METHOD

Carbon footprints and reduction requirements: the Swiss real estate sector

Rolf Frischknecht¹, Martina Alig², Carsten Nathani³, Pino Hellmüller⁴ and Philippe Stolz⁵

Abstract
The real estate sector and its supply chains, i.e. up- and downstream processes, are responsible for a significant share of the greenhouse gas (GHG) emissions in most countries. The GHG emissions from the Swiss building stock are quantified and the hotspots identified along its supply chain using the multiregional, environmentally extended input–output tables Exiobase v3. Biodiversity impacts caused by land use, water stress due to water consumption, air pollution and eutrophication impacts are also quantified. The environmental impact-reduction requirements were estimated based on global planetary boundaries assuming that each economic sector will reduce its impacts according to the required global reduction. The Swiss real estate sector causes more than 24 Mt CO₂e/year, which is 480 ppm of global emissions, while its gross value-added share is 200 ppm. Hence, the GHG emissions per US dollar gross value added of the Swiss real estate sector are above average. Two-thirds of the emissions are caused during the use stage of buildings, whereas 30% are caused by the supply chains. A reduction to net zero is needed within the next two to three decades to comply with the 1.5°C limit. The real estate sector must address its supply chains, but also must its tenants and users.

Policy relevance
The Swiss real estate sector building-related GHG emissions are analysed, taking into account the full building life cycle. The requirements for environmental impact reduction are estimated based on global planetary boundaries, assuming that each economic sector reduces its impacts with the same global percentage. The Swiss real estate sector is found to be environmentally inefficient: it causes more GHG emissions compared with its gross value-added share. Two-thirds of the emissions are caused during the use phase of buildings, with the remainder caused by the supply chain. A reduction to net zero is needed at the latest by 2050 in order to comply with the 1.5°C limit. The real estate sector should thus further increase the energy efficiency of buildings, phase out the use of fossil fuels and address its supply chains (particularly the construction materials and products) to develop zero emission products.

Keywords: carbon budget; construction; environmental footprint; environmentally extended input–output; greenhouse gas emissions; planetary boundary; real estate sector; Switzerland

1. Introduction
The required drastic reduction in CO₂ emissions to reach net zero in the next one to two decades (IPCC 2019) is a challenge for all actors, i.e. governments, industry and private households. The real estate sector (in economics it is also called ‘real estate services industry’) and its supply chains are responsible for a significant share of the greenhouse gas (GHG) emissions. The share of operational and embodied CO₂ emissions of buildings in the global energy-related CO₂ emissions is 28% and 11%, respectively (IEA & UN Environment 2018), or nearly 40% in total. Recently published

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meta-analyses showed the growing importance of embodied GHG emissions (Röck et al. 2019). Hence, disregarding the GHG emissions of the supply chains (embodied emissions) may lead to suboptimal solutions. Additionally, public and private building owners face the risk of a long-term lock-in effect if they disregard the life-cycle-based GHG emissions of their buildings portfolio. A cross-sectoral view on the Swiss real estate services industry contributes to mitigate the deficiencies and reduce the risks of decisions based on a too narrow scope.

The analysis described in this paper takes a cross-sectoral view on the Swiss real estate services industry. The GHG emissions and other environmental impacts caused by the sector and its supply chains are quantified. Based on these data, environmental hotspots are identified.

The Swiss real estate services industry analysed includes commercial real estate services as well as private households as real estate owners.2 The construction industry, which includes the development of buildings projects, the construction of residential and non-residential buildings, civil engineering (roughly one-quarter of the turnover of the construction sector), and specialised construction activities (e.g. installation, roofing, painting), is the main supplier to the real estate sector (Figure 1).

With the knowledge gained, real estate and construction companies have an excellent basis from which to engage in supply chain management and effectively reduce and minimise their life-cycle-based environmental impacts. The paper is an excerpt from a report on environmental hotspots in the supply chain of Swiss companies (Nathani et al. 2019), which resulted in an ‘Environmental Atlas Supply Chains Switzerland’ (Alig et al. 2019). This work was inspired by a similar analysis performed for German industry sectors (Jungmichel, Schampel, & Weiss 2017). The German Environmental Atlas does not cover the construction or the real estate industries.

2. Methods
The applied method is described with respect to GHG emissions. The same approach was applied to further environmental impacts as described further below: section 2.1 presents the approach determining the carbon footprint of the sector; and section 2.3 presents the derivation of sectoral planetary boundaries.

2.1 GHG footprint of the Swiss real estate sector
The GHG footprint of the Swiss real estate sector is defined as the total GHG emissions caused by the sector’s products, including all its supply chains from resource extraction to the factory (exit) gate. The use stage of the buildings is also part of the GHG footprint. The post-consumer disposal stage is disregarded due to missing data. Disposal services as intermediate inputs, however, are included in the supply chains. The scope thus includes:

- direct GHG emissions of the real estate sector itself
- GHG emissions of the sector’s entire supply chain, i.e. all economic activities from resource extraction to handing over, including construction, replacement and repair, deconstruction as well as disposal activities of the industry itself and
- the GHG emissions occurring during the use stage of the buildings.

The environmental footprints of the Swiss real estate sector are analysed using Exiobase v3 (Wood et al. 2015), an environmentally extended multiregional input–output table (EE-MRIOT) combined with the official Swiss IOT for 2008. A new version of the Swiss input–output table (IOT) 2008 was developed (Frischknecht, Nathani, & Stolz 2015;

![Figure 1: Relationship between the construction industry and the real estate sector. Source: Adapted from Nathani et al. (2019).](image-url)
Nathani et al. 2016), which includes substantial disaggregation and improved data quality for the environmentally relevant energy, transport and food sectors, and a wide range of environmental data. A two-step approach was used, combining the new Swiss environmentally input–output table (EE-IOT) for the calculation of environmental impacts in Switzerland and Exiobase for the calculation of environmental impacts in foreign countries. In this two-step approach the calculation steps are as follows:

- Starting with the total production output of the real estate sector, the total output and gross value added induced in other Swiss industries are calculated with the Swiss EE-IOT. The results are adjusted to eliminate double-counting of intermediate inputs of the real estate sector.
- The GHG emissions caused by Swiss industries are then determined by multiplying the output with industry-specific emission coefficients as reported in the Swiss EE-IOT.
- The calculation also yields the imports by product group that are induced in the supply chain of the real estate sector. These imports are then distributed to source countries, based on a table of product-group-specific country shares, distributing imported product groups to source countries. The table was derived from the Swiss foreign trade statistics (for source countries of goods), the Swiss balance of payments and the Organisation for Economic Co-operation and Development (OECD)-World Trade Organization (WTO) Balanced Trade in Services Statistics (for source countries of imported services). The table distinguishes between imported product groups used for intermediate consumption and for final consumption.
- The imports by product group and source country are then fed into Exiobase, which is used to calculate the total output in all industries in all countries induced by these imports (following trade until the countries of origin) and the total GHG emissions caused by these foreign production activities.

A further adaptation of the approach refers to the inclusion of investment goods into the supply chain calculations. In IOTs only the use of intermediate inputs in industries is recorded and included in the calculation of output multipliers. The use of investment goods in industries is recorded in total as depreciation in the factor inputs matrix, but not allocated to supplying industries. The use of investment goods in the industries was roughly estimated by distributing each industry’s depreciation to product groups. The estimation of the investment matrix in the Swiss EE-IOT is explained by Nathani et al. (2019). It includes the estimation of each industry’s depreciation (distinguishing between buildings and other equipment) and the distribution of depreciation to supplying industries (e.g. construction, machinery, design) with shares from the final demand matrix and assuming same shares for all investing industries, since specific data are not available. In the Exiobase MRIOT each industry’s depreciation is recorded, but it is not differentiated between buildings and other equipment. The depreciation of the real estate services was fully allocated to construction and that depreciation of other industries was allocated to supplying industries according to the shares from the final demand matrix (after deduction of the above-mentioned construction related values).

The investment matrix was then included in the calculation of multipliers used to determine total output effects. Table 1 displays the elements of this approach.

The results of these calculations are:

- total economic output and gross value added in all industries and all countries caused by the Swiss real estate production activities and
- total GHG emissions (and further environmental impacts) in all industries and all countries caused by the Swiss real estate production activities.

The economic and environmental impacts are structured by supply chain stages, distinguishing between the real estate sector itself, direct suppliers to the real estate sector, resource extraction industries and other industries of the supply chain.
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The annual environmental impacts during the use stage was modelled using statistical data about the annual energy and water consumption of as well as the land occupied by the building stock in Switzerland (BFE 2018; BFS 2016; SVGW & BFS 2019). The one-year depiction of the real estate sector is combined with the one-year energy and water consumption of the Swiss building stock. This approach thus deviates from a classical product-based environmental life cycle assessment where the construction, use and end-of-life stages of one particular product (here, the building stock in a given year) are assessed. The effect of this inconsistency introduced is being addressed in the conclusions section.

2.2 Further environmental impacts addressed

Besides GHG emissions, the biodiversity impacts caused by land use (using the biodiversity damage potential—BDP; Chaudhary et al. 2015, 2016a, 2016b; Chaudhary & Brooks 2017, 2018), water stress due to water consumption (using the available water remaining—AWARE; Boulay et al. 2017), air pollution (fine particles; Goedkoop et al. 2009) and eutrophication impacts (Goedkoop et al. 2009) were quantified. AWARE and BDP indicators are recommended by UN Environment (Frischknecht & Jolliet 2016). Environmental impacts related to resource consumption are not addressed because of missing data on global planetary boundaries.

2.3 Applying planetary boundaries to the Swiss real estate sector

The GHG emissions (and other environmental impacts) reduction requirements were estimated based on global planetary boundaries (Steffen et al. 2015), which were used to deduce global limit values (or ‘budgets’) for footprints. To determine those limit values the methodological approach from Dao et al. (2015) was adopted and applied to the GHG emissions and other environmental indicators.¹ In addition, new and further findings from Steffen et al. (2015) were taken into account, in particular regarding biodiversity impacts due to land use.

According to the calculations of Dao et al. (2015), the global yearly limit for GHG emissions is 12.3 Gt CO₂-eq/year. This corresponds to the remaining global carbon budget until 2100 to comply with the 2°C temperature increase target. This remaining budget is well above the net-zero CO₂ emission target, which is required to remain within the 1.5°C temperature increase target (IPCC 2019). Hence, the target used in this approach is illustrating the need for a massive reduction and representing an intermediate target on the way to the ultimate target of net-zero CO₂ emissions as required based on the 1.5°C report of the IPCC (2019) and as decided in the Paris Agreement (UNFCCC 2015).

Table 2 shows an overview of the yearly emission budgets available for GHG emissions and the other environmental impacts, the worldwide emissions in 2008 and the necessary reduction. The reference year 2008 was used to ensure compatibility with the Swiss EE-IOT.

The planetary boundary is then applied on the real estate sector using the contraction approach on the absolute emissions and impacts, respectively (Sabag Muñoz & Gladek 2017). The contraction of absolute GHG emissions approach was implemented as follows:

- The absolute GHG emissions (i.e. including the whole supply chain, and the use stage) of the Swiss real estate sector were quantified.
- The target values were determined by multiplying the respective relative global reduction requirement with the current (2008) absolute GHG emissions of the Swiss real estate sector.

This allocation approach is debatable like any other allocation approach for at least two reasons: ‘Emission permits’ cannot objectively be allocated to economic sectors. It requires choices and value judgements such as:

Table 2: Yearly emission budgets, global emissions in 2008 and the necessary reduction at the global level for each environmental indicator analysed.

<table>
<thead>
<tr>
<th>Environmental indicator</th>
<th>Unit</th>
<th>Limit for the global footprint (reference year)</th>
<th>Current global environmental footprint, 2008</th>
<th>Necessary reduction (global level) (%)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG footprint</td>
<td>Mt CO₂-e/year</td>
<td>12,300⁰</td>
<td>50,800</td>
<td>76%</td>
<td>Dao et al. (2015)</td>
</tr>
<tr>
<td>Biodiversity footprint</td>
<td>10⁶ PDF*year/year</td>
<td>15,000</td>
<td>88,901</td>
<td>83%</td>
<td>Steffen et al. (2015); Frischknecht et al. (2018a)</td>
</tr>
<tr>
<td>Eutrophication footprint</td>
<td>Mt N/year</td>
<td>47.6</td>
<td>55.6</td>
<td>14%</td>
<td>Dao et al. (2015)</td>
</tr>
<tr>
<td>Air pollution footprint</td>
<td>Mt PM₁₀-eq/year</td>
<td>65.3</td>
<td>106.3</td>
<td>39%</td>
<td>Frischknecht &amp; Büsser Knöpfel (2013)</td>
</tr>
</tbody>
</table>

Notes: ¹Intermediate limit; net-zero emissions (100% reduction) required to stay within a 1.5°C temperature increase. GHG = greenhouse gas; N = nitrogen; PDF = potentially disappeared fraction (of species); PM = particulate matter.
• Should the current size and structure of economic sector be used (‘grandfathering’) or should future developments be accounted for? If the latter, how are these developments defined and by whom?
• Do the emission permits cover only direct emissions of the sectors or do they include supply chain emissions? If the latter, how are the supply chain emissions estimated and how are double counts dealt with?

The proposed simple approach avoids discussions about the emission reduction an industry achieved in the past or about the perceived or real technical or economic difficulties of an industry to reduce emissions.

Specific Swiss-reduction requirements are available regarding the GHG emissions and the eutrophication footprint (Table 3). For these two footprints the target values were derived using a weighted average of the Swiss and the global reduction requirements. The weighting was based on the respective shares of domestic and foreign emissions, i.e., the reduction requirements are composed of the sum of the share of emissions occurring in Switzerland multiplied by the specific Swiss reduction requirements, and the share of emissions occurring abroad multiplied by the relative global reduction requirements.

The target values of the Swiss real estate sector as well as its current (2008) environmental footprints were finally divided by the respective global environmental footprints. These target values determine the industry-specific planetary boundaries. The real estate sector’s GHG emissions and other impacts were compared with these planetary boundaries.

3. Results
3.1 Overview

Table 4 contains an overview of the total environmental footprints caused by the Swiss real estate sector, including the use stage (i.e., environmental impacts caused by energy, water, and land use of buildings). On the one hand, the footprints are reported in absolute terms, and, on the other, as intensities in relation to gross output as well as to gross value added of the industry itself. It should be noticed that the different footprints cannot be compared amongst each other since they are completely different measures with different units.

Aiming to understand the supply chain stages in which the different environmental impacts take place, Figure 2 displays the share of supply chain stages in total impacts as well as the share of the industry in the global impacts for all environmental footprints (and value added/gross production value for comparison reasons). Thus, it shows how much of the total environmental impacts induced by the real estate sector stem from the industry itself, how much is caused in the supply chain and the use stage, and finally the contribution of the Swiss real estate sector to the global environmental impacts and gross value added.

Figure 2 shows that the use stage accounts for large shares of the various footprints. It is most important for the GHG footprint (with a share of 68%), for the water footprint (51%) and the air pollution footprint (49%), including, e.g., the environmental impacts of households’ energy use for heating and cooling, other electricity use and water use. The use stage is less relevant for the biodiversity and the eutrophication footprint. The real estate sector itself and its direct suppliers (e.g., construction) generate much of the value added but only small shares of the environmental footprints. The remaining upstream chains (e.g., cement and tile industries) have significant shares in the GHG (22%), the air pollution (39%) and the eutrophication footprints (32%). Finally, raw material extraction dominates the biodiversity footprint (85%), but is also quite relevant for the eutrophication (45%) and the water (38%) footprint. The share of the use phase is expected to be lower today (2020) than in 2008 because of the continuous increase in operational energy efficiency of the building stock (see also Röck et al. 2019).

The results show that the real estate sector of Switzerland causes more than 24 Mt CO₂e/year, which is about 21% of the consumption based GHG footprint of Switzerland (113.8 Mt CO₂e/year; Frischknecht et al. 2018b). Two-thirds of the emissions are caused during the use stage of buildings, whereas 30% are caused by the supply chains. The sector itself contributes only 2% to its carbon footprint.

Table 3: Necessary reduction at the global and Swiss levels for each environmental indicator analysed.

<table>
<thead>
<tr>
<th>Environmental indicator</th>
<th>Unit</th>
<th>Necessary reduction (global level) (%)</th>
<th>Necessary reduction (Swiss level) (%)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG footprint</td>
<td>Mt CO₂e/year</td>
<td>76%</td>
<td>80%</td>
<td>Global: Dao et al. (2015); Swiss: Frischknecht &amp; Büsser Knöpfel (2013)</td>
</tr>
<tr>
<td>Biodiversity footprint</td>
<td>10⁻⁶ PDF*year/year</td>
<td>83%</td>
<td></td>
<td>Steffen et al. (2015); Frischknecht et al. (2018a)</td>
</tr>
<tr>
<td>Eutrophication footprint</td>
<td>Mt N/year</td>
<td>14%</td>
<td>34%</td>
<td>Global: Dao et al. (2015); Swiss: Frischknecht &amp; Büsser Knöpfel (2013)</td>
</tr>
<tr>
<td>Air pollution footprint</td>
<td>Mt PM₂o₅eq/year</td>
<td>39%</td>
<td></td>
<td>Frischknecht &amp; Büsser Knöpfel (2013)</td>
</tr>
</tbody>
</table>

*Note: GHG = greenhouse gas; N = nitrogen; PDF = potentially disappeared fraction (of species); PM = particulate matter.*
Table 4: Environmental footprints caused by the Swiss real estate sector, 2008.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Unit</th>
<th>In absolute terms</th>
<th>... of which in the use stage</th>
<th>... of which in production</th>
<th>Per gross output (only production) (CHF millions)</th>
<th>Per gross value added (only production) (CHF millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG footprint</td>
<td>kt CO₂e</td>
<td>24,286</td>
<td>16,569</td>
<td>7716</td>
<td>0.11</td>
<td>0.15</td>
</tr>
<tr>
<td>Biodiversity footprint</td>
<td>nano PDF*year</td>
<td>66.31</td>
<td>879</td>
<td>5753</td>
<td>0.08</td>
<td>0.11</td>
</tr>
<tr>
<td>Water footprint</td>
<td>million m³</td>
<td>3,707</td>
<td>1,884</td>
<td>1,823</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Air pollution footprint</td>
<td>t PM₁₀-eq</td>
<td>28,254</td>
<td>13,756</td>
<td>14,499</td>
<td>0.20</td>
<td>0.29</td>
</tr>
<tr>
<td>Eutrophication footprint</td>
<td>t N-eq</td>
<td>7,173</td>
<td>925</td>
<td>6,249</td>
<td>0.09</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Gross output (industry itself)   | CHF (millions) | 70,412            |

Gross value added (industry itself) | CHF (millions) | 50,064            |

Source: Nathani et al. (2019).

Figure 2: Environmental footprints caused by the Swiss real estate sector in 2008 by supply chain stages, share of the industry in global gross production value and global environmental footprints, as well as the reduction necessary to comply with the planetary boundaries. The greenhouse gas (GHG) footprint target is an intermediate value; the final target value is net zero. The length of the bars on the right-hand side shows the share of the environmental footprints, and for comparison the gross value added of the Swiss real estate sector on the global total environmental footprints and total global gross value added, expressed in parts per million (ppm), are shown. The bars on the right-hand side represent the dimensionless score of each indicator after normalisation (according to ISO 2006), dividing the environmental footprint of the sector by the global environmental footprint. Source: Nathani et al. (2019).
The shares of the GHG footprint of the Swiss real estate sector in the global GHG footprint is about 480 ppm, while the share of the gross value added in the global gross value added is nearly 200 ppm. Hence, the real estate sector contributes over-proportionally to the global GHG footprint. A reduction of more than 75% is required to keep the GHG footprint within the 2°C temperature increase limit and a reduction of 100% is required to meet the net-zero emission target in order to comply with the 1.5°C temperature increase limit.

### 3.2 GHG emissions

The real estate services have a large GHG footprint (Figure 2 shows the share of the respective footprint in the global footprints compared with the share of the gross production value of the real estate services in the gross production of the entire global economy).

The emissions during the use stage are grouped into space heating, warm water supply, electricity use and water use allowed by the granularity of the underlying statistical data (BFE 2018; BFS 2016; SVGW & BFS 2019).

Regarding the supply chain, Figure 3 (lower part) displays which industries of the supply chain (aggregated over all countries) emit the GHGs. The largest emitter is the industry ‘electricity from fossil fuels’, which is accountable for 5% of the GHG footprint. ‘Mining and quarrying’ follows on the second place (4%). In general a large fraction of GHG emissions stems from basic industries such as other non-metallic minerals or basic metals. Real estate services and construction are responsible for almost 2% of the emissions. Transport, petroleum products and chemicals follow among the top 10. Industries outside the top 10 account for more than 8% of the GHG footprint.

![Figure 3](https://example.com/figure3.png)

**Figure 3:** Greenhouse gas (GHG) footprint caused by the real estate sector in 2008 by supply chain stage and supplying industries. Source: Nathani et al. (2019).
Figure 4 illustrates how the responsible sectors are distributed across supply chain stages and countries. The lower part of Figure 4 shows that more than three-quarters of the footprint are due to emissions in Switzerland (68% during the use stage and more than 8% by the industry itself and by Swiss supply chain industries), while the remaining emissions take place abroad. The share of domestic emissions will most likely be lower today due to an increase of the operational energy efficiency of the building stock, a shift from fuel oil to natural gas and electric heat pumps and a lower GHG footprint of the Swiss electricity supply mix.

The country differentiation of GHG emissions reveals China and Germany to be the largest foreign polluters in the real estate sector’s supply chain, followed by Russia, the US and Italy. Countries outside the top 10 account for 9% of the footprint. Emissions abroad are mainly caused by remaining upstream chains and to a lesser extent by raw material extraction.

Figure 4: Greenhouse gas (GHG) footprint caused by the Swiss real estate sector in 2008, differentiated by supply chain stage and source countries. Source: Nathani et al. (2019).
From a practical point of view it is useful to understand which direct intermediate inputs purchased by the Swiss real estate sector are responsible (to what extent) for the total GHG emissions caused by the industry within its supply chains. This allows the companies to identify which of their suppliers they should access with which priority in order to optimise the environmental performance of their supply chain. The analysis presented in Figure 5 (lower part) allocates the GHG emissions caused by the Swiss real estate sector within the supply chain to domestic and foreign direct suppliers. Thus, each direct supplying industry is presented with its own GHG footprint, including all emissions along its own supply chain. The emissions of the industry itself are shown for comparison reasons.

The results show that construction as a direct supplier to the real estate sector is responsible for almost 18% of the GHG footprint. Surprisingly financial services and other business services are also relevant with shares between 3% and 4%, respectively. Here the main contributors are energy use and the use of investment goods, which are GHG intensive. The impact of other suppliers is rather small. Therefore, in order to optimise its total induced GHG emissions, real estate service providers need to focus on the use stage, i.e. energy consumption of buildings, and the energy and materials used for the construction of buildings.

Figure 5: Greenhouse gas (GHG) footprint caused by the direct suppliers of intermediate goods and services for the Swiss real estate sector in 2008. Source: Nathani et al. (2019).
4. Discussion
The analysis of the Swiss real estate sector in 2008 allows for a detailed insight into the main drivers of GHG emissions and further key environmental impacts. The main share of the GHG emissions of the real estate sector is still generated during the use of the buildings. This is mainly due to the consumption of fossil heating fuels and the electricity requirements for lighting and climate control systems and because the assessment covers a large share of the existing building stock with lower energy efficiencies compared with the building standards pertinent at that time.

Within the supply chain, the ‘construction’ industry is the biggest GHG emissions contributor of the Swiss industry ‘real estate services’. The construction industry, including construction material manufacturers and many other building supplier industries in its supply chains, accounts for about 60% of the impacts. Besides ‘construction’, also ‘other business services’ as well as ‘financial services’ make a substantial contribution to the GHG emissions of the Swiss ‘real estate services’ industry. Three-quarters of the supply chain GHG emissions are caused abroad.

Like any other industry sector, the real estate sector needs to substantially reduce its GHG emissions to comply with the climate change planetary boundary of 2°C and to reach net-zero GHG emissions no later than 2050 to comply with the 1.5°C target.

The approach and the results shown in this paper are subject to uncertainty and variability. The shares of construction and use stages of individual buildings may substantially deviate from the results shown for the Swiss building stock in 2008 and the Swiss building stock in 2020 may differ in performance compared with the Swiss building stock in 2008.

5. Conclusions and outlook
The assessment of the Swiss real estate sector revealed the importance of both the use and the construction stage of buildings. The assessment results are valid for the situation in 2008. The model and data used combine one-time construction activities (new buildings, refurbishments, replacements and repair) with the annual operation of the entire (average) building stock in 2008. This differs from a traditional process-based environmental life-cycle assessment approach, in which the construction, operation (50–60 years) and end of life of one and the same building are analysed. The approach described in this paper nevertheless provides useful insights because the Swiss real estate industry was not unusually expanding in the first decade of the 21st century.

The use stage is traditionally in the focus of energy and environmental legislation leading to high-energy-efficient new buildings. In addition, numerous low-carbon heating and cooling solutions are commercially available to support a substantial reduction of greenhouse gas (GHG) emissions caused during the use stage. The share of operational GHG emissions of buildings in 2008 of roughly two-thirds is likely to be lower today and will most probably further decrease in the coming decades. Embodied GHG emissions will likely become the dominant source of GHG emissions during the life-cycle of buildings for the following reasons:

- An increase in operational energy efficiency.
- The increasing use of low-carbon operational energy sources (electric heat pumps operated with electricity from renewable sources, solid biomass etc.) to cover the remaining energy demand.
- A further increase in the standard of living (e.g. number and equipment of bathrooms, etc.).
- The fact that some of the main construction materials are being manufactured using energy-intensive processes from 20 to 50 years ago.

The comparison with the planetary boundaries shows that a high priority should be given to the massive reduction of the GHG emissions in a concerted action of the real estate sector and key players in its supply chain. The approach chosen allows the Swiss real estate sector to identify key economic sectors, key countries as well as key direct suppliers to engage with. The real estate sector should further reduce the energy consumption during the use stage and phase out fossil-based fuels. It should encourage construction material manufacturers to develop and offer zero-emission products. In the recent past, material associations such as European Aluminium (2019), Eurofer (2013) and Cembureau (2017) published road map reports showing the contribution of their materials to a low-carbon society in 2050. Some of their member companies launched low-carbon materials or ramped-up pilot plants to produce zero-carbon cement and steel. In cases where CO₂ and other GHG emissions are inevitable (e.g. CO₂ from carbonisation in clinker production), negative emission technologies (Minx et al. 2018) should be used to ensure net-zero emission products.

Individual real estate service companies may follow the assessment approach described in this paper and analyse the GHG emissions of their specific activities and supply chains. This will assist them to achieve substantial reductions in GHG emissions needed in the three next decades.

Notes
1 Real estate services are defined by Nomenclature générale des activités économiques (NOGA); specifically, NOGA 68 (NOGA 2008) and NOGA 70 (NOGA 2002); private households as real estate owners are defined in NOGA 98 (NOGA 2008) and NOGA 97 (NOGA 2002). Public sector buildings are included when managed by commercial real estate service companies.
2 Water availability and scarcity depends very much on the geographical location. Water shortage in one region cannot be compensated by excess water in another region. Thus, no water footprint planetary boundary was defined.

3 This includes the GHG emissions of the construction industry’s supply chain.

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Competing interests
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