An integrated energy-system and multisectoral economic model for long-term transition analysis

Topic: Enriched IO Models
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Abstract
1. The research question
Energy transition pathways are characterized by profound structural transformations that simultaneously influence energy technologies, production systems, investment dynamics, and macroeconomic outcomes. Stand-alone economic or energy models cannot capture the pervasive interactions and constraints of future energy transitions; therefore, a linkage between models is necessary. However, standard approaches typically rely on one-way, soft-linked integrations between economic and energy system models. This limits their ability to represent feedback mechanisms, non-linear dynamics, and internally consistent physicalâ€“monetary interactions. Our aim is to overcome the limitations of existing modelling approaches when analyzing energy transition scenarios by incorporating technological, economic and social sustainability perspectives into a single long-term modelling tool.

2. The method
Our methodological approach goes beyond existing literature, consisting of a new hard-linked model that tightly integrates a detailed energy system optimization model with a newly developed long-term multi-sectoral stock-flow consistent model of the Italian economy. This integration is achieved through an iterative linear programming algorithm. In order to achieve the integration between the two models, it is necessary for them to be consistent in terms of (i) technological disaggregation and granularity and (ii) formal structure.
3. The data used
Regarding the latter, both models are based on Supply-Use Tables (SUTs) (OECD/European Union 2025) and adopt the main equations of the Input-Output analysis. An extended Italian SUT database for the year 2019 has been built with 115 technologies using several sources of data. For the energy system model, the main sources are the energy balances from the IEA as well as information from the national statistical office (ISTAT) and EUROSTAT offices complemented by multi-regional input-output databases and peer-reviewed studies. For the economic model, an initial economic SUT is assembled by combining data for standard NACE Rev.2 sectors and CPA 2.1 products from official statistical databases. For additional key energy transition technologies, additional data are sourced from multi-regional input-output as well as from scientific and grey literature. Consumption and investment matrices are constructed to link the extended SUT to final demand components. The resulting initial SUT is thus balanced using the Stone-Byron algorithm. The economic model also uses institutional and financial account data to explicitly model income distribution and financial assets and liabilities within the economic system.

4. The novelty of the research
The approach has many novel features. Firstly, the hard link integration of two fully developed, multisectoral energy and economic models is an important contribution to existing literature. Secondly, gathering data and creating a new dataset with classifications suitable for technological and economic purposes is a key step in developing this tool, which could be used as a pilot for other countries. Finally, the multisectoral economic model goes beyond the traditional input-output approach, fully developing the Inforum philosophy by taking into account long-term dynamic relations and interactions between stocks and flows in different markets.

All data processing, database construction, model generation, and optimization procedures were implemented using the open-source Python package CVXLab, specifically developed to manage large-scale techno-economic datasets and integrated modelling frameworks. CVXLab was used to manipulate and harmonize raw statistical sources, automatically generate the structured SQL database underlying the extended Supply-Use Tables, construct the fully integrated mathematical optimization problem linking the energy and economic modules, and solve the resulting set of convex numerical problems by means of the Gauss-Seidel procedure. This ensured transparency, reproducibility, and full consistency between data preparation, model formulation, and computational solution within a unified workflow.
Results confirm the potential of the proposed framework as tool for policy-relevant scenario analysis. Indeed, it allows endogenous definition not only of technology deployment and energy investments, but also of energy demand, prices, and investments in all the non-energy sectors, under technological, financial, and socio-economic constraints. This enhances the analytical consistency of long-term energy transition assessments.