Primary energy factor values for the current and future European electricity system

A briefing on intermediate results

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In Europe, the energy performance of buildings is often expressed in terms of primary energy use (PE). To calculate the amount of primary energy associated with the electricity consumption of the building, a primary energy factor (PEF) is used, expressed in kWh_p/kWh_e . This conversion factor considers the consumption of primary energy in the process of producing electricity and transporting it to the end user. For example, a PEF value of 2 would imply that each unit of electricity consumed by the building, translates into two units of primary energy consumption.

A PEF is itself calculated by considering how electricity is produced. Each fuel-consuming electricity generation technology (nuclear, coal, gas, oil, biomass, etc.) has a specific thermal efficiency, dictating how many units of primary energy are consumed (in the form of fuel), to generate a unit of electricity. This thermal efficiency can be expressed as a technology-specific primary energy factor (PEF_T). For example, nuclear power can be assumed to have a PEF_T of 3.3, since it is conventionally associated with a thermal efficiency around 33%. Other electricity generation technologies, like various forms of hydro, wind and solar power, are typically assumed to have a conversion efficiency of 100%, in the sense that 'no energy is lost' when they produce electricity. This translates into a PEF_T of 1 kWh_p/kWh_e. Alternatively, the PEF_T of non-fuel-consuming renewables can be assumed to be 0, in the sense that 'no primary energy is consumed' in the traditional sense, when they produce electricity.

In its most basic form, a PEF is calculated as a weighted average. The electricity production by each technology is multiplied by its respective PEF_T , to subsequently take the sum for all technologies (in kWh_p) and divide this by the total electricity production (in kWh_e). It is therefore highly comparable with a CO₂-intensity (expressed in g_{CO2}/kWh_e), which reflects the amount of CO₂ emissions that should be associated with the consumption of a unit of electricity. To take into account energy losses in the process of transporting electricity from generators to end-users (across transmission and distribution networks), this weighted average can be multiplied by an additional factor. For example 1.1, if the aggregated grid losses of are assumed to be 10%.

The PEF takes a central role in the European policy framework with respect to building energy performance assessment. A European PEF value of 2.5 was introduced in the Energy Services Directive 2006/32/EC, on the basis of a very high-level estimation that the average conversion efficiency of generators in the European electricity system is 40%. Henceforth, this value has been applicable in the various iterations of the Energy Performance of Buildings Directive (EPBD) in 2010 and 2018. Member

States are however allowed to calculate and apply their own national PEF values, although a standardized methodology do so has so far been missing¹.

PEF values are the subject of considerable controversy, because the relative attractiveness of various building energy technologies and measures can be co-determined by them. For example, the calculated PE of a heat pump is largely dependent on the assumed PEF, determining its comparative attractiveness to a traditional gas condensing boiler. Similarly, the degree to which the PE of a building with electrical resistance heating is reduced by insulation measures, is also partially driven by the assumed PEF. An accurate calculation of PEF values, both at the European and the national level, is therefore desirable.

The European Commission recognized the need to reevaluate the conventional European PEF value of 2.5, when it contracted a study doing so in 2016². However, while the study concluded that a value of 2.5 is no longer adequate and should be revised, it did not provide a high-quality database of calculated PEF values for the European and national levels. As the study explains, the use of an advanced power system simulation tool is required to generate this type of database.

Reflecting on the need for academic researchers to obtain and use such a high quality database of PEF values, we have simulated the current and future European electricity system in order to calculate these values and make them available to those who need them. The simulation tool used for this purpose is PLEXOS[®], developed by Energy Exemplar³.

To feed our model of the European electricity system in terms of the various necessary input assumptions (electricity demands, generator capacities, generator conversion efficiencies, fuel prices, CO₂ prices, interconnection capacities between European countries, etc.), we largely replicate externally developed scenarios. Namely, the scenarios proposed in the Ten Year Network Development Plan (TYNDP) 2018 report by the European Network of Transmission System Operators (ENTSO-E)^{4,5}. To our best knowledge, these are the most thoroughly developed and well-founded scenarios for the European electricity system. They are the result of a broad stakeholder consultation with representatives from across Europe, aggregated with the combined expertise of all European TSO's as well as the expertise of ENTSO-E itself.

The TYNDP 2018 report is associated with a website on which most of the input assumptions are made public⁶. A 'best estimate' scenario was made for the year 2020⁷, as well as three scenarios for the year 2030 and three scenarios for the year 2040. The future scenarios reflect the uncertainty about various trends. For example with respect to electricity demand and the speed at which new renewable

¹ The European Committee for Standardization (CEN) is currently in the process of developing a standardized methodology for the calculation of a (national) PEF.

 ² Fraunhofer ISI - 2016 - Evaluation of primary energy factor calculation options for electricity. <u>https://ec.europa.eu/energy/sites/ener/files/documents/final report pef eed.pdf</u>
³ www.energyexemplar.com

www.energyexemplar.com

⁴ <u>https://tyndp.entsoe.eu/tyndp2018/scenario-report/</u>

⁵ A new TYNDP report is expected to be released sometime in the year 2020, with a refreshed set of future scenarios. If and when the input data used for the new report is made public, our simulations can be updated to reflect these new scenarios. However, since the new scenarios are expected to be incremental updates to the 2018 scenarios, we do not expect any major changes in the PEF values we project for the years 2030 or 2040. ⁶ <u>https://tyndp.entsoe.eu/tyndp2018/</u>

⁷ For our simulation of the (current) year 2020, we choose to use the input data from the '2020 best estimate' scenario of the 2018 report, instead of using the most recent available 'actual' data for the year 2020. This is preferable because the report's data for 2020 is much more complete (e.g. in terms of assumptions about power plant technical characteristics, load profiles, and so forth) than the available data about the actual current system.

capacities will be added in the various European countries. For a full description of the storylines, we refer to the TYNDP 2018 scenario report. What is most relevant with respect to the calculation of future PEF values, is the fact that the most important uncertainties with respect to the future of the European system are 'covered' across the various scenarios.



Scenario's included in the ENTSO-E TYNDP 2018 report⁴.

Our simulations consist of a traditional unit commitment economic dispatch (UCED) optimization. The optimization takes the form of a mixed integer linear program (MILP), because generator technical constraints like minimum up-time and minimum down-time are included in the model. To achieve a reasonable duration in terms of computation, the simulated year is split up into 365 individual optimization problems (one for each consecutive day), which are solved in a chronological manner using the Gurobi solver. In each 24-hour dispatch optimization, generators and electricity demands in the entire interconnected European system (pictured below) are considered simultaneously. The solution to a single 24-hour optimization identifies the lowest-cost dispatch of electricity generators across Europe to satisfy the electricity demands in every country. Each scenario-year (2020, 2030.DG, 2030.EUCO, 2030.ST, 2040.DG, 2040.ST and 2040.GCA) is simulated three times. Each of these three 'samples' uses climate data from a different historic year, to reflect uncertainties in electricity demand, wind and solar power generation.



Graphical scope and resolution of our model of the European electricity system.

Since the input data provided in the TYNDP 2018 report is incomplete from a modelling perspective, some elements of the European system are modelled according to expert judgement. For example, we:

- split the ENTSO-E technology category 'gas' into 75% combined-cycle gas turbines and 25% open-cycle gas turbines,
- fill in the absent input assumptions about hydro pumped storage energy capacities (in MWh) in each country with the best data available elsewhere⁸,
- assume the ENTSO-E technology categories 'Biomass and other RES' and 'Other non-RES' have a must-run (flat) generation profile.

The preliminary results of these simulations in terms of the PEF values for each country (as well as for Europe as a whole), in each scenario-year, can be freely received by contacting the author at the abovementioned email address. These preliminary results include both the yearly PEF values as well as the PEF values during each simulated hour. As discussed above, the PEF can be calculated by assuming either a PEF_T value of 1 or 0 for non-fuel-consuming renewables, so we provide results for both cases. Moreover, CO_2 -intensities are similarly included in the output dataset, both at the yearly and hourly temporal resolutions.

This modelling exercise and its resulting PEF and CO_2 -intensity values are due to be finalized and submitted for publication in an academic journal later this year. This forthcoming work will include a more complete description of the model, as well as a detailed analysis of its output.

⁸ Geth et al. - 2015 - An overview of large-scale stationary electricity storage plants in Europe Current status and new developments