The energy system transition pathway towards carbon reduction using a model-coupling approach

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Energy system transition is widely regarded as an important strategy to achieve carbon reduction and is aligned with the commitment to reach peak carbon emissions by 2030. However, most modelling approaches in the existing literature do not pay sufficient attention to inter-sectoral dynamics. By using a model-coupling approach, this paper aims to study inter-sectoral energy consumption flows from 2000-2021 and to explore energy system transition pathways at the national and city levels.

Existing studies, commonly employing models including input-output (IO) analysis, integrated assessment models (IAMs), etc., discuss the impact of energy transition policies on energy consumption and emissions. Taking the IO model as a case in point, most of the existing studies based on the IO models use national data for research at the city or regional levels, which are rather homogeneous in scope. Moreover, these models are generally used only for short-term simulations to assess the effects of emission reduction policies and are not suitable for studies on the long-term impacts of emission reduction policies. The IAMs provide an integrated assessment of policies through the construction of large-scale simulation models. The long-range energy alternatives planning system (LEAP) model, for example, is used to simulate energy demand, generation mix, carbon emissions, and total costs under different scenarios at the city level. However, IAMs omit details of interdependencies between sectors and the indirect impacts on the energy system supply chain. And interactions among sectors should be further explored, as recent research has argued that inadequate treatment of intersectoral interdependencies in current modelling approaches substantially understates the challenges of meeting existing climate targets and is a major shortcoming.

In order to address the limitations of a single model, including a single scope of study and unclear trends in changing industrial structure, model coupling combines IO and IAMs models to systematically study the impacts of energy transition on energy consumption and climate change. Research on coupling IO with IAMs models mainly focuses on improving one model using the results of the other. The macro-analysis of IO models is enhanced by the detailed technical outputs of IAMs. By soft-linking top-down IO analysis to bottom-up IAMs with rich technology details, such coupling model can be used to assess the evolution of the electricity mix under energy regime scenarios and apply future energy scenarios to IO analysis. The results provided by IO analysis can be used to improve the evaluation of the economic-social module of IAMs.

In this study, we use sectoral data from 20 sectors and consumption data from 16 cities to explore the energy system transition pathway towards carbon reduction, by developing a model-coupling approach. At the national level, we study inter-sectoral energy consumption flows using a IO-LEAP model and then use scenario analysis to suggest sectoral-level specific strategies from 2000-2030 and city-specific strategies from 2019-2030. This paper makes the following contributions. We propose model-coupling of IAM and IO modelling to address the limitations of existing approaches. The coupling model tracks energy consumption, production and transition across sectors of an economy. Despite the widespread recognition of importance of energy transitions, IAMs underestimate the indirect effects of changing energy mix and effects of intersectoral interdependencies. Recent studies attempt to solve this problem; however, they generally limit to a specific industry or urban setting. We propose a multi-industry and multi-city perspective.

The results show that historically heavy industries have consistently maintained a high share of energy consumption and emissions accounting for 49.9% and 60.7% respectively by 2021, mainly caused by direct energy-resource inputs rather than post-processing inputs. In the scenario analyses, compared to the baseline scenario, the national EES scenario can reduce energy consumption by 6.7% and emissions by 24.6% in 2030, while the EES_CCS scenario can further reduce emissions by 48.4%. Furthermore, the energy consumption and carbon emissions across cities are influenced by the industrial structure, the degree of electrification, and the amount of new energy installed.