Estimating CO2 emissions related to residential electricity consumption – the importance of using load and CO2-intensity data with a high temporal resolution

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Overview

The reduction of CO2 emissions related to the energy use of buildings is one of the key challenges within the energy transition. We focus in particular on the electricity use of residential buildings, using measured consumption profiles with a high temporal resolution. It is important to consider the timing of residential electricity consumption because the CO2-intensity of electricity on the grid is not constant over time. Depending on which generators are producing electricity at each moment in time, the CO2-intensity in a particular region can fluctuate considerably. It is therefore beneficial from a CO2 perspective to move the demand for grid electricity towards times when the CO2-intensity is low and vice versa.

The most straight-forward way to estimate the CO2 emissions related to the residential consumption of grid electricity is to multiply the total consumption over the estimation period (e.g. a year) with the average CO2-intensity of grid electricity in the same period. This can however result in a bad estimate, because grid electricity consumption may be heavily concentrated during hours of high or low CO2 intensity. Increasing the temporal resolution of both the consumption and the CO2 intensity may therefore provide a more accurate result. We estimate the difference between both calculation methods for a large set of residential buildings, to assess the value of using the more accurate method.

Methods

A dataset with smart meter readings from residential buildings was acquired from a Belgian distribution system operator, which includes a variety of different consumption profiles. We estimate the CO2 emissions related to each of these profiles by combining them with a profile for the CO2-intensity of grid electricity with the same temporal resolution. These CO2-intensity profiles are generated by simulating national power systems. This is done with PLEXOS [1], a sophisticated power systems modelling tool that uses mixed integer optimisation techniques to determine the least cost unit commitment and dispatch solution to meet demand while respecting generator techno-economic constraints. Several countries are simulated including Belgium, The Netherlands and France. For each residential consumption profile, we estimate the corresponding amount of CO2 in each country (i.e. each time assuming that the building is located in each particular country). We multiply the amount of grid electricity consumption at each moment in time (in MWh) with the corresponding CO2-intensity (in kg/MWh).

Results

Our results focus on the difference between the outcomes of both estimation methods. The straight-forward method on one hand and the more accurate method using high temporal resolutions on the other. A difference in outcomes indicates the added value of using high temporal resolutions. Preliminary results show that for each residential consumption profile, the corresponding amount of CO2 emissions is 3-15% higher when estimated with the more accurate method. If we use the CO2-intensity profile generated for the French electricity system, the emissions are 8- 37% higher. Using the profiles generated for The Netherlands, this becomes 0% to -1%.

We can explain these differences by looking at the technology mix used for generating electricity in each country. While the CO2-intensity of power on the grid fluctuates very heavily in nuclear-heavy countries like Belgium and France, it fluctuates much less in The Netherlands. Relatively speaking, the difference between low and high CO2-intensities are much larger in Belgium and France than they are in The Netherlands. The fact that the CO2-intensity fluctuates less in The Netherlands results in a lower impact of the consumption profile on the corresponding CO2 emissions. This implies that a reasonable estimate can be made using the straightforward method in some countries, but not in others. This depends on the size of the relative fluctuations of the CO2-intensity caused by the electricity generation mix in each country.

Conclusions

The amount of variable renewable electricity generation is increasing in various national electricity systems. From a CO2-perspective, it is therefore increasingly appealing to incentivize well-timed residential electricity consumption. Moving the residential demand for grid electricity towards times when the CO2-intensity is low and vice versa.

For a large dataset of residential electricity consumption profiles, we estimate the corresponding amount of CO2 emissions by taking into account the temporal fluctuations of the CO2-intensity of grid electricity. We found that there are large differences in outcomes for different simulated countries, including Belgium, France and The Netherlands. While the CO2-intensity fluctuates more in nuclear-heavy countries, it does much less so in others. This implies that the case for shifting residential electricity demand towards moments with a lower CO2-intensity is weaker in the former countries than in the latter.

References

[1] Energy Exemplar, PLEXOS for Power Systems. www.energyexemplar.com