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GR4SP: Modelling policy mixes for Victoria's electricity provision to achieve sustainability transitions

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Abstract: We present the Generic Recursive Simulation of Socio-technical Systems for Service Provision (GR4SP), an open-source suite of software tools for the socio-technical analysis and simulation of electricity systems in the context of the Victorian electricity system. This system has been traditionally polluting the environment because of its reliance on the state's vast brown coal reserves. The stakes are high from climatic, energy security and equity perspectives to manage the transition to a hybrid or fully decarbonised system well. The GR4SP suite aims to support this by providing tools to simulate the effects of government policy interventions or socio-technical innovations on performance metrics ranging from emissions to energy poverty. The GR4SP suite has been validated against historical data – collected from archival sources – from the 1880s to 2019, providing the confidence to explore future scenarios.

GR4SP consists of a simulation engine (SE) and auxiliary modules. Its implementation is based on socio-technical layouts (STLs) (Rojas and de Haan 2019) to represent the system in terms of generation, network, storage and consumption assets, the various actors, and the rules they make and abide by – STLs bridge qualitative and quantitative methods for a more comprehensive understanding of transition dynamics. Unlike the canonical frameworks in sustainability transitions research, such as the multi-level perspective or technological innovation systems, STLs provide more precise conceptual mapping that facilitates formalisation into computer models, such as the explicitly nested structure of networked infrastructure as well as the actors involved in the socio-technical system at different governance levels.

The SE uses an agent-based model to reproduce the economic dispatch of the electricity market – half-hourly bidding process used to balance supply and demand. In contrast, historical data is mapped without such a market in the early eras. Indicators (including retail price) are quantified in the SE. The auxiliary modules are the (1) Sectoral Network Analysis to analyse the organisational networks of, for example, historical ownership relations of the electricity system; (2) Energy Vulnerability Assessment to quantify energy vulnerability based on a modified low-income, high-cost indicator; and (3) Exploratory Modelling and Analysis (EMA) based on the EMA workbench (Kwakkel 2017).

The EMA module is used to explore transition trajectories with the SE from 2019 to 2050. Results indicated the importance of single interventions—changes in one input—to decrease greenhouse gas emissions and increase the use of renewable energy and the need for multiple and simultaneous interventions and innovations—multiple and combined input changes—to decrease wholesale prices and tariffs. Using three transition scenarios: Low-carbon, Just, and Sustainable, and algorithms to explore the output space of socio-technical configurations to achieve them, we found that affordability and low-carbon systems are not mutually exclusive, as there are multiple policy mixes to achieve sustainability transitions. A key finding is that interventions must be well timed and managed to achieve the desired outcomes.

The suite contributes empirical insights into the socio-technical evolution of energy systems in Australia to the sustainability transitions modelling community. It is a methodological contribution to the entire transitions research field. Future work is needed to use modelling insights with qualitative work and decision-making approaches to implement and monitor real-life interventions.

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