Research Project #2

Implications of the European transformation pathway to greenhouse gas-neutral energy systems on air quality and human health (ICE-2 & ICE-3)

Following the ambitious goals of the European Green Deal, the European Climate Law enforces climate neutrality of the European Union's member states by the year 2050. By then, the member states are committed to net-zero emissions of Greenhouse Gases (GHG). To achieve this, European economy is facing large transitions in the use and development of technologies and the supply and storage of carbon neutral energy. However, the pathway towards net-zero GHG emissions is not finally agreed upon.

The ETHOS (Energy Transformation patHway Optimization Suite) modeling suite [1] from the Institute of Climate and Energy Systems – Jülich System Analysis (ICE-2) provides tools to analyze cost-optimal transformation pathways of Europe's energy infrastructure on different scales. It is based on assumptions on techno-economic parameters and the transition of different emission sectors (e.g. buildings, traffic, and industry). ETHOS provides information on potential technological changes in the various emission sectors for individual years of the transformation path. Based on these results, corresponding carbon dioxide (CO_2) emissions can be derived. These transformations of the energy system imply not only the reduction of CO_2 emissions but also of the emissions of air pollutants, such as nitrogen dioxide, sulfur dioxide, and particulate matter. Thus, the different pathways to achieving net-zero GHG emissions have implications for air quality and human health in Europe, which are not currently considered by ETHOS. The HITEC project aims at enhancing the applicability of ETHOS to the prediction of air quality under different energy transformation scenarios. The aim is to relate the reduction of CO_2 emissions to emission reductions of air pollutants considering the current knowledge about emission shares, data from technology emission assessments, and existing datasets on emission transformations from environmental agencies and the Coupled Model Intercomparison Project (CMIP). Finally, the project aims to assess potential ways to include air quality-related boundary conditions into the ETHOS optimization procedure.

To evaluate the changes in air quality due to transformations of the energy systems, the chemistry transport model EURAD-IM (EURopean Air pollution Dispersion – Inverse Model; [2]) developed and operationally used by the Institute of Climate and Energy Systems – Troposphere (ICE-3) is utilized to simulate energy transformation scenarios. For all scenarios, air pollutant emissions are calculated for different years towards 2050. For each of these emission datasets, a full year simulation with EURAD-IM is conducted. To assess the sensitivity of air quality to the emission changes, the meteorology of the year 2024 is kept fixed as a reference simulation, for which the most recent actual emission data is available. The air quality assessment is conducted by replacing the actual emissions in 2024 by the reduced emissions from the scenarios. Thus, the direct effect of emission changes on air pollution can be evaluated. Finally, the impact of the different scenarios on human health will be evaluated using data from the Global Burden of Disease database according to previous studies (e.g., [3]).

The project is subdivided into different tasks:

- Evaluation of different suitable pathway scenarios for net-zero emissions by 2050
  - Investigation and adaptation of the underlying assumptions
  - Potential analysis of the combination of assumptions on different technologies
  - Definition and calculation of scenarios using the ETHOS modeling suite
- Estimation of air pollutant emission changes for each pathway scenario
  - Evaluation of CO_2 emissions from different technologies and related changes
  - Evaluation of the emission ratio of CO_2 and air pollutants for existing technologies
  - Evaluation of existing emission scenarios provided by environmental agencies and climate projections (e.g., CMIP)

  - Calculation of emission changes for different pathways based on technologies defined above
- Simulation of air quality for the ensemble of pathway scenarios in Europe
  - Identification of a reference year for simulating current air quality as baseline
  - Setup of modeling framework for the EURAD-IM to simulate the set of emission pathway scenarios defined above
- Evaluation of the implication of energy transformations on air quality and human health
  - Assessment of the air quality in Europe for each scenario
  - Comparison with air quality guideline levels defined by the World Health Organization in 2021
  - Computation and evaluation of changes in mortality due to air pollution for each scenario
  - Discussion of the potential to incorporate air quality-related boundary conditions within the ETHOS module suite

The project is expected to provide new insights into the potential of changing energy systems for air quality and human health. Thus, the project enables to include air quality related issues into climate mitigation considerations, illustrating the co-benefit of long-term climate mitigation actions on short-term air quality improvements. Further, the project reflects the uncertainty incorporated in the pathway calculations by including different potential pathways into the calculation. Here, the emission scenarios of the CMIP assessment are supplemented by a set of ambitious but realistic transformation pathways using a comprehensive approach. Finally, the project aims to bridge the gap between realistic future transformations of the energy systems and health effects due to air quality improvements.

Location of the HITEC Fellow	Forschungszentrum Jülich, Institute of Climate and Energy Systems - Jülich Systems Analysis (ICE-2), Director: Prof. Dr.-Ing. Jochen Linßen https://www.fz-juelich.de/en/ice/ice-2
Partners of the HITEC Project	Forschungszentrum Jülich, Institute of Climate and Energy Systems – Troposphere (ICE-3), Director: Prof. Dr. Anke Nölscher https://www.fz-juelich.de/en/ice/ice-3
Specific **requirements**	- Master's degree in physics, meteorology, natural sciences, computer science or related field to energy systems analysis - Programming experiences in python and/or Fortran - Interest in working with complex simulation frameworks - Experience in data analysis - Experience in handling large datasets - Very good communication skills in English
For **project specific** questions please **contact**	Dr. Theresa Klütz, ICE-2, t.kluetz@fz-juelich.de Dr. Philipp Franke, ICE-3, p.franke@fz-juelich.de

[1] Jülicher Systemanalyse, "ETHOS Model Suite." Nov. 14, 2025. [Online]. Available: https://www.fz-juelich.de/de/ice/ice-2/leistungen/model-services

[2] H. Elbern, A. Strunk, H. Schmidt, and O. Talagrand, "Emission rate and chemical state estimation by 4-dimensional variational inversion," *Atmos. Chem. Phys.*, vol. 7, no. 14, pp. 3749–3769, Jul. 2007, doi: 10.5194/acp-7-3749-2007.

[3] P. Franke, A. C. Lange, B. Steffens, A. Pozzer, A. Wahner, and A. Kiendler-Scharr, "European air quality in view of the WHO 2021 guideline levels: Effect of emission reductions on air pollution exposure," *Elem Sci Anth*, vol. 12, no. 1, p. 00127, May 2024, doi: 10.1525/elementa.2023.00127.