Deriving global carbon budgets for the Swiss built environment

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Abstract. In order to limit global warming, remaining carbon budgets have been defined by the IPCC in 2018. In this context translating global goals to local realities implicates a set of different challenges. Standardized methodologies of allocation can support a target-cascading process. On the other hand, local strategies and norms are not currently designed to directly respond to limited carbon budgets in a 2050 horizon. The life cycle assessment of buildings implicates an intricate cross-industry and cross-border carbon accounting. For these reasons, effective and aligned carbon targets are needed to support and guide all actors in the construction sector. This research aims at addressing these challenges by developing a new methodology of allocation of a global carbon budget at different scales using the Swiss built environment as a case study. This approach allows the assessment of current best practices in regards to limited carbon budgets. Results show misalignment of global goals with current practices at all levels and present the magnitude of effort that would be required to have a chance to limit global warming to 1.5°C.

1. Introduction

Stringent limits and reduction strategies paths on greenhouse gas (GHG) emissions are being defined at different levels to limit global warming. In 2018 the IPCC published a special report outlining the impact that an increase in temperature of 1.5°C will have on our daily activities [1]. In this context, global carbon budgets (GCB) were defined for both a 66% chance of limiting global warming to 1.5°C and to 2°C among others. Respectively, the budgets in 2018 were 420GtCO₂eq and 1170GtCO₂eq. Carbon budgeting is a useful tool to quantify the remaining allowance of GHG emissions that can be emitted to limit global warming to a specific temperature. Switzerland is also committed to tackle the climate crisis and has defined a national climate strategy as well as a newly revised CO₂ law [2]. The confederation refers to two main strategies to reduce its impact. First, the main national goal of reaching carbon neutrality by 2050 and secondly, intermediate impact reduction targets for 2020, 2025 and 2030 (respectively of 20%, 35% and 50% with reference to 1990 emissions) [2]. While in the frame of the Paris Agreement countries must report only domestic emissions, the federal council recognizes in the new proposed CO₂ law the need to reduce indirect emissions with at least ¼ of the reduction efforts happening abroad. Switzerland is a net-importer, meaning that more than double its domestic emissions are imported [3], creating a high level of responsibility on indirect emissions [4]. In this setting, the built environment, as a cross-sectorial and transnational area of activity, plays a crucial role in today’s carbon emissions and future reduction’s potential [5]. In Switzerland, the operation of existing buildings and construction activities account for 35% of total domestic emissions, excluding impact caused by imported materials. This study investigates the relation between a global carbon budget and local climate strategies with an emphasis on the impact of the built environment. The following research questions
are raised: Is the climate strategy of Switzerland in line with a limited global carbon budget? Are the current standards and targets for buildings on path to limit global warming to 1.5°C? To which extent emissions in the built environment have to be reduced in order to comply with the IPCC carbon budget? 

2. Methodology

To answer the above-mentioned questions, this study applies a top-down approach to derive global carbon budgets at three main scales that are then compared to the relevant current strategies and targets. At first, the global carbon budget is determined at national level, giving a first insight on where the Swiss climate strategy stands in terms of remaining budget. The so defined national budget is then distributed to sectors with a focus on construction activities. Finally, the building stock is assessed to determine its future contribution in using these budgets. 2018 is the reference as most data was available.

2.1. National “global” carbon budget

Various methods of allocation of carbon budgets to countries and cities can be found in the literature [6][7][8][9]. The discussion around a fair distribution is broad and out of the scope of this research. For the purpose of this study it was assumed that GCB is shared equally by the world population (equal per capita). Although this method gives an equal right of emitting to all humans, it does exclude all concepts of responsibility, capability and sovereignty that could result in more just national budgets [7]. The Swiss Carbon Budget (CBCH) is accordingly calculated with equation (1). Knowing the initial level of emissions (GHGe.CH.18)[3], the final goal of carbon neutrality (referring to a balance between emissions and carbon capture) and assuming a linear decrease, the remaining years before depletion of CBCH can be calculated with equation (2) that simply refers to the base of the triangle formed by the area (CBCH).

\[ \text{CBCH} = \frac{\text{Pop}_{\text{CH}}}{\text{Pop}_{\text{world}}} \times GCB \]  
\[ \text{N.years.depletion} = \left( \frac{2 \times \text{CBCH}}{\text{GHGe.CH.18}} \right) - 1 \]

2.2. Sectoral and activities’ carbon budgets

The 4 main activity sectors from the Swiss emissions’ report [3], namely operation of buildings; transport; industry and “others” including agriculture and waste management are used in this study as the data was readily available. After assessing the current share of emissions, the estimated share in 2050 is considered from the literature [10] as shown in Figure 1 (a). This estimate assumes that Switzerland will be capable to capture and store the remaining emissions (ca. 10MtCO₂eq) with technologies inside or outside the territory. This process acknowledges the fact that some sectors have a lower potential to bring their emissions to 0 than others (ex. Agriculture and some industrial processes) and therefore require a bigger future budget. The cumulative share of emissions is then calculated and the relative sectoral limited budgets (CBS) are assigned with equation (3).

Figure 1: (a)Sectors’ shares of emissions and potential reduction in 2050; (b) Derivation of building’s related emissions from the Swiss industry activity sector.

Allocation to construction activities is less evident due to their trans-sectorial and trans-national nature. Only 30% of residential construction emissions are actually produced inside Switzerland and are
traced back to the sector “industry” while the remaining 70% comes from abroad [11]. The whole repartition is presented in Figure 1 (b). Details from the national inventory report [12] were analyzed in order to estimate that ca. 40% of industry’s emissions are related to the broad construction sector. From these, only 30% was accounted for the construction of buildings, in line with the assessment from cemuisse [13] and further details in the aforementioned report [12]. The relative limited budget (CB_CB) is calculated accordingly with equation (4) with CBi corresponding to industry’s carbon budget.

\[
\text{CBS} = \frac{\sum_{i=1}^{32} \text{GHG}_i}{\sum_{i=1}^{32} \text{GHG}_{\text{tot}}^i} \times \text{CB}_{\text{CH}} \quad (3)
\]

\[
\text{CBCB} = \frac{\left(\text{CB}_i \times 40\% \times 30\%\right)}{30\%} \times 70\% \quad (4)
\]

2.3. Assessment of the carbon intensity of buildings and construction activities

The emissions due to operation of buildings are easily retrieved as it is in itself a main activity sector [3]. Emissions due to construction activities are derived as described in section 2.2. and Figure 1 (b). In order to retrieve emission intensities of buildings per square meter, a model of the Swiss building stock and its activities was created. The calculation of surfaces (existing, renovated and newly built) is based on statistical data from the federal office [14]. The operational emissions are then divided with the total existing surface of buildings in Switzerland in order to get an average carbon intensity for operation of the stock. The same was done for construction and renovation emissions. These two activities largely differ in levels of impact as well as amount of surfaces treated. Therefore, the total intensity was weighted proportionally. The same emissions’ ratio used in the SIA2040 [15] was taken, respectively 64% and 36% as well as the difference in surfaces, 53% and 47% respectively.

Future developments of the stock are based on the estimated increase in population till 2050 and assuming no change on average surface per capita (46m²) and average number of dwellings built per year (6 per 1000 inhabitants). Three scenarios are then developed to estimate the future emissions and to be able to compare them with top-down defined budgets. The variables used in each scenario are presented in Table 1. The business as usual (BAU) scenario refers to a possible current best case scenario and applies the target values of the SIA2040 [15] for operational and embodied emissions in case of new or renovated buildings. It is to be noted that contrary to the SIA methodology, in this study embodied emissions are not amortized over the life span of the building. This means that the SIA2040 targets are considered in a cumulative way (over 60 years) and distributed to the main life cycle events of a buildings as presented in the SIA2032 [17]. Most of the emissions are happening in year 0 for the production and construction process stage (2/3 in case of new buildings and ½ in case of renovations) [16][17]. The remaining emissions are left for maintenance, replacement and end of life, considered to be happening, for simplification, after 30 years (average year of life cycle events presented by SIA 2032 [17]). Scenario 1 tests some theoretical trends and goals by increasing the renovation rate and considering a full decarbonization of operation of new and renovated buildings starting in year 0. The last scenario (Scenario 2) instead, proposes a way to be able to respect the limited carbon budgets for operation and embodied emissions. All values are kept constant till 2050. In all scenarios the operational emissions of non-renovated buildings are assumed constant at the current average value. Due to the non-dynamic evolution of the used variables, the scenarios do not represent a realistic development and are meant to only give a sense of the order of magnitude needed to comply with limited carbon budgets.

Table 1: Used variables to estimate future emissions in the three scenarios.

|                           | BAU     | Scenario 1 | Scenario 2 |
|---------------------------|---------|------------|------------|
| Renovation rate           | 1%      | 3%         | 5.5%       |
| Operational emissions (new construction) kgCO₂/m².y | 2       | 0          | 0          |
| Operational emissions (renovated buildings) kgCO₂/m².y | 5       | 0          | 0          |
| Operational emissions (non-renovated buildings) kgCO₂/m².y | 28      | 28         | 28         |
| Embodied emissions (new construction) kgCO₂/m²    | 360 (year 0) | 360 (year 0) | 160 (year 0) |
| Embodied emissions (renovations) kgCO₂/m²          | 180 (year 30) | 180 (year 30) | 80 (year 30) |
| Embodied emissions (renovations) kgCO₂/m²          | 150 (year 0) | 150 (year 0) | 30 (year 0) |
3. Results

3.1. Swiss global carbon budgets

Two carbon budgets (CBCH) are calculated for Switzerland, one for a 1.5°C limit and one for 2°C, respectively 476MtCO2eq and 1326MtCO2eq. Figure 2 represents the two budgets (grey areas) accounting only for domestic emissions (a) or including indirect emissions (b). When compared to the cumulative emissions derived by the Swiss climate strategy (dotted red line), we can conclude that global carbon budgets have decisively more limiting requirements. As part of the Paris Agreement, national climate strategies are based on direct emissions and countries agreed to limit global warming to 2°C and pursue efforts to limit it to 1.5°C. This is reflected in Figure 2 (a), where the climate strategy lies in between the two budgets and possible future carbon capture could decrease the gap towards the 1.5°C limit. However, this study wants to raise awareness on the impact of indirect emissions and show to which extent global warming is dependent on consumption-based emissions Figure 2 (b).

![Figure 2](image)

**Figure 2:** Allocation of remaining global carbon budgets (1.5°C and 2°C) with linear decrease accounting for (a) only direct emissions or (b) direct and indirect emissions.

From the 1.5°C national budget and using equation (3), the remaining budgets for the 4 main sectors (CBS) are determined. Results show that transports and “others” get the biggest share of the carbon budget (each 28%). In the case of transports, the determining factor is the high current share of emissions (32%), while for “others”, it is mainly due to its predicted inability to get to 0 emissions by 2050. Industry and operation of buildings take on their side 24% and 21% respectively. Following, also the limited budget for construction activities (CBCB) is calculated with equation (4), resulting in 32MtCO2eq.

3.2. Buildings’ operation and construction

In 2018 operation emissions accounted for 11.2 MtCO2eq [3]. When reported to the stock’s surface (ca. 393 million m²), an average value of 28 kgCO2eq/m² was deducted. Following the logic described in section 2.3, buildings’ construction emissions accounted for 4.5 MtCO2eq. When reported to a newly built surface of ca. 5 million m² and a renovated one of ca. 4.5 million m², it results in a total intensity of 466 kgCO2eq/m². Using the weighting factors as described in section 2.3, the construction of new buildings recorded an intensity of 560 kgCO2eq/m² while renovation 354 kgCO2eq/m².

In the BAU scenario, as seen in Figure 3 (a), Figure 4 (a) and Figure 5 (a), both budgets (operational and embodied) are not respected and cumulative emissions are up to 3 times higher. This scenario also misses the carbon-neutral goal of 2050 as emissions are far from 0 and would heavily rely on external carbon removal technologies. The main contributor in this case is the operation of existing buildings. It is evident from Figure 3 (b), Figure 4 (b) and Figure 5 (b) that also in scenario 1 both budgets are not met, and especially interesting is the important increase in the impact of embodied emissions due to stronger renovation activities. From the operational perspective (assuming decarbonization of the energy
supply) the only leverage left to reduce impact is to increase the renovation rate Figure 3 (c). But as seen from Scenario 1, doing so would massively increase the embodied emissions to be invested in a short period of time. In order to also meet the embodied budget (Figure 4 (c) and Figure 5 (c)), impact per square meter of construction activities will also have to decrease as presented in Table 1. This could be achieved by either decarbonizing existing materials [18] or by implementing bio-based materials to capture and compensate emissions. The sudden decrease in embodied emissions from renovations in Scenario 1 and 2 corresponds to a fully renovated stock due to the increased renovation rate.

Figure 3: Operational emissions (a) scenario BAU (b) Scenario 1 and (c) Scenario 2.

Figure 4: Embodied emissions (a) Scenario BAU (b) Scenario 1 (c) Scenario 2.

Figure 5: Total emissions (a) scenario BAU (b) Scenario 1 and (c) Scenario 2.

4. Conclusions and discussion
This study investigates a top-down method to allocate a global carbon budget to first Switzerland, then the main emitting sectors and more in details to the operation and construction of buildings. The current impact of buildings’ activities in Switzerland is assessed from a macro-level perspective. The future development of building stock’s emissions using current SIA targets is modelled and compared to the top-down derived budgets in order to identify the current gap of strategies. Results show a first incoherence between scales and emissions’ accounting, mainly looking at domestic emissions at national level but reporting consumption-based emissions at building scale. Defining a budget for Switzerland with a simple equal per capita methodology and taking responsibility for indirect emissions results in consuming the 1.5°C budget in 5 years (following a linear decrease) and the 2°C budget in 10 years. This puts the Swiss climate strategy out of these budgets’ boundaries and reinforces the degree of urgency that our climate crisis requires. Similarly, assessing current targets for operation and embodied emissions in buildings shows the misalignment of current best practices with stringent climate goals, spending around 3 times the remaining budget. The efforts presented in the proposed scenarios want to
give a degree of magnitude and do not represent a realistic evolution. Important limitations of the model appeared to be the dynamic evolution of the parameters used as well as the temporal frame. This first preliminary study raised the question on the relevance of defining a budget at different scales and especially on the viability of defining average budgets that don’t take into consideration the specific potential of the area or the socio-economic complications. An average budget could in a way be more scalable (as current energy targets are) but less refined. More specific budgets would, on the other hand, require not easily available data and competences thus decreasing the usability of the budget. In the next phase of this study a dynamic model will be built accounting for additional variables in the development of the built environment, such as the gradual decarbonization of the energy mix till 2100 and the related improvement of material’s production. This will allow a better assessment of the input parameters. Furthermore, scenarios compliant with the budgets will be assessed in a systematic way and further studies on the feasibility of new targets will be conducted (ex. buildings as carbon sink).

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