HEALTH CO-BENEFITS OF EU POWER DECARBONISATION SCENARIOS FROM AVOIDED $PM_{2.5}$ MORTALITY AND ASSOCIATED HEALTH COSTS

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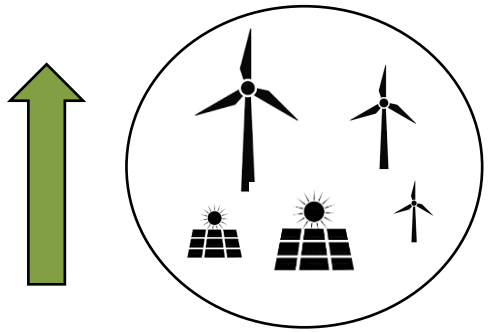
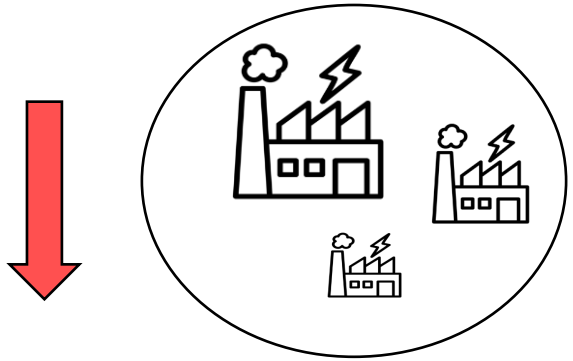
Motivation

- EU power system is expected to transition quickly towards renewable energy



- Motivation for decarbonisation is mainly rooted in greenhouse gas emission reduction to mitigate climate change



- Does the decarbonisation of the power sector have beneficial impacts on health costs from air pollution?

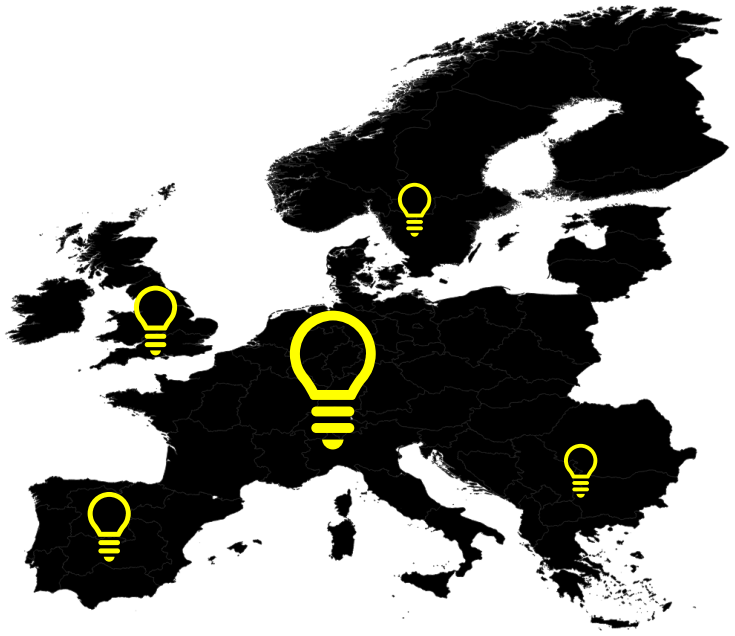
?

State of Research

- Existing works often lack high-resolution estimations necessary to represent dynamic power system changes

- In many cases, they do not consider a changing power infrastructure over time (e.g. shutdown of coal plants)

- Research gap regarding the local impacts of power sector decarbonisation on emissions, mortality and health costs

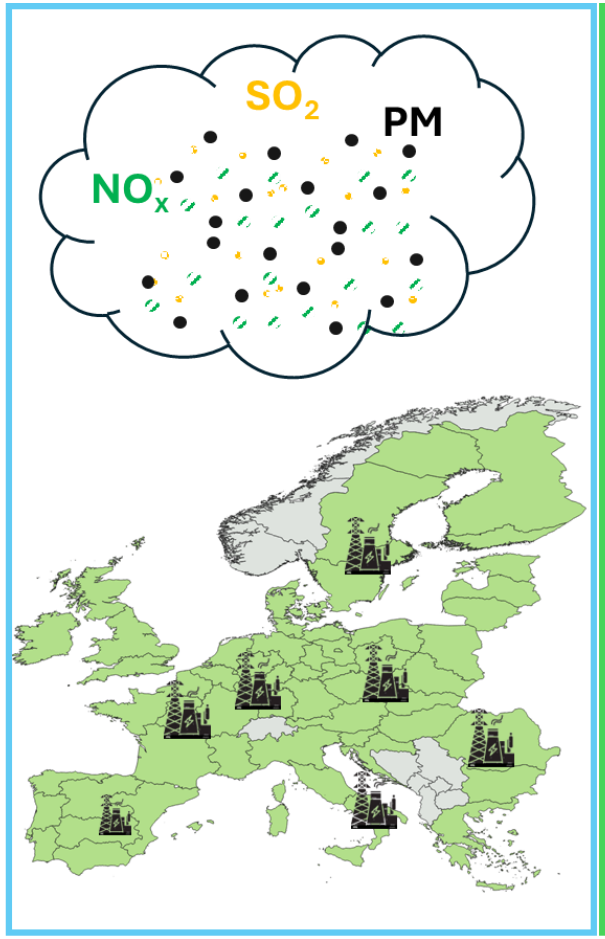


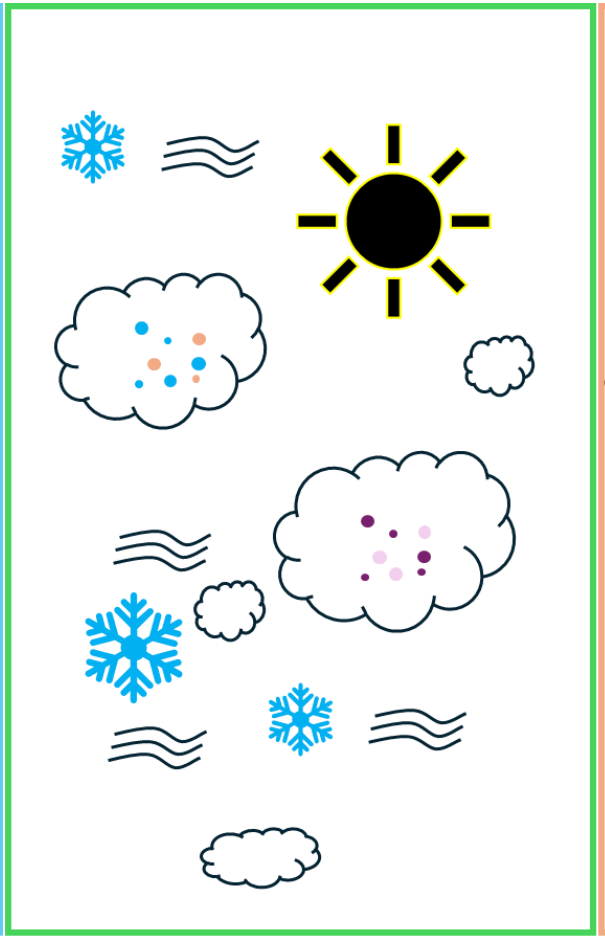
Scenarios

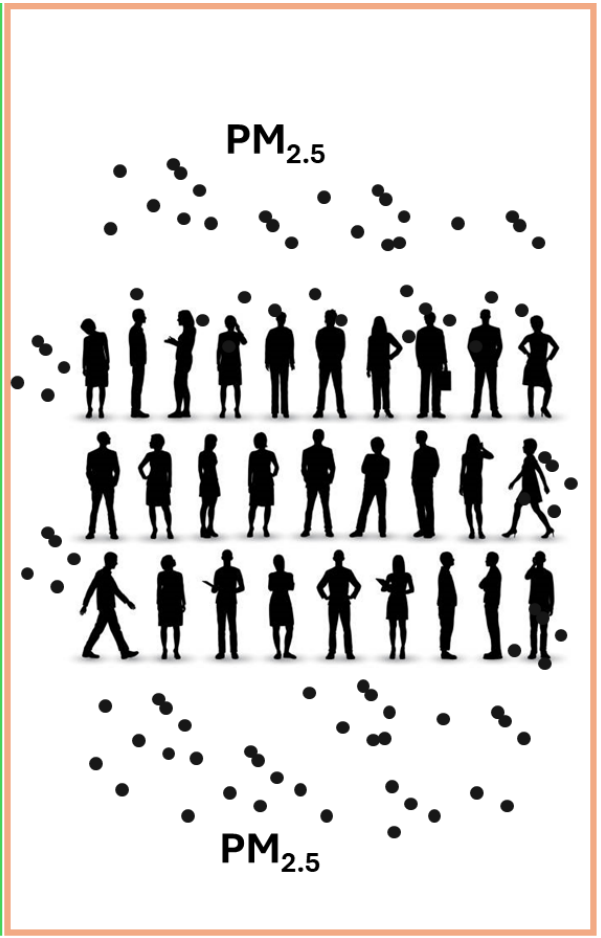
Scenario		Wind & Solar capacities	Power Plant dataset
2019	**baseline**	2019	2019
2030	**optimistic**	100% of 2030 targets	2030
	realistic	75% of 2030 targets	
	No coal		2030 without coal

Objective: Estimate the reduction of mortality and health costs due to power sector decarbonisation between 2019 to 2030

Methodology Overview



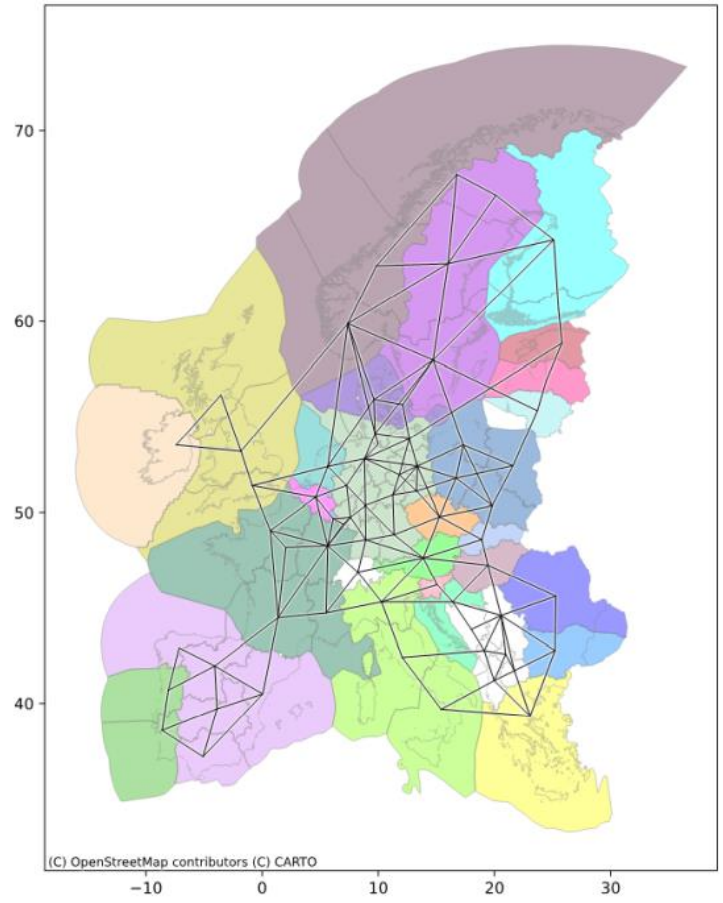




Energy System and Emissions Model	Air Quality Model	$PM_{2.5}$-Exposure and Mortality Estimate	Health Cost Estimate

Energy System Model

- Breakdown of Continental Europe into 70 interconnected sub-regions
- Cost-optimized modelling of power generation in hourly resolution with REMix
  - carbon limits
  - imports and exports
  - changes of power plant fleet (e.g. coal phaseout)
- Output: Technology-level power generation for each sub-region

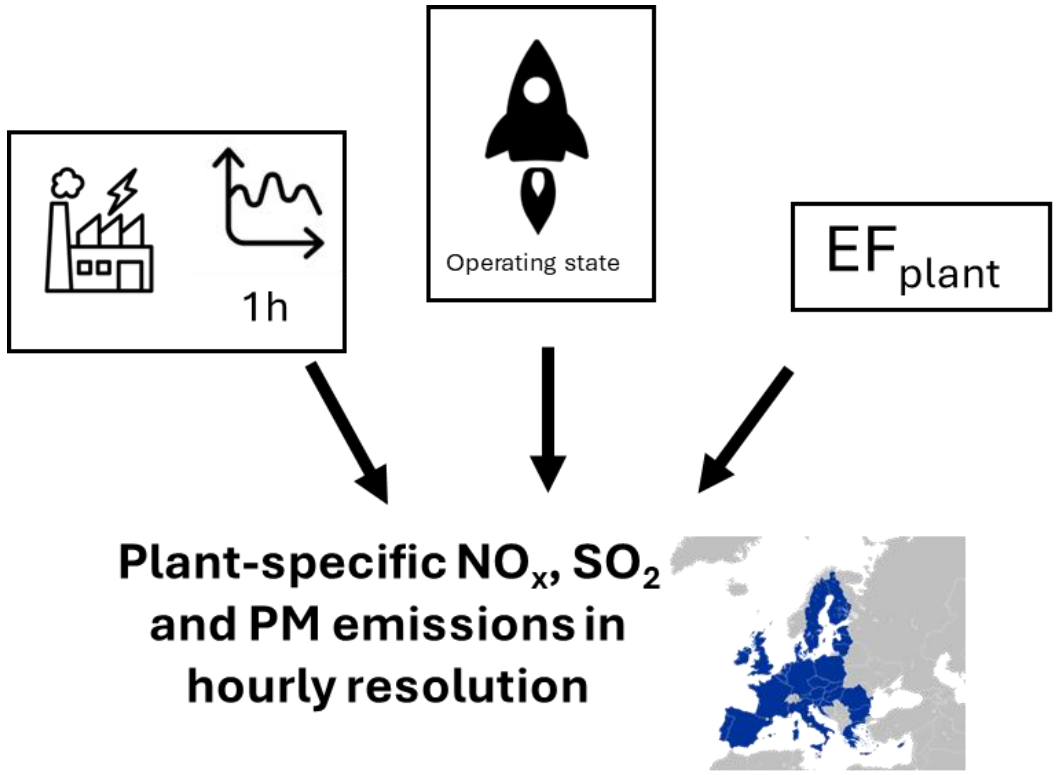


REMix
Renewable Energy Mix
Welzel 2024

Patrick Draheim, German Aerospace Center (DLR)

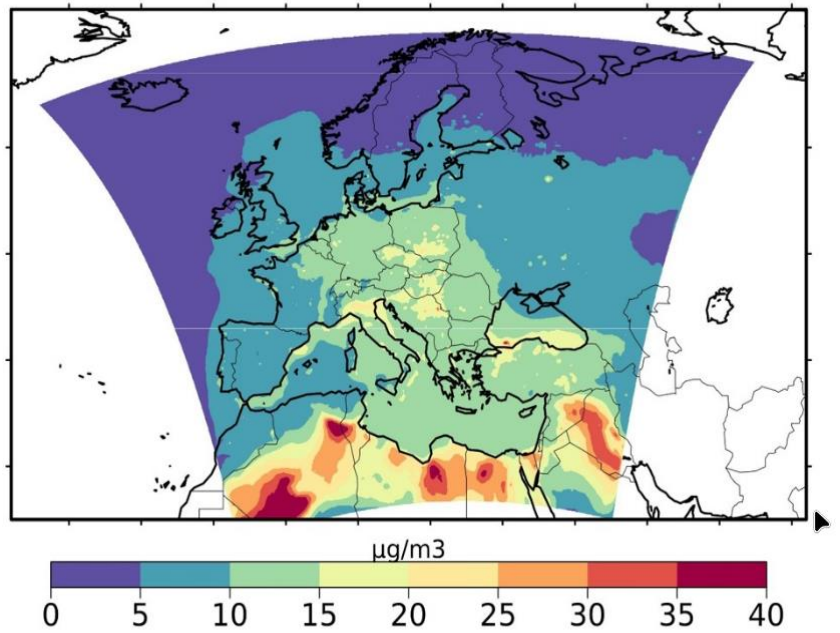
Emissions Model

- Based on energy system model results, we derive hourly power plant-specific generation time series (EU 27 + UK)
- PM_{10},$PM_{2.5}$, SO_2 and NO_x estimation using plant-specific emission factors (LCP 2019)
- Consideration of emission factor changes due to non-optimal operating states, e.g. startup (Draheim et al. (in review))



Air Quality Model

- WRF-Chem model used for air quality estimation (Grell 2005), Boundary from MOZART (Emmons et al. 2010)
- Background emissions: EDGAR v8.1 AP for 2019 (Crippa et al., 2026)
- Replace power sector emissions (1A1a) in EDGAR with emisions from our work
- Identical simulations with only power plant emission difference for full scenario year
- Estimate the impact of changed emissions on air quality



Exposure and Mortality Estimate

- Exposure Response Function: FUSION (Burnett et al. 2022)
  - Estimates all-cause PM2.5-attributable mortality (non-communicable diseases (NCD) and lower respiratory infections (LRI)
  - Age dependence: 25 years + for NCD and LRI, also for 0-5 years for LRI
- Mortality estimate will make use of:
  - Baseline mortality rate (BMR) data from the Global Burden of Disease for NCD and LRI (Murray et al. 2020)
  - Gridded population projections from NASA Socio-Economic Data and Application Center (SEDAC)
- Mortality estimate will produce for each scenario:
  - Gridded mortality
  - Country-level mortality

Air pollution attributable health costs

Total costs = Unit costs x Health impacts

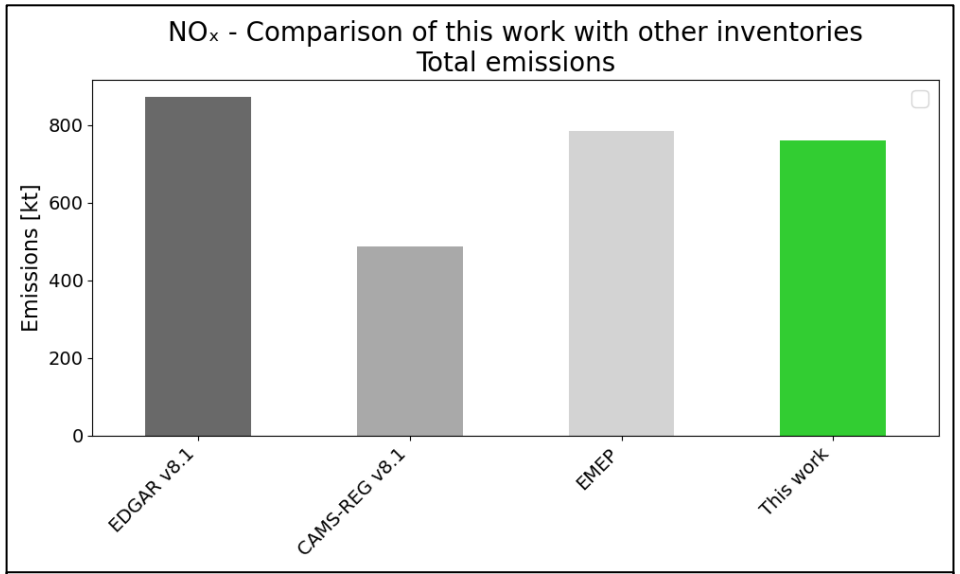
Value of a Statistical Life (VSL)

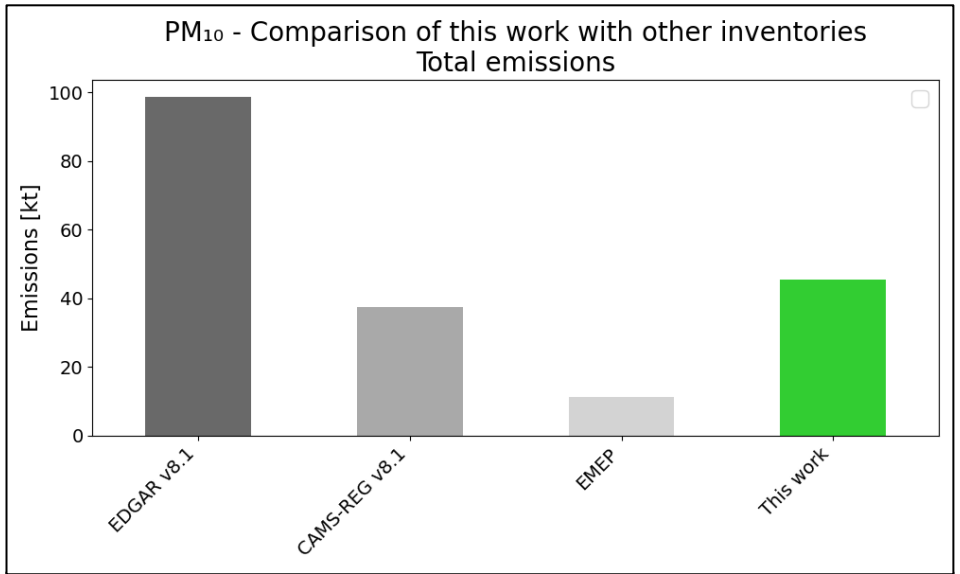
Δ Mortality

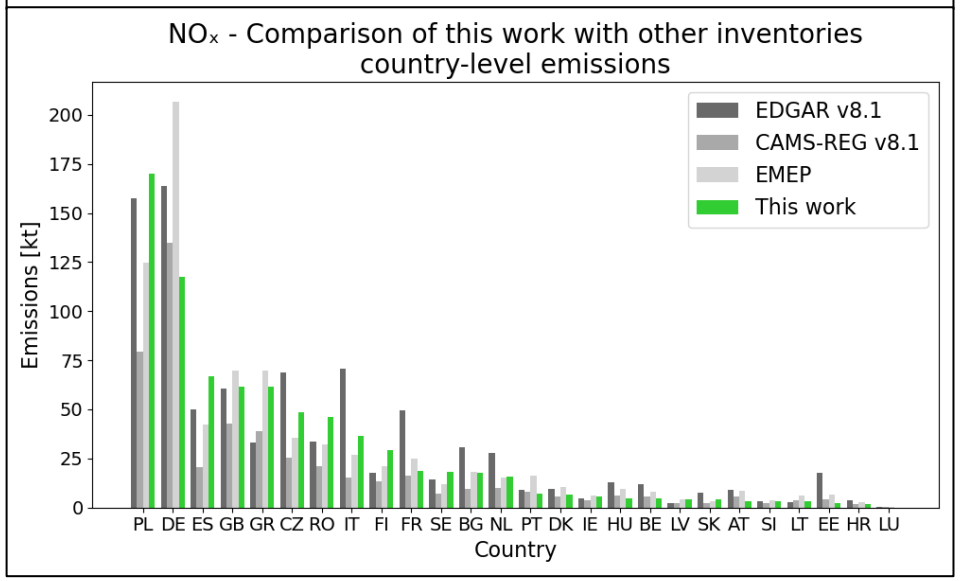
- VSL estimates are used to assess the monetary value of a reduction in mortality risk in terms of premature deaths on country level
- The mean VSL depends on various variables:
  - Economic growth (GDP)
  - Socio-economic (GINI)
  - Demographic (population)
  - Health (number of doctors)
  - Interaction term: GDP x income

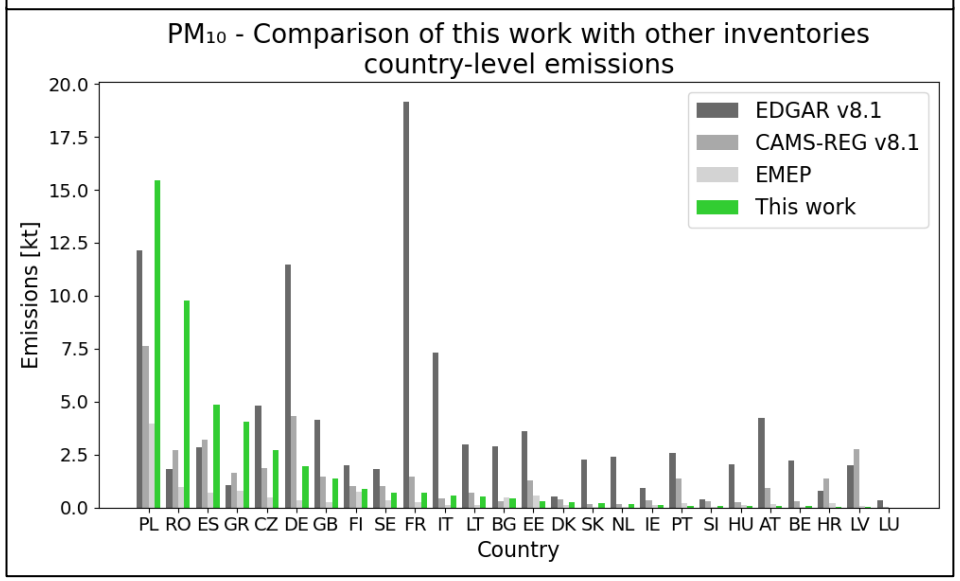
Ciarlantini *et al.* (2025)
https://doi.org/10.1016/j.jenvman.2025.124824

Validation of Emissions Model for the year 2019

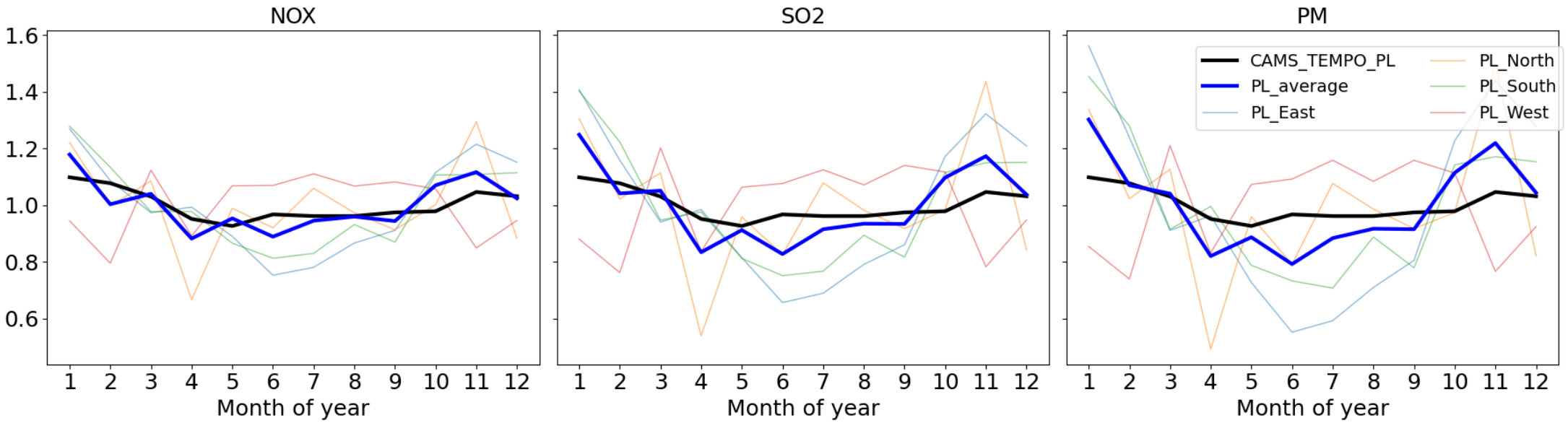






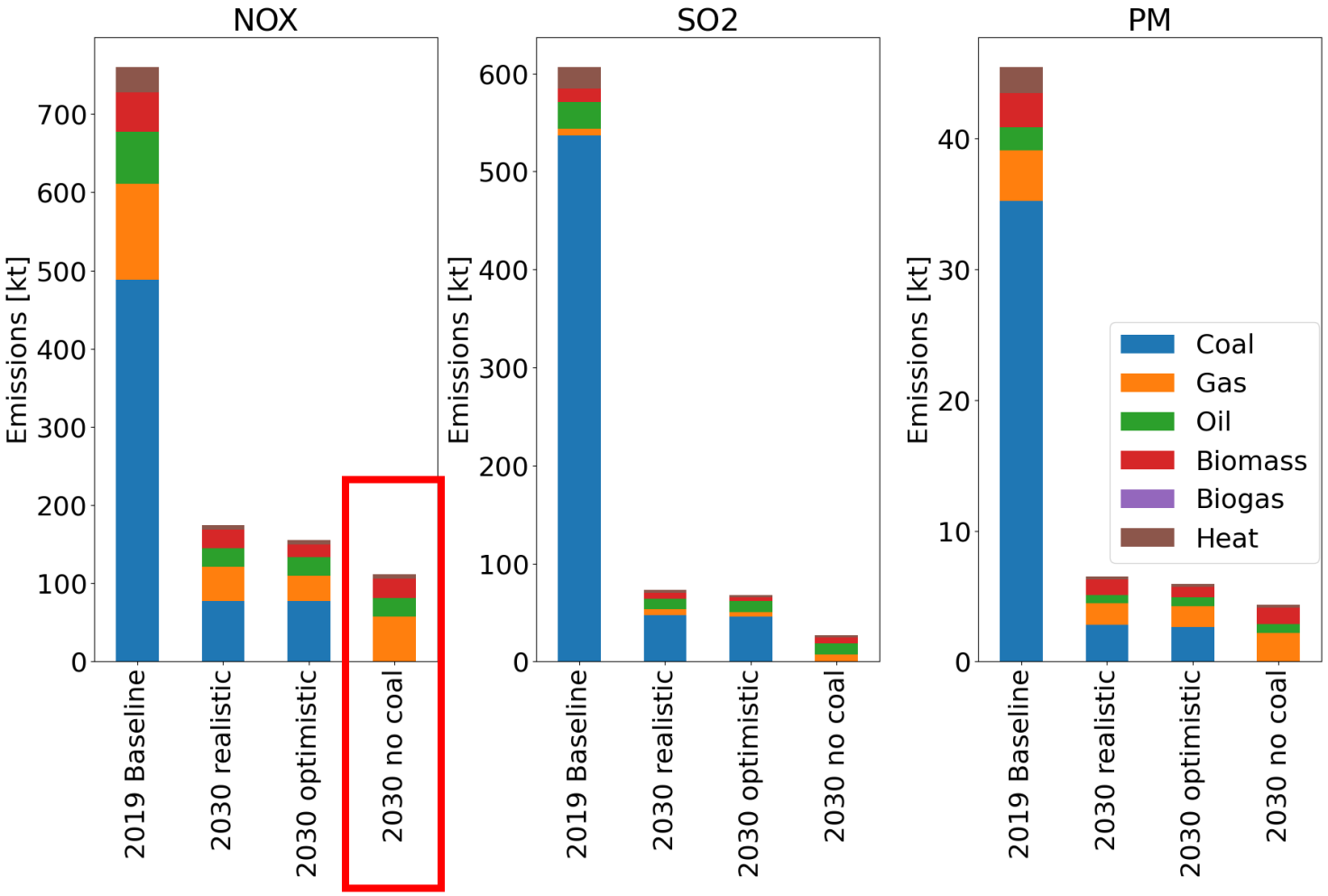


Validation of Emissions Model for the year 2019
Monthly temporal emission profiles of Poland



- Average profile of this work matches CAMS-TEMPO (Guevara et al. 2021, 2025) quite well
- Sub-country emission profiles (thin lines) partly show quite strong deviations from the country average

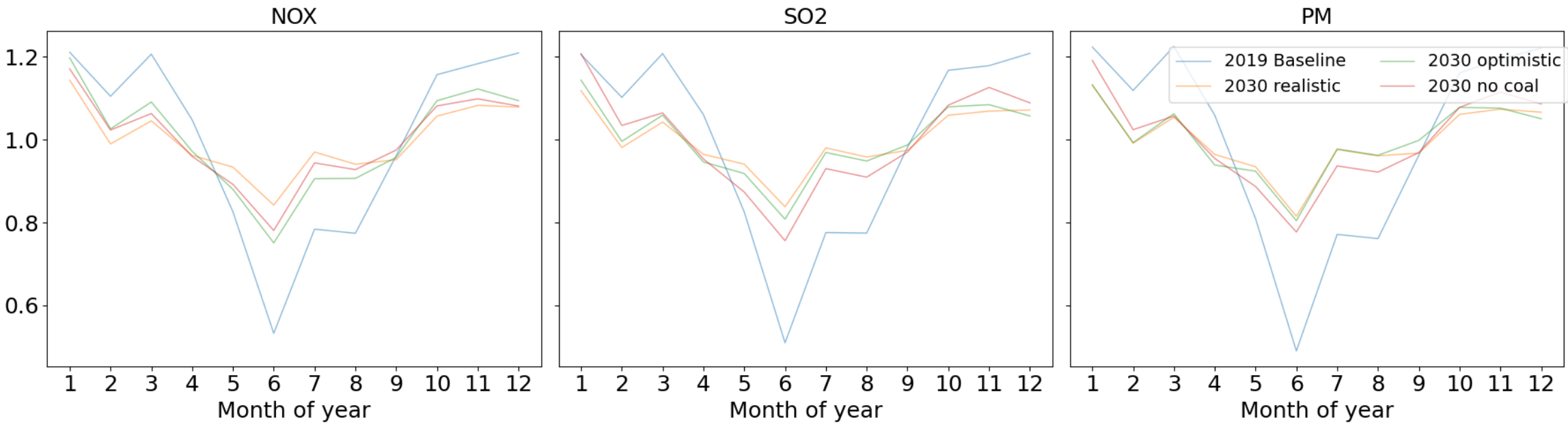
Emissions model
Comparison of the 4 power sector scenarios



- Strong emissions decline (up to ~90%) can be expected
- Power from coal combustion contributes most to total emissions
- Gas compensates for missing coal plant generation in no coal scenario

→ Power system dynamics become apparent

Emissions model – Results
Baden-Württemberg, Germany



- Monthly emission profile for power sector in 2019 differs from 2030 scenarios!

Conclusions

Preliminary results

- Energy System and Emissions Model compare well against statistics and other works
- Pollutant emissions are expected to decline strongly due to power sector decarbonisation
- Dynamics in the power system become evident in the emission results
- Sub-country level temporal emission profiles can differ strongly from country-average

Up to come:

- Air quality modelling of scenarios
- Human mortality and health cost estimation
- Paper submission in 2026 to „Environmental Science and Technology“

References

- Beyondfossilfuels.org (2026): Europe's Coal Exit – Overview of National Coal Phase Out Commitments, available at**:** https://beyondfossilfuels.org/europes-coal-exit/
- Burnett, Richard T., Joseph V. Spadaro, George R. Garcia, and C. Arden Pope. "Designing Health Impact Functions to Assess Marginal Changes in Outdoor Fine Particulate Matter." Environmental Research 204 (March 2022): 112245. https://doi.org/10.1016/j.envres.2021.112245.
- Ciarlantini, S., Frontuto, V., Pezzoli, A., Gavros, A., Belis, C.A. (2025). Econometric model derived from meta-analysis to estimate VSL and VOLY associated to air pollution at a global level. J. Env. Man. 379. doi: https://doi.org/10.1016/j.jenvman.2025.124824
- Crippa, Monica; Guizzardi, Diego; Pagani, Federico; Banja, Manjola; Muntean, Marilena; Schaaf, Edwin; Becker, William; Monforti Ferrario, Fabio; Quadrelli, Roberta; Risquez Martin, Arnau; Grassi, Giacomo; Rossi, Simone; Brandao De Melo, Joana; Jacome Felix Oom, Duarte; Branco, Alfredo; San-Miguel, Jesus; Vignati, Elisabetta (2026): EDGAR v8.1 Global Air Pollutant Emissions. European Commission, Joint Research Centre [Dataset] doi: 10.2905/JRC.E1ZGQER PID: http://data.europa.eu/89h/a3af16e4-21ac-420a-b98c-b78a9b7723be
- Emmons, L. K., Walters, S., Hess, P. G., Lamarque, J.-F., Pfister, G. G., Fillmore, D., Granier, C., Guenther, A., Kinnison, D., Laepple, T., Orlando, J., Tie, X., Tyndall, G., Wiedinmyer, C., Baughcum, S. L., and Kloster, S.: Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4), Geosci. Model Dev., 3, 43–67, https://doi.org/10.5194/gmd-3-43-2010
- Grell, Georg A. and Peckham, Steven E. and Schmitz, Rainer and McKeen, Stuart A. and Frost, Gregory and Skamarock, William C. and Eder, Brian. Fully coupled "online" chemistry within the WRF model. Atmospheric Environment. Volume 39, issue 37. https://doi.org/10.1016/j.atmosenv.2005.04.027
- Guevara, M., Jorba, O., Tena, C., Denier van der Gon, H., Kuenen, J., Elguindi, N., Darras, S., Granier, C., and Pérez García-Pando, C.: Copernicus Atmosphere Monitoring Service TEMPOral profiles (CAMS-TEMPO): global and European emission temporal profile maps for atmospheric chemistry modelling, Earth Syst. Sci. Data, 13, 367–404, https://doi.org/10.5194/essd-13-367-2021, 2021.
- Guevara, M., Colette, A., Guion, A., Petiot, V., Adani, M., Arteta, J., Benedictow, A., Bergström, R., Bolignano, A., Camps, P., Carvalho, A. C., Christensen, J. H., Couvidat, F., D'Elia, I., Denier van der Gon, H., Descombes, G., Douros, J., Fagerli, H., Fatahi, Y., Friese, E., Frohn, L., Gauss, M., Geels, C., Hänninen, R., Hansen, K., Jorba, O., Kaminski, J. W., Kouznetsov, R., Kranenburg, R., Kuenen, J., Lannuque, V., Meleux, F., Nyíri, A., Palamarchuk, Y., Pérez García-Pando, C., Robertson, L., Russo, F., Segers, A., Sofiev, M., Struzewska, J., Timmermans, R., Uppstu, A., Valdebenito, A., and Ye, Z.: Technical note: sensitivity of the CAMS regional air quality modelling system to anthropogenic emission temporal variability, Atmos. Chem. Phys., 25, 13245–13278, https://doi.org/10.5194/acp-25-13245-2025, 2025.
- Murray, Christopher J. L., Aleksandr Y. Aravkin, Peng Zheng, et al. "Global Burden of 87 Risk Factors in 204 Countries and Territories, 1990–2019: A Systematic Analysis for the Global Burden of Disease Study 2019." The Lancet 396, no. 10258 (2020): 1223–49. https://doi.org/10.1016/S0140-6736(20)30752-2.
- Wetzel et al., (2024). REMix: A GAMS-based framework for optimizing energy system models. Journal of Open Source Software, 9(99), 6330, https://doi.org/10.21105/joss.06330

Thank you for your attention!

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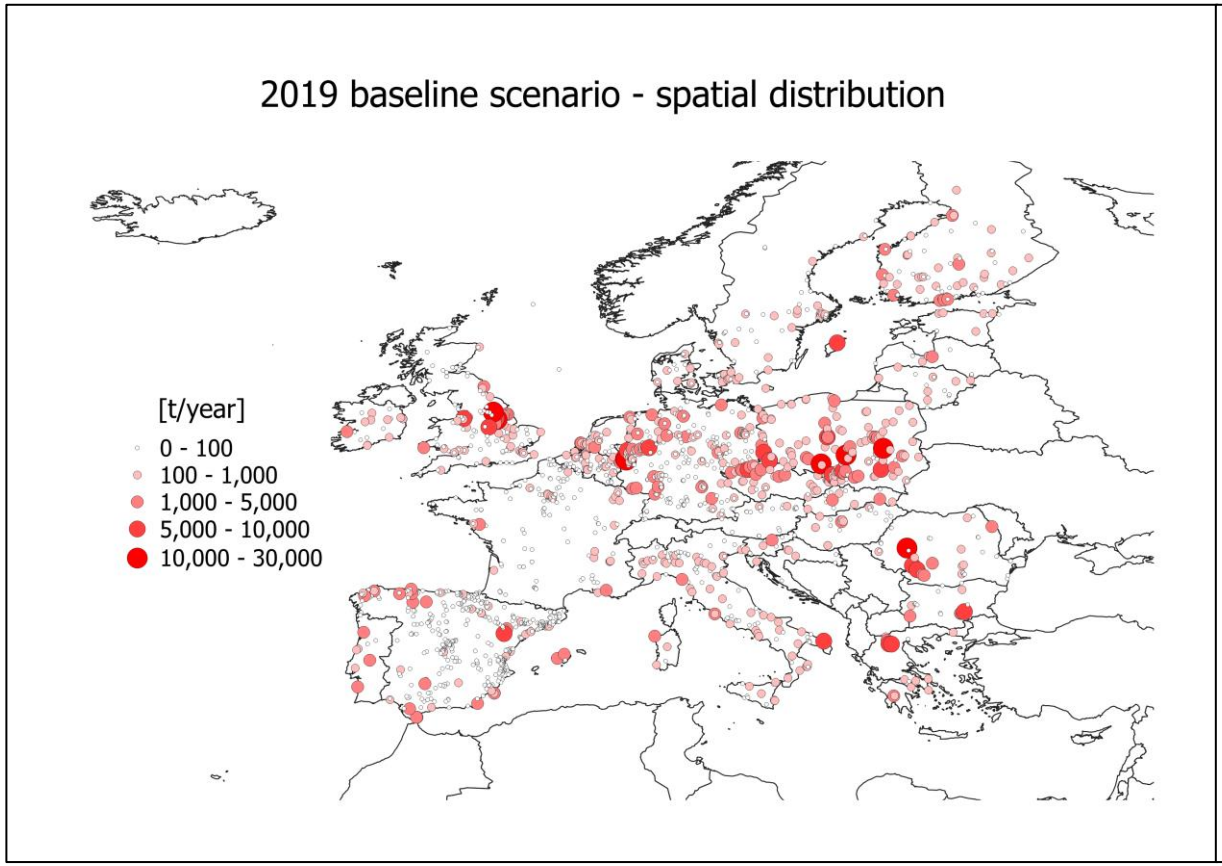
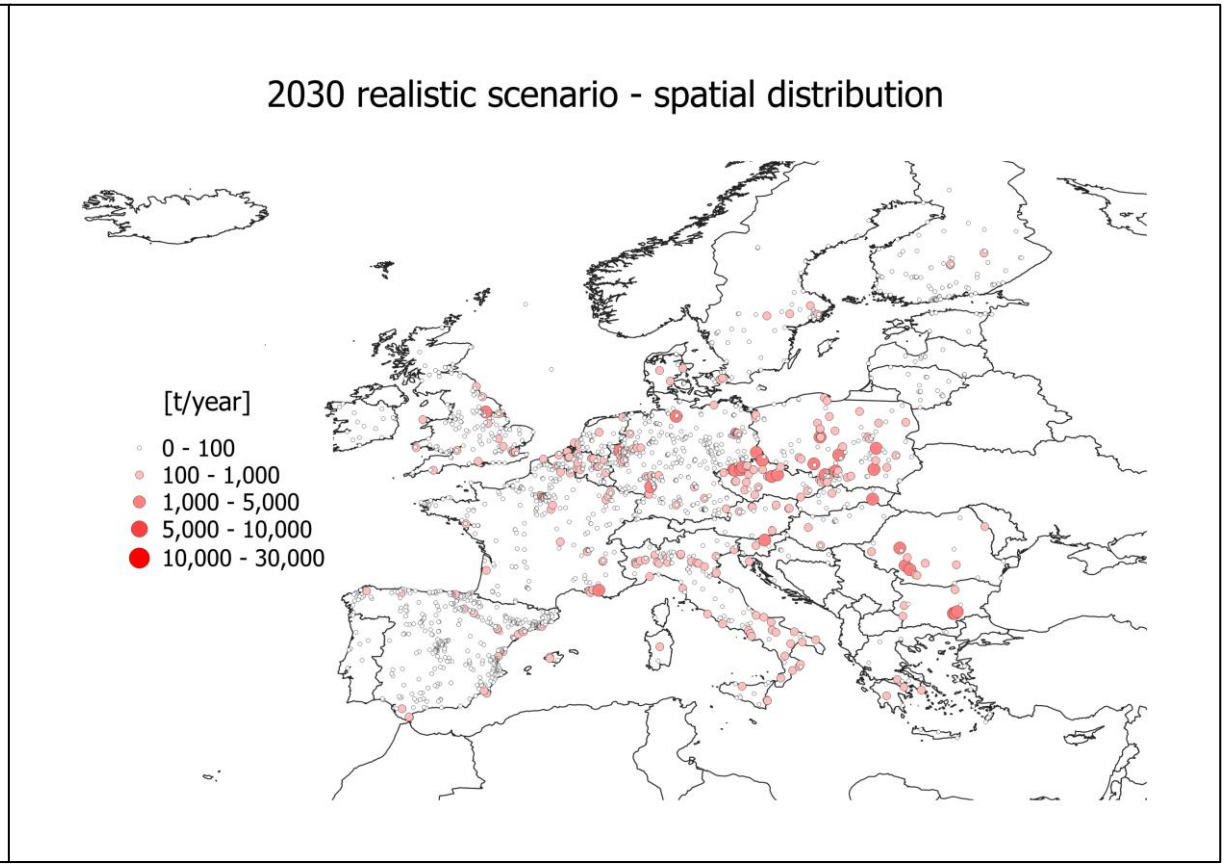
Spatial distribution





- Heavy emitters are strongly reduced, even in countries without coal phaseout plans

→ Increasing renewable power generation replaces conventional fuels

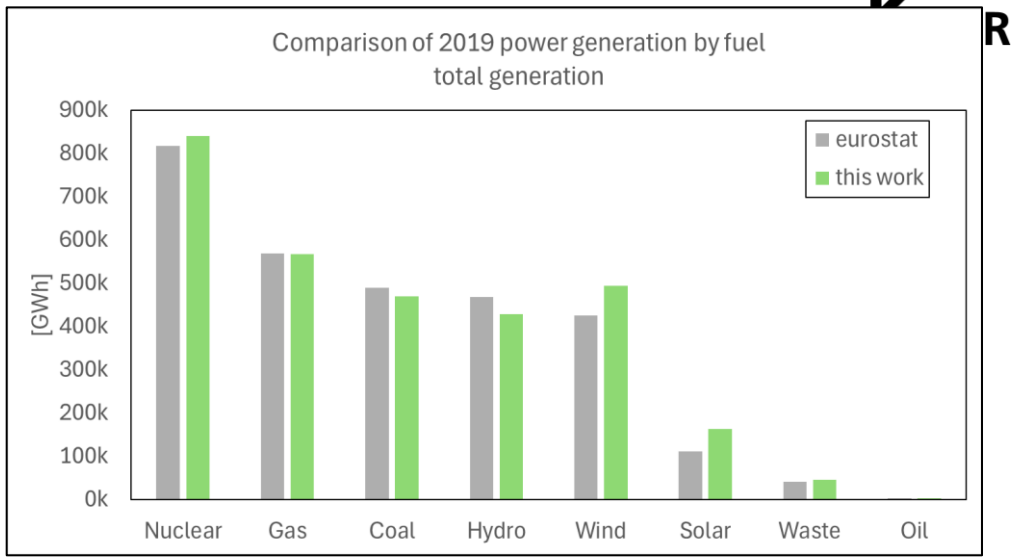
State of Research

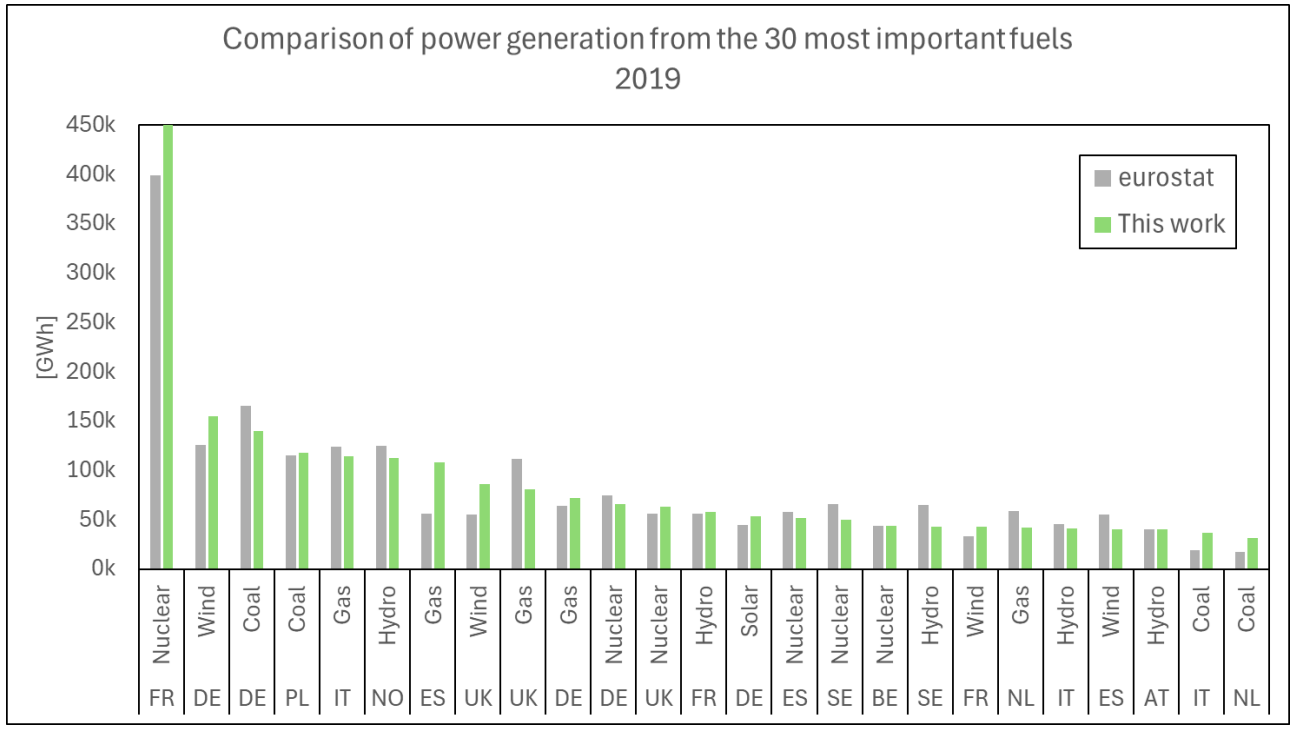
- Existing works often lack high-resolution estimations
- In many cases, they do not consider a changing power infrastructure (e.g. Jacobson et al. 2019, Schmidt et al. 2019, Rao et al. 2017)
- High-resolution emission data lead to more reliable air quality estimates (Czarnowska et al. 2012)

→ Research gap regarding the local impacts of power sector decarbonisation on emissions, mortality and health costs

Validation of Energy System Model

- Validation of modelled fuel generation against eurostat statistics for 2019
- Distribution of generation by fuel is well captured





- Fuel generation by country largely matches with statistics
- Small differences are normal

→ „overfitting“ of the model to the year 2019 would negatively impact scenario model runs

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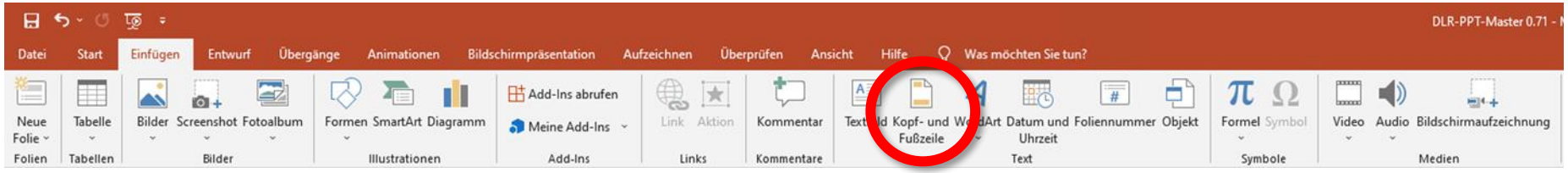
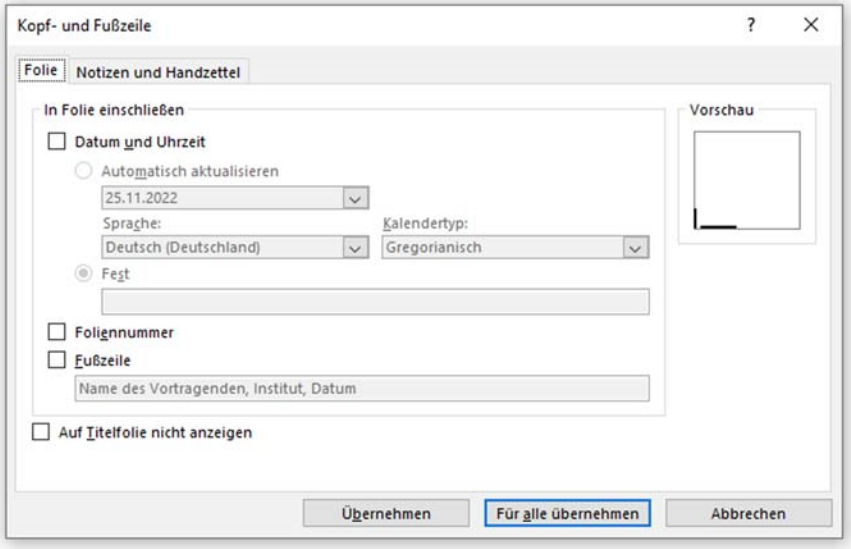


Screenshot 2



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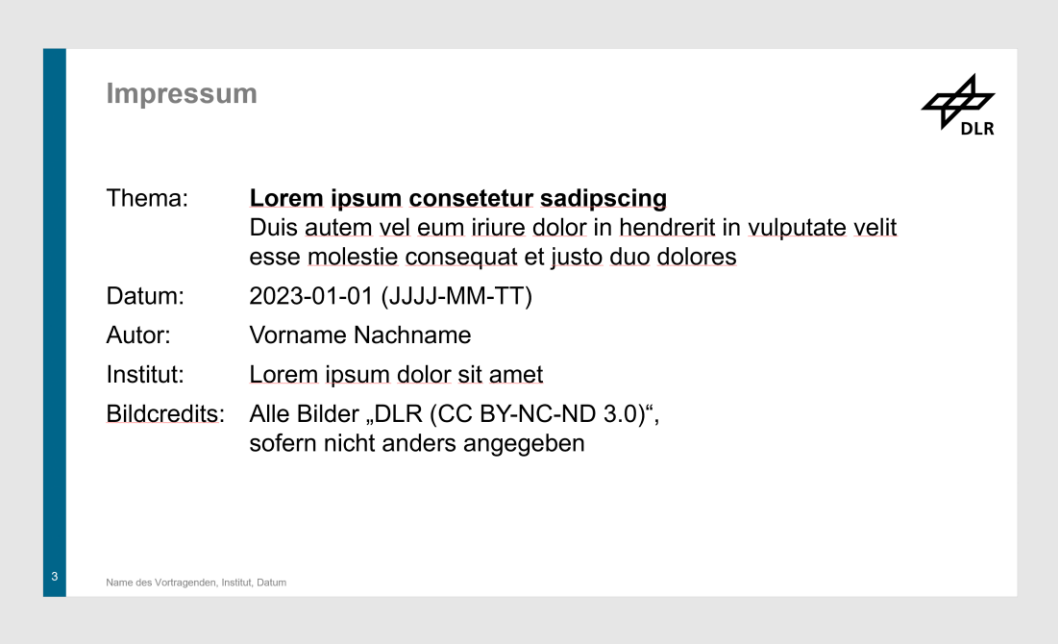

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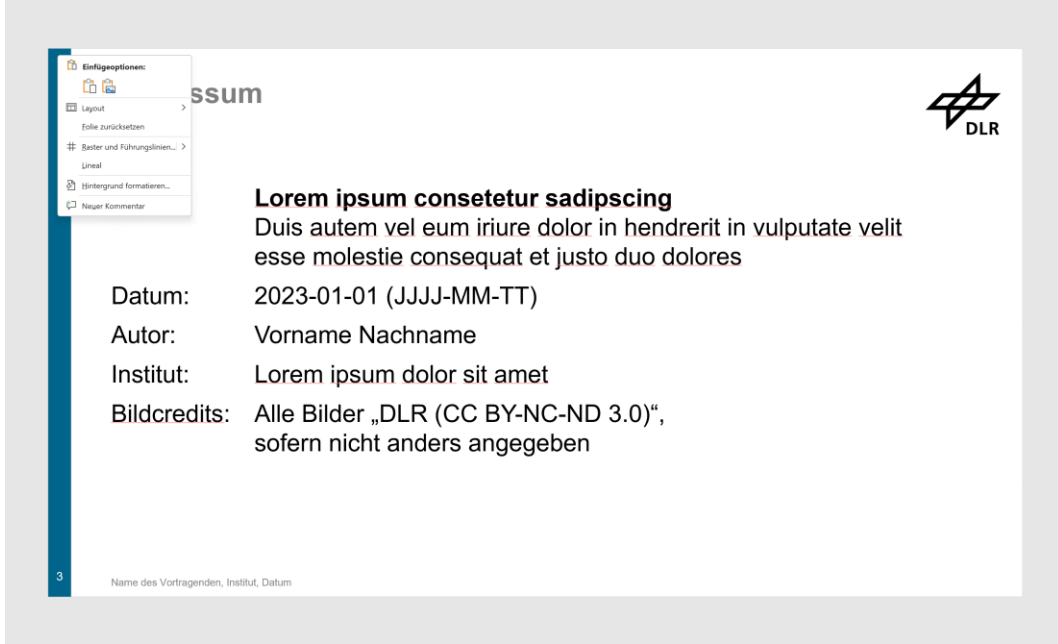

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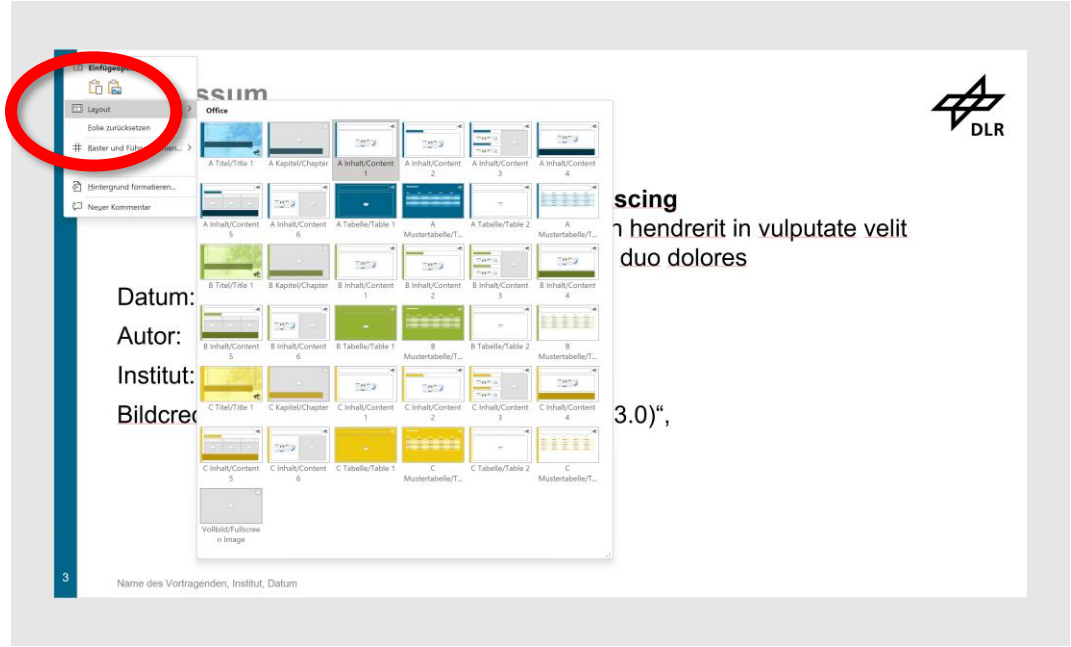

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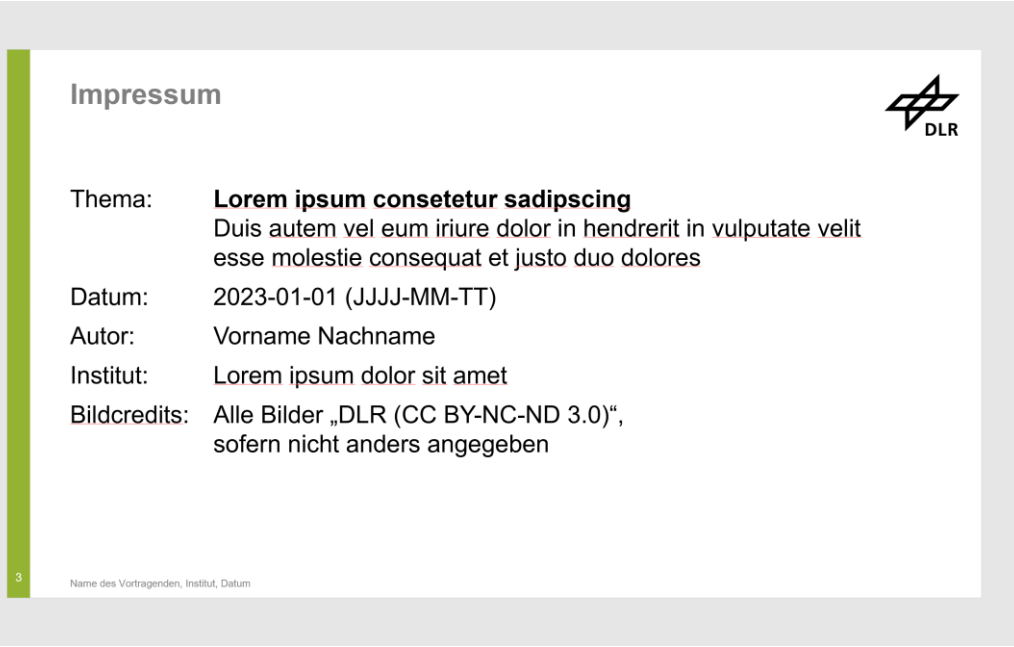

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English: The finished result.

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