of a slightly decreasing construction rate of new building between 2035 and 2050. The shares of the support structure, the building envelope and the building technologies on the total are in the same order of magnitude and differ slightly by the considered assessment indicator.

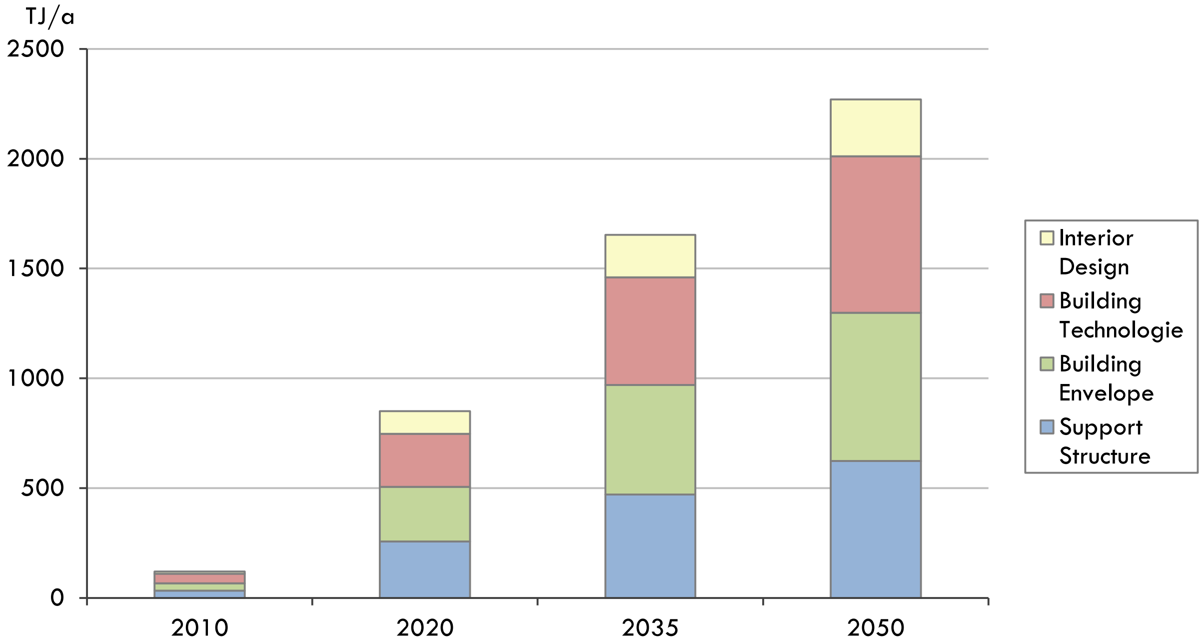

Fig. 4: Embodied energy of the building stock over time to 2050 in the efficiency scenario attributed to groups of building components

The differentiation by construction element reveals interesting findings, for instance the high importance of flat roofs, electrical appliances, heating distribution, air conditioning, sanitation and wall covering that are often excluded in current environmental assessments (Fig. 5).

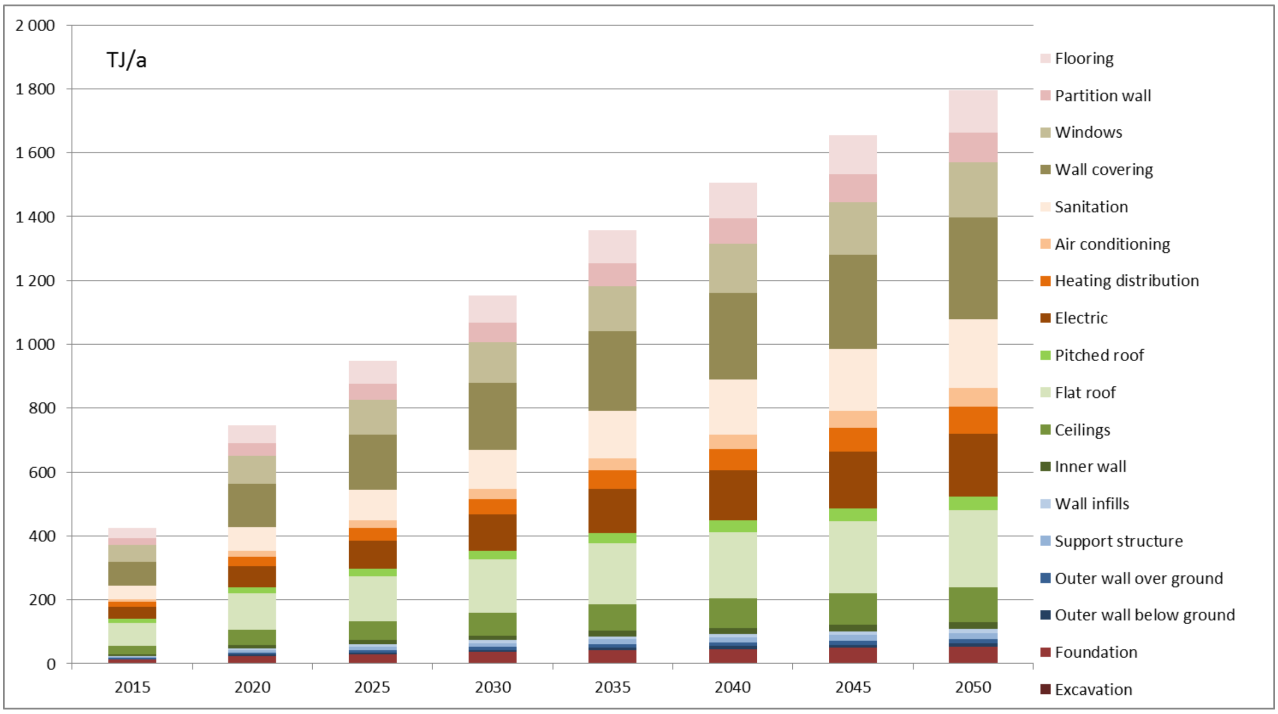

Fig 5. Embodied energy in TJ/a for the reference scenario, (Life expectancy according to TEP/Wallbaum)

3.2 Sensitivity analysis: Life expectancy of the building components

The assumed life of the components has an important influence on the results. The results of the environmental impact per component are proportional to a change of the life expectancy. The life expectancies considered in this paper is different from the assumptions provided by the standard SIA 2032 [8]. This is on the one hand based on a more elaborated definition of the life expectancy of the component by type of building. This reflects the fact that the building usage influences the life time the building components. For instance, an office building is retrofitted more frequently than a school building. On the other hand, the life expectancy of various components are higher, in particular the supporting structure but also individual elements in the areas of building envelope, building technologies and interior design. The life expectancy of the building components are based on empirical retrofit and construction rates rather a technical lifetime or economical payback period. All assumptions about life are documented in the full report. The influence of the different definition of life expectancy compared to standard SIA 2032 will be shown in Fig 6 for the example for the embodied energy in the efficiency scenario. The embodied energy is on average 30% higher in the application of SIA-life expectancy values.

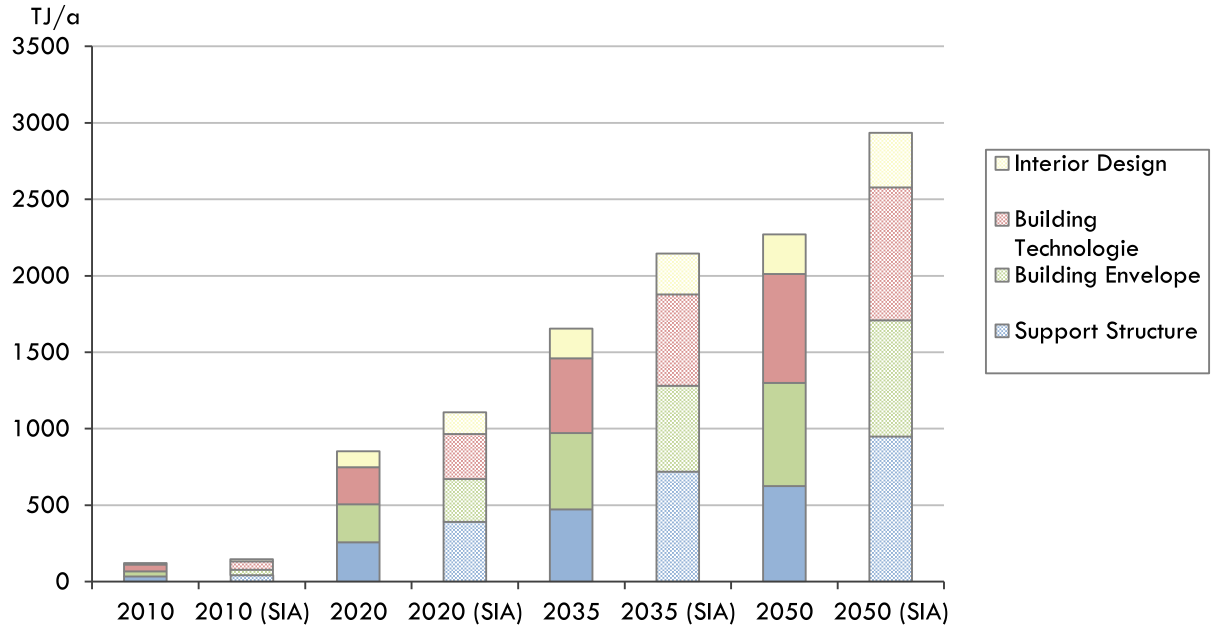

Fig 6. Embodied energy in TJ/a for the reference scenario, (Life expectancy according to TEP/Wallbaum vs. SIA 2032)

3.3 Comparison operating energy versus embodied energy of the efficiency scenario

In 2050, the embodied energy of new constructions and refurbishment from 2010 to 2050 sums up to 630 GWh per year. This is roughly 10% of the operating energy. The greenhouse gas emissions amount to almost 90% of greenhouse gas emissions from the operation in 2050. This large share of embodied greenhouse gas emissions is partly due to the low level of greenhouse gas emissions from the operation in the efficiency scenario of the EK2050 model due to the assumed extensive energy efficiency policies and the substitution of fossil fuels.

4. Discussion and outlook

This findings need to be discussed more in detail but obviously the considered life expectancy as well as the high environmental factors of certain construction materials have a significant influence on the overall results. The efficiency scenario leads to higher embodied energy values as the reference scenario mainly because of the high material intensity of building envelopes of high energetic standards. Interesting enough, the eco-efficiency scenario leads to the highest embodied energy values. This can be explained by a much higher energetic standard that is assumed in both efficiency sc. and the increased amount of wood that is considered in the eco-efficiency scenario. Some wooden material applications in buildings have a lower life expectancy than other construction materials and the currently used building material specific embodied energy values, e.g. provided in the KBOB construction material-list, seem to be too high and need to be revised.

Acknowledgement

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