Carbon Dioxide Emissions from Operation of Czech Building Stock and Potential for Their Reduction

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Abstract. The paper presents a study that modelled potential for savings of CO$_2$ emissions from the Czech building stock in ten scenarios. Input data in scenarios were taken from analyses of energy saving potentials of Czech building stock from NGO Chance for Buildings. The results provided values of modelled CO$_2$ emissions of the Czech building stock for each year in period 2016–2075. Cumulative data for periods 2015–2030, 2031–2050 and 2051–2075 were compared to the proposed national carbon budget coming from the UN Emissions Gap Report. The study estimated production of CO$_2$ from Czech building stock in 2016 at 44.57 Mt, which represented share of 43% in the total national CO$_2$ production. The scenario S5 in RCP 8.5 showed potential for annual reduction of CO$_2$ emissions from current 44.57 to 15.29 Mt in 2075 (reduction by 66%). The needed reduction of CO$_2$ emissions calculated from the global carbon budget for climatic goal 2$^\circ$ is much larger. It is very likely, that even the most stringent of the proposed energy saving scenarios would not be sufficient for the Czech building stock to comply with the Paris Agreement.

1. Introduction

1.1. Climate change as a global challenge
Climate change is one of the major challenges of our time. It is forecasted to cause a significant impacts on ecosystems and lives of societies [1]. The majority of the scientific community came to the conclusion that the uptake of the climate change is strongly related to manmade emissions of greenhouse gases – the last report of the Intergovernmental Panel on Climate Change concluded that “It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.” [2] Consequently, it means that the humanity is also empowered to make change, to limit its undesirable behavior and thus reduce its impact on the global environment.

The international community strives for finding ways to significantly reduce the emissions of greenhouse gases [3–5] in order to prevent the failure of the climatic systems after reaching their limit of carrying capacity [6–8]. The recent studies of needed cuts in greenhouse gases propose quite drastic interventions across all sectors [9].

1.2. Contribution of building sector to climate change
A significant contributor to the production of greenhouse gases is the construction sector. Especially buildings are responsible for approximately 40% of energy consumption and 36% of CO$_2$ emissions in the EU [10]. At the same moment, the building sector has the highest potential for delivering...
significant and cost-effective MEGHG reductions [11]. The European Union's Roadmap for Moving to a Competitive Low Carbon Economy in 2050 ('carbon roadmap') states that in comparison to 1990, CO\textsubscript{2} emissions of the building sector should be reduced by 90% by 2050 [12]. Some European countries have made their studies on potential of their building stocks to become in line with the climatic requirements (for instance [13]), such detailed research tasks still waits to be made for the building stock of Czechia.

1.3. Objectives
The motivation for the presented work was to enable a national discussion on possible contribution of energy savings at building stock level to national climate change mitigation efforts. The primary objective was to take national building stock energy saving scenarios proposed by Chance for Buildings and provide a gross estimation of the theoretical CO\textsubscript{2} savings resulting from them. The secondary objective was to put the resulting CO\textsubscript{2} reduction potentials in perspective with the carbon budget allocated to Czechia on per capita basis from the Emissions Gap Report [8].

2. Materials and methods
The methods summarization of scenarios of energy savings in Czech building stock until 2075 and adaptation of datasets received from Chance for Buildings; quantification of energy consumption in buildings in each year towards 2075; setting scenarios of future energy proportion of energy sources for operation of Czech building stock; quantification of emission factors for calculations of saved CO\textsubscript{2} emissions from the amount of saved energy; quantification of CO\textsubscript{2} savings in various scenarios for selected time periods; and expression of results in the context of total national amount of CO\textsubscript{2} emissions and in relation to the carbon budget.

2.1. Summarization of scenarios of energy savings in Czech building stock until 2075
The calculations of the presented potentials for CO\textsubscript{2} savings were based upon datasets that originated from the series of public studies provided by Chance for Buildings: Investigation of the Czech Residential Building Stock and Potential for Savings [14], Investigation of the Czech Non-Residential Building Stock and Potential for Savings [15] and Strategy for Retrofitting of Buildings [16]. These reports are based on energy simulations of Czech building stock in various scenarios.

The energy simulations of existing residential building stock [14] used a stochastic model that calculated energy demand for heating of set of 1,000 buildings divided into 78 categories by typology, size and age based upon statistical data. The model was calibrated according to available statistical data on final energy consumption of building stock. Statistical data from various sources provided input for estimations of proportion of residential building stock that already undergo energy retrofitting, that was reckoned as 35%. For buildings statistically retrofitted in low-energy standard and without retrofitting were simulated construction interventions leading to reduction of energy demand for heating and the improved efficiency of heating due to replacement of heat sources. The potential savings on preparation of domestic hot water and on lighting were simulated separately.

The energy modelling of existing non-residential building stock [15] was based on a sample of 100 non-residential buildings with detailed energy simulations and an additional sample of 20 existing buildings with detailed data from real energy consumptions. The building typologies included in the study contained office buildings, administrative buildings, commercial buildings, educational buildings, cultural buildings, hotels, restaurants, medical facilities, sport facilities, storage buildings and also buildings with mixed use. The simulated energy consumptions were extrapolated to whole Czech non-residential building stock using national statistical data on proportions of each type of buildings in the whole building stock. For the modelled buildings that were in lower than current energy standards were simulated energy-saving interventions that spanned from partial improvement of thermal characteristics of building envelopes to complex retrofitting actions that included replacements of heat sources and installations of mechanical ventilation systems with heat recovery.
and new renewable energy systems. There were made also estimations of proportions of heat source types in existing buildings.

The combination of models of existing residential and non-residential buildings and their potential energy improvements in various levels of interventions were used to simulate the Czech building stock in the five retrofitting scenarios [16]:

- S1: Base scenario (business as usual – no state interventions, 1% shallow or medium retrofitting each year, starting 2025);
- S2: Fast but shallow retrofitting (3% shallow or medium retrofitting each year, starting from 2025);
- S3: Slow but deep retrofitting (1.5% deeply retrofitted each year, starting from 2025);
- S4: Fast deep retrofitting (3% deeply retrofitted each year, starting from 2025);
- S5: Immediate deep retrofitting (3% deeply retrofitted each year, starting immediately).

In the context of the study shallow retrofitting means that the building envelope is upgraded to required U-values given by standard ČSN 73 0540; moderate to the recommended U-values; and deep to the values prescribed for passive houses and the building is equipped with mechanical ventilation with heat recovery.

In addition, to consider the future effects of climate change, each of the retrofitting scenarios was modelled twice – in the boundary conditions of IPCC’s Representative Concentration Pathways (hereafter abbreviated as RCP, definitions in [17]) 4.5 and RCP 8.5. The difference in boundary conditions lead to variations in energy demand for heating and for cooling and in proportion of installed external shading devices or cooling systems in simulated building stock [18].

The resulting datasets [final version of simulations obtained from Czech NGO Chance for Buildings, data generated 16.11.2016], included for residential and non-residential building stock quantitative description of each scenario in and predicted amount of final yearly energy consumption for heating and cooling per energy sources for the period between 2016 and 2100. For illustration, the Table 1 shows just selected input data for 2016, 2020, 2030, 2050 and 2075 for RCP 4.5. More details and charts are available in the report [16].

| Scenario     | 2016   | 2020   | 2030   | 2050   | 2075   |
|--------------|--------|--------|--------|--------|--------|
| S1: Base     | 96,904 | 96,130 | 90,871 | 79,875 | 66,412 |
| S2: Fast shallow | 96,904 | 95,089 | 80,592 | 62,725 | 58,211 |
| S3: Slow deep | 96,904 | 95,618 | 85,687 | 65,332 | 51,115 |
| S4: Fast deep | 96,904 | 94,800 | 76,286 | 52,566 | 49,460 |
| S5: Immediate deep | 96,904 | 90,792 | 69,735 | 50,362 | 47,596 |

### 2.2. Scenarios of future proportion of energy sources of Czech building stock

The initial proportion of energy sources came from reports [14,15]. In cooperation with Chance for Buildings we decided to estimate proportions of energy sources for each scenario in 2060 and then use a linear interpolation for the period between current state and 2060, obtaining discrete values for each year per sources. Given the uncertainties, we did not calculate with the figures beyond 2060, so the proportion after 2060 remains constant. The considered proportions of energy sources are summarized in Tables 2 and 3.
Table 2. Considered shares of energy sources for residential buildings in the five scenarios.

| Energy source            | 2016       | 2060       |
|--------------------------|------------|------------|
|                          | S1 (as 2016)| S2, S3 | S4, S5 |
| Fuel oil                 | 0.07%      | 0%        | 0%     |
| Natural gas              | 33.18%     | 36.20%    | 24.90% |
| Coal                     | 10.54%     | 2.70%     | 0%     |
| Biomass                  | 18.34%     | 18.60%    | 17.60% |
| Local district heating   | 17.46%     | 24.60%    | 24.00% |
| Electricity              | 20.28%     | 7.00%     | 6.30%  |
| Other (incl. solar heat) | 0.13%      | 10.90%    | 27.10% |

Table 3. Considered proportions of energy sources for non-residential buildings in the five scenarios.

| Energy source            | 2016       | 2060       |
|--------------------------|------------|------------|
|                          | S1, S2 (as 2016)| S3 , S4, S5 |
| Natural gas              | 27.1%      | 27.0%      |
| Coal                     | 0.2%       | 0.2%       |
| Natural gas cogeneration | 1.5%       | 1.6%       |
| Local district heating   | 28.7%      | 31.3%      |
| Electricity              | 42.1%      | 34.9%      |
| Other (incl. solar heat) | 0.4%       | 4.8%       |

2.3. Calculation of CO₂ savings in various scenarios for selected time periods
In the study were taken emission factors from national Decree No. 480/2012 that is commonly used for calculations in energy audits. It prescribes the following figures (in tonnes CO₂/MWh of calorific value): brown coal 0.36; black coal 0.33; light fuel oil: 0.27; fuel oil 0.27; light fuel oil 0.26; natural gas 0.20; biomass 0; electricity 1.17. In fuel oil without distinction between light and heavy was used the mean value 0.265 and similarly for generic coal value 0.345. In local district heating was used very rough generalization to 0.2 and in gas co-generation unit to 0.1 tonnes CO₂/MWh. Being aware of the imperfection, for solar energy and for heat pumps the was taken 0. Czechia does not have available any relevant source that would provide prediction of the future energy mixes in the national energy grid. To forestall speculations, the calculations were made with the current figures. The amounts of CO₂ for each scenario were calculated for each year from the final energy consumptions per energy sources, each multiplied by the respective emission factors.

2.4. Czech carbon budget
The carbon budget calculations in Emissions Gap Report 2016 [8] provide the cumulative amounts of CO₂ that can be released into the atmosphere for the global temperature target 2.0 °C with probability >66%. The global carbon budgets for periods 2015–2020 (533 Gt CO₂); 2031–2050 (362 Gt CO₂); and 2051–2075 (70 Gt CO₂) were recounted to respective national carbon budgets, resulting in 762; 517; and 100 Mt CO₂. The recount was based on allocation per population according to World Population Data Sheet 2016 [19].

2.5. Base Czech CO₂ emissions
As the basis for comparison of the results was taken figure on the national CO₂ emissions from the National Greenhouse Gas Inventory of the Czech Republic [20]. The latest data was for 2015 and the value was 103,769.75 kt CO₂ without net CO₂ from LULUCF (Tab ES 1).
3. Results

3.1. Modelled CO₂ emissions of Czech building stock between 2016 and 2075 in scenarios

The calculated CO₂ emissions from operation of the Czech building stock in 2016 were 44.57 Mt, which represented approximately 43% of the national total CO₂ emissions (in relation to 103.77 Mt in 2015 [20]). The residential sector in 2016 produced 23.28 Mt CO₂ (22% of the national total CO₂ emissions) and non-residential sector 21.29 Mt CO₂ (21% of the national total CO₂ emissions). According to the most optimistic simulated scenario S5 and RCP 8.5, there is potential to reduce the amount from current 44.57 to 17.90 in 2050 and further to 15.29 Mt in 2075.

The resulting CO₂ emissions are summarized in Table 4 and for data for RCP 8.5 are also presented in Figure 1.

Table 4. The resulting simulated CO₂ emissions of Czech building stock in Mt CO₂, first part of data for period 2016–2030 (research provided calculations for period 2016–2075, but space in this paper is too limited to include all datasets).

| Year | RCP 4.5 | RCP 8.5 |
|------|---------|---------|
|      | S1      | S2      | S3      | S4      | S5      | S1      | S2      | S3      | S4      | S5      |
| 2016 | 44.57   | 44.57   | 44.57   | 44.57   | 44.54   | 44.58   | 44.58   | 44.54   | 44.58   | 44.58   |
| 2017 | 44.48   | 44.21   | 44.17   | 44.08   | 43.67   | 44.44   | 44.16   | 44.13   | 44.04   | 43.62   |
| 2018 | 44.41   | 43.81   | 43.76   | 43.55   | 42.70   | 44.35   | 43.76   | 43.71   | 43.49   | 42.65   |
| 2019 | 44.33   | 43.37   | 43.33   | 42.95   | 41.67   | 44.26   | 43.30   | 43.27   | 42.88   | 41.60   |
| 2020 | 44.25   | 42.88   | 42.88   | 42.29   | 40.56   | 44.17   | 42.80   | 42.80   | 42.21   | 40.48   |
| 2021 | 44.04   | 42.21   | 42.27   | 41.43   | 39.34   | 43.94   | 42.12   | 42.18   | 41.34   | 39.25   |
| 2022 | 43.82   | 41.48   | 41.64   | 40.50   | 38.13   | 43.71   | 41.38   | 41.53   | 40.40   | 38.03   |
| 2023 | 43.60   | 40.71   | 40.98   | 39.50   | 36.94   | 43.48   | 40.60   | 40.87   | 39.39   | 36.83   |
| 2024 | 43.38   | 39.88   | 40.29   | 38.42   | 35.77   | 43.25   | 39.76   | 40.17   | 38.30   | 35.65   |
| 2025 | 43.15   | 39.00   | 39.57   | 37.25   | 34.61   | 43.02   | 38.87   | 39.45   | 37.13   | 34.48   |
| 2026 | 42.92   | 38.12   | 38.87   | 36.10   | 33.47   | 42.78   | 37.98   | 38.73   | 35.97   | 33.33   |
| 2027 | 42.69   | 37.25   | 38.17   | 34.96   | 32.34   | 42.55   | 37.10   | 38.03   | 34.83   | 32.20   |
| 2028 | 42.46   | 36.38   | 37.47   | 33.84   | 31.23   | 42.31   | 36.23   | 37.33   | 33.69   | 31.08   |
| 2029 | 42.22   | 35.52   | 36.78   | 32.72   | 30.13   | 42.06   | 35.37   | 36.64   | 32.57   | 29.98   |
| 2030 | 41.98   | 34.67   | 36.10   | 31.62   | 29.05   | 41.82   | 34.51   | 35.95   | 31.46   | 28.89   |

Figure 1. Calculated CO₂ emissions of Czech building stock in five scenarios for RCP 8.5 [in Mt].
3.2. Evaluation of the simulated scenarios from the perspective of Emissions Gap Report

To estimate climate change mitigation goals for the building sector, it was considered, that the share of 43% from the previous session that buildings have on the total national CO₂ emissions will be kept – when national emissions goal for 2015–2030 form the Table 4 was 762 Mt, then the limit for buildings stock 43% of that figure (328 Mt CO₂) was considered. Similarly, for 2031–2050 that limit was 223 and for 2051–2075 44 Mt CO₂ (all cumulatively on the respective periods).

The comparison of the results of modelling variants with the emission goals is made in Table 5. As the simulations started with 2016, to get sum for period 2015-2025, figures for 2016 were counted twice to get 2015 proxy.

Despite the substantial reductions of carbon emissions modelled in the scenarios, from Table 5 is obvious, that all scenarios significantly exceed the theoretical building stock carbon budgets in all given period.

Table 5. Comparison of the modelling results for RCP 4.5 and RCP 8.5 in five scenarios with the emission goals for 2 °C target, >66% probability. Building stock carbon budget calculated proportionally as 43 % of the national carbon budget. In Mt CO₂.

| Period     | Results for RCP 4.5 | Results for RCP 8.5 | Czech building stock carbon budget (reference) |
|------------|---------------------|---------------------|-----------------------------------------------|
|            | S1  | S2  | S3  | S4  | S5  | S1  | S2  | S3  | S4  | S5  |                   |
| 2015–2030  | 697 | 649 | 655 | 628 | 599 | 695 | 647 | 654 | 627 | 597 | 328               |
| 2031–2050  | 789 | 567 | 590 | 468 | 437 | 787 | 562 | 587 | 463 | 431 | 223               |
| 2051–2075  | 852 | 563 | 493 | 422 | 410 | 856 | 554 | 486 | 413 | 400 | 43                |

4. Discussion

4.1. Limitations of the study

The present study has several categories of sources of uncertainties: Input data for energy saving potentials in five scenarios; future technology development; uncertainties about the scenarios of future share of energy sources for building operation; and emission factors.

The input data provided by Chance for Buildings were calibrated and thoroughly verified as described in the above-mentioned studies. Nevertheless, the basis of the scenarios’ development was in predicting possible futures from the perspective of the actual knowledge in 2016.

It is possible and desirable that technical development brings significant ecological improvement of energy sources, which would lead to reduction of future significance of the building sector in the total national CO₂ emissions.

Similarly, with the predictions of future share of energy sources in buildings. The scenarios provided in the study were rather conservative, but there is hope for higher share of solar thermal, building-integrated photovoltaics and heat pumps. Faster increase of use these technologies in buildings would lead to further reduction of CO₂ emissions.

The present emission factors for the energy sources can vary around the considered values. The used figures given by national legislation for making energy audits in Czechia. There were made gross simplifications in the emission factor of the local district heating, where value typical for natural gas-based system was taken. The real values can vary significantly by the technical parameters of the particular district heating system and also over the year. Real emission factor for electricity would be actually lower than what was considered based on the legislation. Another simplification was applied to solar energy, where emission factor was taken as zero, but in reality, there is used at least auxiliary electricity and there is certain energy embodied in the whole renewable energy system. Similar situation is with the heat pumps. As the combined share of renewable energy systems was rather low for the current state as well as in the future predictions, the error in doing so is not high. But for possible future more precise modelling these factors shall be set more precisely.
Czechia is in the process of negotiating its energy and emissions targets with the EU, and at the time of writing of this paper the conclusion is not available and the expectations of future development of the Czech energy grid and energy policy as a whole are unclear. This problem could have been overcome by modelling of future energy mixes in variants, but this was not possible due to limited time for the study. Therefore, the calculations were made with the existing emission factors, which are very much on the safe side (as there can be expected reduction of this value as result of increasing share of renewables and natural gas cogeneration) knowing, that the future amounts of CO\textsubscript{2} from energy consumption of buildings would likely be lower.

In addition to the uncertainties, there was made one aware neglection – this study works only with operational energy, but there are completely neglected amounts of CO\textsubscript{2} embodied in building materials and products which would be released by their production, transportation, installation, maintenance and the end of their life cycle. This is task for future work, which – knowing the modelled scenarios of energy efficiency interventions – is workable, but it was out of available time capacity for this project.

4.2. Conclusions

The present paper describes calculations of CO\textsubscript{2} emissions of the Czech building stock in five scenarios for two RCPs that were based on analysis of energy saving potential in Czech buildings provided by Chance for Buildings. The study showed that the estimated production of CO\textsubscript{2} from operation of the whole Czech building stock in 2016 was 44.57 Mt, which represented share of approximately 43% in the total national CO\textsubscript{2} production (compared to 2015 national data). The residential sector in 2016 produced 23.28 Mt CO\textsubscript{2} (22% of the national total CO\textsubscript{2} emissions) and non-residential sector 21.29 Mt CO\textsubscript{2} (21% of the national total CO\textsubscript{2} emissions).

The actual Czech building stock has a potential to significantly reduce its CO\textsubscript{2} emissions – in the scenario S\textsubscript{5} and in RCP 8.5 there is potential for annual reduction of CO\textsubscript{2} emissions from current 44.57 to 15.29 Mt in 2075 (reduction by 66%). To put it in perspective, such saving of 29.28 Mt CO\textsubscript{2} is equal to approximately 28 % of total national CO\textsubscript{2} emissions in 2015. It means that improving energy efficiency of the Czech building stock can play a pivotal role in the national climate change mitigation plans.

On the other hand, the real needed reduction of CO\textsubscript{2} emissions calculated from the Emissions Gap Report is much greater: in the most favourable scenario S\textsubscript{5} for RCP 8.5 the cumulative CO\textsubscript{2} emissions from the Czech building stock for the period 2015–2030 would be 597 Mt, but for the 2 °C climatic target value lower than 335 Mt would be needed instead (597 Mt would represent 78% of the total 762 Mt budget available for all sectors in 2015–2030). That means, that it is very likely, that even the most stringent of the proposed energy saving scenarios would not be sufficient for the Czech building stock to comply with the Paris Agreement (when using per capita allocation of the climatic commitments and keeping the actual proportion of the building sector in the total national emissions). For compliance with the global carbon budget it would be needed that Czech buildings reduce their energy demand much more than projected and switch to low-emission sources of energy (including electricity) at much higher pace than forecasted.

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