Development of an open-source and open-data energy system optimization model for the analysis of the European energy mix

In the context of strategical planning in support of the ongoing energy transition, energy system modeling tools allow to perform comprehensive analyses of the role of current and innovative technologies and their respective interactions.

Technology assessment requires a bottom-up approach calling for the adoption of least-cost optimization energy system models. Those models work with large techno-economic databases to provide a detailed description of the system under exam over a medium-to-long-term time scale and on large spatial scales. Therefore, the validity of the tool used for the analyses and the quality of the adopted technological database affect the analyses performed with energy system optimization models.

Proprietary energy system optimization models rely on source codes that can be easy to access but difficult to be modified and on input data usually not shared with the public. That contributes to undermining the reliability of such tools, especially when they are used for policy-relevant analyses. The results of energy system models are already subject to the impossibility of verification against actual future developments, and the inaccessibility to data represents an impassable barrier at least to ensuring that the results of the analyses are unbiased by the customers' requirements.

In a framework of increasing interest towards open-source modeling tools, the OSeMOSYS and TEMOA projects, considered mature enough to compete with either commercial or proprietary frameworks, are paving the way to increase the scientific validity of energy system modeling tools.

This work aims to develop an open-data and open-software model instance for the European continent on a long-term time scale up to 2100, TEMOA-Europe, mostly updated in the last few years with parameters coming from freely accessible sources and based on a completely accessible open database. As this work is developed taking advantage of the involvement in the EUROfusion Socio-Economic Studies WorkPackage, the assessment of the role of nuclear fusion in future energy scenarios is indeed its main driver. Thus, the necessity of producing reliable studies to drive research and development and public investment choices cannot ignore the full accessibility and repeatability of the analyses.

That specific purpose presents a broader spectrum of activities involving the review of the techno-economic characterization modules for those sectors that will call for progressively larger electrification of end-uses, specifically transportation and industry (usually defined as "hard-to-abate sectors"), and for the hydrogen sector that may contribute to change the way energy is produced and used. Extensive databases for the mentioned sectors are presented and deeply analyzed in this work in terms of characterization and results obtained from TEMOA-Europe.

Moreover, as constraints for the development of the energy system are as important as parameters for the characterization of energy technologies and socio-economic trends, a method to compute possible trajectories for the capacity deployment of electricity generation technologies is presented. Such a

method relates the historical development trends for the installed capacity to the widely accepted theory of the S-curves. Constraints based on the actual levels of electricity generation capacity building at the European level are obtained to implement maximum capacity constraint trajectories in TEMOA-Europe and then used for scenario analysis. Three nuclear fusion technological alternatives based on the ARC, EU-DEMO and Asian-DEMO reactor concepts are analyzed in this open model to guarantee a non-biased characterization of nuclear fusion technologies. Constraints based on the abovementioned S-curve theory were derived to reasonably bind the adoption of nuclear fusion, and the presented results show how fusion may not come too late to contribute to the energy transition in Europe when considering ambitious decarbonization targets. Moreover, a set of outputs is shown to present the capabilities of TEMOA-Europe to provide useful insights into future energy system developments.