

1 elmada: Dynamic electricity carbon emission factors and 2 prices for Europe

3 **Markus Fleschutz^{1, 2} and Michael D. Murphy¹**

4 **1** Department of Process, Energy and Transport Engineering, Munster Technological University **2**
5 Institute of Refrigeration, Air-Conditioning, and Environmental Engineering, Karlsruhe University of
6 Applied Sciences

DOI: [10.21105/joss.03528](https://doi.org/10.21105/joss.03528)

Software

- [Review](#) ↗
- [Repository](#) ↗
- [Archive](#) ↗

Editor: [Pending Editor](#) ↗

Submitted: 23 July 2021

Published: 23 July 2021

License

Authors of papers retain
copyright and release the work
under a Creative Commons
Attribution 4.0 International
License ([CC BY 4.0](#)).

7 Summary

8 The expansion of intermittent renewable energy sources such as solar and wind requires in-
9 creased operational flexibility in electricity systems. To properly assess this flexibility within
10 energy system models, it is essential to know the wholesale price and associated carbon emis-
11 sions per unit of electricity for a given time step.

12 elmada is an easy-to-use open-source Python package designed to provide dynamic electricity
13 carbon emission factors and prices for European countries. The target group includes modelers
14 of distributed energy hubs who need electricity market data. This is where the name **elmada**
15 comes from: **e**lectricity **m**arket **d**ata. elmada is developed in the open on GitHub ([Fleschutz,](#)
16 [2021a](#)) and each release is archived on Zenodo ([Fleschutz, 2021b](#)). To the best of the authors'
17 knowledge, elmada is the first free and open-source Python interface for dynamic emission
18 factors in Europe. This makes elmada an important complement to existing commercial
19 services, such as the electricityMap API ([Tomorrow, 2021](#)) and the Automated Emissions
20 Reduction from WattTime ([WattTime, 2021](#)).

21 Currently, elmada provides data for 20 European countries and for each year since 2017.
22 elmada works mainly with data from the ENTSO-E Transparency Platform ([European Network](#)
23 [of Transmission System Operators for Electricity \(ENTSO-E\), 2021](#)).

24 Two types of carbon emission factors are calculated:

- grid-mix emission factors (XEFs), which represent the emission intensity based on the
25 current generation mix of the electricity system,
26
- and marginal emission factors (MEFs), which quantify the emission intensity of the
27 generators likely to react to a marginal system change.
28

29 MEFs are more challenging to approximate than XEFs since MEFs require the identification
30 of the marginal power plants per time step. In elmada, this is done through a merit order
31 simulation within the PP and PWL method described in ([Fleschutz et al., 2021](#)).

32 So far, elmada has been used in a study where MEFs, XEFs and the results of load shift
33 simulations based on them are compared across 20 European countries ([Fleschutz et al., 2021](#)).
34 In ongoing research, elmada is used to quantify the costs and emission-saving potentials that
35 arise from the exploitation of existing and future flexibility in decentral energy hubs.

36 We hope that elmada reduces the difficulty associated with the use of dynamic carbon emission
37 factors and prices in the modeling of decentral energy systems.

Acknowledgements

The author acknowledges funding by the MTU Risam scholarship scheme and the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU) via the project WIN4Climate (No. 03KF0094 A) as part of the National Climate Initiative.

References

- European Network of Transmission System Operators for Electricity (ENTSO-E). (2021). *ENTSOE Transparency Platform*. <https://transparency.entsoe.eu>
- Fleschutz, M. (2021a). *Elmada*. <https://github.com/DrafProject/elmada>
- Fleschutz, M. (2021b). *Elmada*. <https://doi.org/10.5281/zenodo.5126771>. <https://doi.org/10.5281/zenodo.5126771>
- Fleschutz, M., Bohlayer, M., Braun, M., Henze, G., & Murphy, M. D. (2021). The effect of price-based demand response on carbon emissions in european electricity markets: The importance of adequate carbon prices. *Applied Energy*, 295, 117040. <https://doi.org/10.1016/j.apenergy.2021.117040>
- Tomorrow. (2021). *electricityMap API*. <https://api.electricitymap.org/>
- WattTime. (2021). *Automated emissions reduction*. <https://www.watttime.org/aer/>