Austrian GHG emission targets for new buildings and major renovations: an exploratory study

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Abstract. To avoid uncontrollable and uncompensated effects of climate change, within the ratification of the Paris Agreement, 197 countries including Austria have committed to limit their emissions of greenhouse gases to hold the warming below 2°C. Achievement of this objective will oblige Austrian society to stay within a carbon budget of 1000 Mt CO₂eq until 2050. Due to the long-life span of buildings as well as their high contribution and reduction potentials regarding embodied and operational greenhouse gas (GHG) emissions, specific environmental benchmarks are required for new buildings and major renovations. The evaluation of environmental targets presented in this paper follows a methodology combining top-down and bottom-up approaches. First, GHG emissions and reduction targets are calculated for the emission intensity of the Austrian energy mix with the help of top-down decomposition. Second, a hybrid top-down-bottom-up approach is applied as a basis for establishing GHG emission targets on building level. The embodied and operational impacts of Austrian building stock and from construction of new buildings are evaluated. Following on from this and using the Austrian carbon budget, the reduction targets are set at building level based on the hypothesis for 2050. This paper present and exploratory study and can be presented as a basis for definition of GHG targets.

1. Introduction

Environmental impacts of buildings (embodied and operational) are identified as largely responsible for climate change. Life cycle assessment (LCA) method is widely used to quantify greenhouse emissions (GHG) and other environmental impacts of buildings [1], [2], [3]. Results of LCA support decision making in favour of a more climate and environmentally friendly production and therefore help to achieve the UN Sustainable Development Goals (SDG), e.g., number 12 (responsible consumption and production) and 13 (climate action). In order to support GHG emission reduction in line with the Paris Agreement, actors across industry sectors, policy makers and governments on various levels as well as clients and building design professionals need specific environmental targets. Building stakeholders have found these environmental targets useful at different levels (i.e. for sectors, whole buildings, components and materials) and they are presented in norms/standards and scientific articles (i.e. the Swiss-2000-watts society vision or the Denmark-context) [4], [5], [6].

In this paper, GHG emission targets relevant for building construction and operation in the Austrian context are calculated combining top-down and bottom-up approaches. On the one hand, a top-down approach is applied with a focus on establishing targets for reducing emission intensity for the energy mix. On the other hand, a hybrid top-down-bottom-up approach was developed focusing on GHG
emission targets on building level, per square meter of floor area. Once the range of GHG emissions coming from building construction and operation is validated by both approaches, we evaluate the targets that buildings have to reach by 2050.

2. Method and materials

2.1. Austrian GHG budget

To keep the warming below 2°C, the Austrian GHG budget for the remaining period until 2050 is limited to approx. 1000 million tons of CO\textsubscript{2}eq [7], [8]. Moreover, the 2050 Austrian targets of GHG emissions are limited to 1 t-CO\textsubscript{2}eq/capita yr. (average of 80-95% reduction compared to 1990) [9]. Figure 1 presents in graphic form the two constraints that Austrian society must respect for the reduction of GHG. The first constraint $I_{2015} \cdot \sum_{i=1}^{35} \%^i$ presents the GHG budget for the period 2015-2050. This constraint represents the smooth transition of the impact reduction is used to build the graphic presented in Figure 1. The symbol ‘%’ presents the rate of impact reduction starting from the year 2015. In other words, the impact target of 2016 shall be calculated from the multiplication of the reduction rate % with the impacts in the year 2015. Following the same logic, the impacts of 2017 are calculated from the multiplication of the reduction rate % with the impact of 2016. The targets for the other years until 2050 ($I_{2050}$) are calculated in the same way. The impact reduction ‘%’ must be calculated by also considering the second constraint that the impact in 2050 shall be equal to 1 t-CO\textsubscript{2}eq/capita yr.

![Figure 1. Austrian GHG budged according to restrictions fixed in the Paris agreement.](image-url)

2.2. The energy perspective, following a top-down approach

The top-down model starts from a global level, correlating GHG emissions with gross domestic product (GDP), population and the quantity of energy used in a certain country, following the equation presented by Kaya [10], [11]:

$$CO_2 = POP \times \frac{GDP}{POP} \times \frac{CED}{GDP} \times \frac{CO_2}{CED}$$  \hspace{1cm} (1)

POP: represents the population of the country (in millions);
GDP: represents the gross domestic product for the country (in million euro);
CED: represents the primary energy consumption (in million MJ);
CO\textsubscript{2}: represents the quantity of greenhouse gases emitted (in million t-CO\textsubscript{2}-eq).
From this equation we can observe three indices. The first, $\frac{GDP}{POP}$, calculated form the ratio of GDP to population, represents the production, in monetary terms, per capita. The second, $\frac{CED}{GDP}$, calculated from the ratio of primary energy used to GDP, presents the energy intensity of the economy. Both indices should be optimized with caution since the first has an influence on citizens and the second on industry. On the one hand the decrease of the first index, $\frac{GDP}{POP}$, is expected to reduce the resource abundance or the economic development of the country, but on the other hand its increase will directly influence the second index and this means that it will be easily possible to purchase primary energy and as a consequence the energy quantity consumed is likely to increase. Regarding the second index, $\frac{CED}{GDP}$, its rise means increasing the price of energy which will have a direct influence to industry, its productivity and the price of goods and services.

Hence, while these first two indices should be changed with caution, and there is (still) a strong intent to maintain or increase their trend, the most pertinent index for tackling the problem of climate change is the third index, $\frac{CO_2}{CED}$. This index calculated from the ratio of GHG emissions to primary energy consumption represents the ‘carbon content’ in the energy mix of the country. In order to achieve the targets defined in the ‘Paris Agreement’ it will be subjected to minimization efforts. Since this index represents the GHG emission content in the mix or the primary energy consumption, however, it is primarily of use for governments and energy production industries. It informs them about the GHG content the energy mix of the country must have in order to reach the future targets. Application of the Kaya concept for the calculation of the impact target requires a large quantity of data, which are generally accessible in national statistical databases. For GHG emissions, these values can be obtained by direct measurements or calculated through input-output models [12]. Direct measurements are mostly obtained for the quantity of primary energy consumed from different sectors and then converted in GHG emission equivalents. These conversions are made with the help of impact coefficients published in literature [13].

2.3. The building perspective, following a top-down-bottom-up approach

Based on the reference year 2015, macro-economic I/O data for Austria [14] is used to identify the economic flows related to the construction of buildings. This data, in combination with data on GHG emissions from the construction of buildings [15], and corrected by factors for translating what were originally territorial values into consumption-based values obtained from literature [16], is used to calculate the GHG emission intensity of building construction in kgCO$_2$eq/€. In order to translate this value from a monetary basis to values per square meter of building, statistical data on construction cost per square meter is used [17] to obtain the emission intensity on building level, in kgCO$_2$eq/m$^2$. Since these values, which are obtained through a combination of data sources, are subject to strong uncertainties, the magnitude of preliminary values is validated through comparison with bottom-up values on GHG emissions per square meter from detailed LCA studies of specific buildings. Here we used data on the embodied, upfront GHG emissions invested per square meter for new buildings and renovations, respectively, as well as energy-related GHG emissions per square meter from operation of the building [18], [19], [20]. In a next step, these emission intensities per square meter are multiplied with the construction activity per year, as obtained from statistical data [21] for the reference year, to calculate the estimated GHG emissions from: i) construction of new buildings; ii) renovation of existing buildings [22] and iii) energy consumption for operation of the building stock.

3. Results

3.1. Energy-related targets

The information for the Austrian population [23], GDP [24], energy and GHG [25] for the years 1990 to 2016 as found in the literature are applied to the Kaya equation. The results obtained are shown in Figure 2 and can be grouped in the two periods: 1) between 1990-2016, and 2) after 2016. The graphics
in Figure 2 are built from three different types of information. The blue lines present the period 1990-
2016 are built from the data found in literature. The red (dotted) lines present the future trend of the
graphics. These graphs are built following the data trend from the last five years (2013-2018). The
green line in the last graphic is built based on the constraints present the smooth transition of the impact
reduction according to the Paris agreement.

The data for the first period (1990-2016) shows the continued increase in population and GDP, leading to an improvement of production per capita. As explained above the trend of this index should be maintained even for the future. Even though the population and the GDP have an increasing trend, the energy consumption had the same trend until 2013. From 2013 the energy consumption trend is stabilized and we can even observe a slight decrease. This is probably due to the development of goods and services with lower energy consumption (i.e. cars with lower diesel consumption, appliances with energy efficiency label A+, etc.), and also a growing awareness in the population about the problem of climate change, which was translated into action by the reduction of their energy consumption. In the context of the GHG emissions data, these had increased steadily until 2005, but after this date the global GHG emissions have shown a reduction trend.

Both the indices for primary energy prices and for carbon content have had a reduced trend in these more recent years, but additional reductions are still required for reaching targets set in the Paris agreement. According to the Paris agreement the GHG emissions in 2050 should be 1 t CO\textsubscript{2}-eq/capita yr. Taking population growth and energy requirements into consideration, the impacts of the energy mix in 2050 should be reduced to 8.4 g CO\textsubscript{2}-eq/MJ or 30 g CO\textsubscript{2}-eq/kWh. Comparing this value with the carbon content of different energy supplier systems given in the Ecoinvent database [26], we observed as of today that only hydro generated electricity, wind power and nuclear plants can currently reach this target. Since nuclear energy production is not supported then without reducing the quantity of primary energy consumption the sole solution to the targets set in the Paris agreement would be to use only hydro and wind generated electricity. Furthermore, while not fulfilling the target value today, the photovoltaic (PV) energy provision is expected to further decrease its emission intensity with the expected changes to the overall energy mix, and might hence meet the target in the future.

Figure 2. Application of Kaya equation for the Austrian context.
This emission target is useful for the government and energy production industries while the target is also useful for building stakeholders by providing them with an indication of the materials and elements that they should consider for use during the development of a project. In terms of the embodied impacts, only materials and elements produced using hydro and wind generated energy should be used in the building itself and also used on completion for the energy supply to the residents in the new building. The target derived from the application of the Kaya equation, however, is not in line with the reference unit used for the evaluation of the environmental impacts of buildings. For this reason, a more pertinent target useful for indicating to designers the objective that the building must reach by 2050, is that of square meters per year. The GHG emissions for different sectors are shown in Figure 3. Based on these results we can state that buildings are responsible for almost 38 % of all the impacts. The embodied impacts of materials and elements account for around 13 % of this, while the operational phase impacts from the completed building account for around 23 %.

The 2050 GHG targets are evaluated by considering the population increment trend; the percentage share of the carbon budget is maintained at the same level as the current one. But in order to achieve a more reliable targets definition the building targets (renovation, new and existing) should be evaluated and this should also be done with the bottom-up approach.

![Figure 3. Greenhouse gases emissions of Austrian sectors [25] and 2050 targets.](image)

3.2. Building-related targets

Figure 4 presents the hybrid top-down-bottom-up approach for establishing GHG emission targets for building construction and renovation. Based on the I/O data [14] we can identify the economic flows related to the construction of buildings to be € 19257 million. The economic data are then used to calculate the emission intensity per area of buildings. The territorial GHG emissions of building construction in Austria [15] are converted to a consumption-based perspective (multiplied by factor of 5.72 [16]) which results in 5778 kt CO₂eq/yr. On combining these data, we obtain an emission intensity for buildings in the Austrian construction sector of 300 kg CO₂eq/€. Using statistical data on construction cost per square meter [26], we can translate this into an emission intensity on building level: 493 kgCO₂eq/m². Validating this figure with values obtained from detailed LCA studies [18], [19], [20], we can not only confirm its magnitude, but we also find surprisingly close values obtained by both the top-down and the bottom-up assessments. In order to conduct a detailed analysis on the GHG emissions related to new construction (the value obtained thus far through the top-down approach) as well as for renovation and existing buildings, we continue by using the data from [19], [20], [22], which showed...
the upfront, embodied GHG emissions for new buildings to be 442 kg CO₂eq/m² and for major renovation 285 kg CO₂eq/m². According to the same source 35 kg CO₂eq/m² are assumed for the operation of existing buildings. The m² values for new and existing buildings and renovation only refer to residential buildings.

Based on statistical information on the construction activity for new buildings and major renovations we can identify construction activity in 2015 as having totalled approx. 9186600 m² of new buildings and 5351109 m² of major renovations. The existing building stock in 2015 amounted to a total of 376824645 m². Multiplying the floor areas of these buildings with the GHG emission values per square meter obtained, we get an insight into the 2015 values in terms of the embodied GHG emissions related to i) production of new buildings (4.06 Mt CO₂eq), and ii) major renovation of existing buildings (1.50 Mt CO₂eq), together with iii) energy-related GHG emissions for the operation of the existing building stock (13.2 Mt CO₂eq). Based in these values, altogether the building environmental impacts in 2016 present 18.76 Mt CO₂eq. This value leaves us with a gap of 1.5 Mt CO₂eq when compared with the value given in [25]. This is probably due to system boundary differences, and will require further detailed analysis in the future. Applying the hypothesis that the rate of renovation will be maintained and that newly built areas will remain the same in each subsequent year, then by 2050 the building stock will consist of 192.6 million m³ of renovated buildings, 184.2 million m³ that have not been renovated and an additional 330.7 million m³ that it is assumed will have been built during 2016-2050. The annual energy consumption of Austrian buildings is some 200 kWh/yr, while renovated and new buildings consume on average 60 kWh/yr. On the assumption that the Austrian electricity mix will be reduced to the targeted 30 g CO₂/kWh by 2050, then the building stock will emit around 2.04 million t CO₂eq/yr in 2050. This first calculation indicates that the targets for GHG of the operational which should be 1.8 kg CO₂/m³ yr. Taking into account the reduction factor of 6, by which actual building emissions must be reduced by 2050, then the total GHG emission from renovation and new building construction will be limited to 1.1 million t CO₂eq. On the assumption that the rate of renovation and new construction in 2050 will be the same as in 2016 then the targets for new construction are 85 kg CO₂eq/m² and for renovation 55 kg CO₂eq/m².

Taking a reference service life of 50 years into account and also the assumption that each building will be renovated twice during this period, the GHG targets for new construction are 4 kg CO₂eq/m² yr for the embodied and 1.8kg CO₂eq/m² yr for the operational phase. The GHG targets for the renovation will be 1.1 kg CO₂/m² yr.

**Figure 4:** Environmental impacts of buildings (top-down-bottom-up approach).

4. Discussion and conclusion
In this exploratory study we presented different ways for calculating current GHG emissions related to building construction and operation and also explored the potential for setting emission reduction targets on macro-level. The application of the Kaya-equation to define target values is considered mostly useful for government and as an abstract target for energy-related industries. The results show that the emission intensity of the Austrian energy mix is moving in the right direction, but not yet fast enough. By maintaining ‘business as usual’, Austria would arrive at an emission intensity in 2050, which would be roughly three times higher than the Paris Agreement’s target. This means that we must put considerable effort into further reducing the CO₂ eq-intensity of energy production and furthermore place a strong focus on low-emission technologies such as hydro and wind power to avoid reducing the GDP/capita or the energy/GDP. The calculation of GHG emissions on the building level was conducted using a hybrid method top-bottom-down-up approach. The focus of the study, the GHG emissions on building level, are calculated with the help of economic data for the construction sector. Thus far, the model was shown to be reasonably accurate for estimating the GHG emissions embodied in the construction of new buildings and major renovations. Furthermore, the energy-related GHG emissions related to operation of the existing building stock could be calculated using this approach. Finally, GHG targets for renovation and new construction are proposed based on several hypotheses. These can be used as a basis for defining the GHG targets, but they still require further development.

As a next step, the values obtained from both approaches will be combined to assess different scenarios for incrementally reducing GHG emissions related to construction and operation of buildings in Austria. The target of reducing building-related GHG emissions to net-zero by 2050 – or 2040, as outlined in the recently published program of the new Austrian government – requires thorough emission reduction targets to consider the investments needed for improving energy-efficiency of the existing building stock as well as the need for GHG emission investments in new buildings. Enforcing the low emission target for energy production derived from the top-down approach will not only help to reduce both embodied and operational emissions of buildings, but the decarbonisation of the whole economy.

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