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Modeling for insights not numbers: The long-term low-carbon transformation

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RESUMEN

Limitar el calentamiento global para evitar un cambio climático peligroso requiere una drástica reducción de las emisiones de gases de efecto invernadero y la transformación hacia una sociedad hipocarbónica. Los modelos económicos energético y climático, que sustentan la toma de decisiones políticas en la actualidad en el camino hacia una sociedad de cero emisiones netas, se perciben con creciente escepticismo en cuanto a su capacidad para pronosticar la evolución de sistemas socio-ecológicos altamente complejos y no lineales. Presentamos un revisión sistemática de la literatura de los últimos avances de los enfoques de modelización, centrándonos en su capacidad y limitaciones para desarrollar y evaluar las trayectorias hacia una sociedad hipocarbónica. Encontramos que los enfoques metodológicos existentes tienen algunas deficiencias fundamentales que limitan su potencial para entender las sutilezas de los procesos de descarbonización a largo plazo. Por tanto, un marco metodológico útil debe ir más allá de las actuales técnicas cumpliendo simultáneamente los siguientes requisitos: 1) representación de un análisis inherentemente dinámico, describiendo e investigando explícitamente las trayectorias entre los diferentes estados de las variables del sistema, 2) especificación de los detalles de la cascada energética, particularmente el papel central de las funcionalidades y servicios provistos por la interacción de flujos energéticos y las correspondientes variables de stock, 3) presentación de una clara distinción entre estructuras del sistema energético sociotécnico y los mecanismos socioeconómicos para desarrollarlo, y 4) capacidad para evaluar las trayectorias conjuntamente con criterios sociales. Para ello proponemos el desarrollo de un marco de modelización integrado versátil y multiobjetivo, partiendo de las fortalezas de los varios enfoques de modelización disponibles al mismo tiempo que excluyendo sus debilidades. Este estudio identifica las respectivas fortalezas y debilidades para guiar dicho desarrollo.

ABSTRACT

Limiting global warming to prevent dangerous climate change requires drastically reducing global greenhouse gases emissions and a transformation towards a low-carbon society. Existing energy- and climate-economic modeling approaches that are informing policy and decision makers in shaping the future net-zero emissions society are increasingly seen with skepticism regarding their ability to forecast the long-term evolution of highly complex, nonlinear social-ecological systems. We present a structured review of state-of-the-art modeling approaches, focusing on their ability and limitations to develop and assess pathways towards a low-carbon society. We find that existing methodological approaches have some fundamental deficiencies that limit their potential to understand the subtleties of long-term low-carbon transformation processes. We suggest that a useful methodological framework has to move beyond current state of the art techniques and has to simultaneously fulfill the following requirements: (1) representation of an inherent dynamic analysis, describing and investigating explicitly the path between different states of system variables, (2) specification of details in the energy cascade, in particular the central role of functionalities and services that are provided

by the interaction of energy flows and corresponding stock variables, (3) reliance on a clear distinction between structures of the sociotechnical energy system and socioeconomic mechanisms to develop it and (4) ability to evaluate pathways along societal criteria. To that end we propose the development of a versatile multi-purpose integrated modeling framework, building on the specific strengths of the various modeling approaches available while at the same time omitting their weaknesses. This paper identifies respective strengths and weaknesses to guide such development.

Keywords: Low-carbon transformation, energy-economic modeling, climate-economic modeling, structured literature review.

1. Introduction

The 2015 Paris Agreement showcased that the global society is stepping up to tackle dangerous climate change by aiming at limiting global average temperature increase to below 2 ºC, seeking 1.5 ºC (UNFCCC, 2015). The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) pointed out that to achieve this ambitious target with a likely chance, a transformation towards a net-zero carbon society has to be achieved by the end of the century, requiring large-scale changes in global as well as regional to local energy systems (IPCC, 2014). However, since global anthropogenic greenhouse gas (GHG) emissions have never been as high as today (Edenhofer et al., 2014), current incentive structures appear insufficient to catalyze such a transformation. Thus, additional policies are required to foster the necessary levels of investment into low-carbon technologies and behavioral change, and to stimulate technological as well as social innovation.

In developing these policies, climate- and energy-economic modeling is crucial for decision support. The number of such models has grown tremendously in recent years, fostered also by large and cheap computing capacities. At the same time existing energy- and climate-economic modeling approaches are being confronted with increasing skepticism with respect to their ability to forecast the long-term evolution of highly complex and nonlinear social-ecological systems such as the socioeconomic-climate-energy nexus considered in this paper, and to assess the transformation pathways leading to the desired low-carbon society (see e.g. Pindyck, 2013; Pindyck and Wang, 2013; Anderson, 2015; Stern, 2016). In particular, there is increasing concern – at least since the publication of the Stern Review (Stern, 2007) – regarding the applicability of the traditional neoclassical economic paradigm in long-term transformation analyses, as some major principles and implicit modeling mechanisms are questioned: the concept of economic equilibrium, the supremacy of market mechanisms, the relevance of relative prices as main endogenous driver of technological change, the implicit behavioral assumptions (profit- and utility maximizing rational agents), the incremental dynamics of technologies (based on exogenous assumptions for total factor productivity improvements), the emphasis on flows (GDP and consumption levels) over stocks (built and natural environment), and the critical role of the discount rate (cf. Barker, 2008). Moreover, the question arises whether it is feasible at all to predict the future evolution of social-ecological systems in the presence of deep or fundamental uncertainties (variations around expected system behavior that cannot be quantified) and (potentially non-stationary) catastrophic risks (Scrieciu et al., 2013).

The existing models to assess different energy- and climate-economic research questions vary considerably and the question arises which model is most appropriate for a certain purpose or situation. Therefore, in the following we seek to answer: What kind of modeling framework is most suitable for assessing the long-term transformation processes needed to drastically reduce global GHG emissions? The aim of this paper is to provide a structured review of state-of-the-art national and international energy- and climate-economic modeling approaches with respect to their ability and limitations to develop pathways for a low-carbon society (including its economy).

In a first step we suggest a set of relevant characteristics for the evaluation of different modeling approaches regarding their suitability for long-term transformation analyses. In a second step we identify specific methodological approaches that have been used in analyses of climate and energy policies in