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Cross-impact analysis of Finnish electricity system with increased renewables: Long-run energy policy challenges in balancing supply and consumption☆

Juha Panula-Ontto[a,*], Jyrki Luukkanen[a], Jari Kaivo-oja[a], Tadhg O'Mahony[a], Jarmo Vehmas[a], Seppo Valkealahti[b], Tomas Björkqvist[b], Timo Korpela[b], Pertti Järventausta[b], Yrjö Majanne[b], Matti Kojo[c], Pami Aalto[c], Pirkko Harsia[d], Kari Kallioharju[d], Hannele Holttinen[e], Sami Repo[b]

[a] *University of Turku, Finland*
[b] *Tampere University of Technology, Finland*
[c] *University of Tampere, Finland*
[d] *Tampere University of Applied Sciences, Finland*
[e] *Technical Research Centre of Finland, Finland*

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ABSTRACT

Climate change and global economic pressures are strong drivers for energy economies to transition towards climate-neutrality, low-carbon economy and better energy and resource efficiencies. The response to these pressures, namely the increased use of renewable energy, creates a set of new challenges related to supply-demand balance for energy policy and electricity system planning. This study analyses the emergent problems resulting from the renewable energy response. These complex aspects of change in the electricity system are analysed with a cross-impact model based on an expert-driven modeling process, consisting of workshops, panel evaluations and individual expert work. The model is then analysed using a novel computational cross-impact technique, EXIT. The objective of the study is to map the important direct drivers of change in the period 2017–2030 in electricity consumption and production in Finland, construct a cross-impact model from this basis, and discover the emergent and systemic dynamics of the modeled system by analysis of this model.

1. Introduction

This paper describes a problem-oriented study of the future electricity system and energy policy of Finland. motivated by the research aims of the EL-TRAN project (see https://el-tran.fi/in-english/). The EL-TRAN consortium works to fundamentally rethink the energy system in Finland, in an attempt to help resolve policy challenges involved in a transition to a resource efficient, climate neutral electricity system. The initial phase of such a transition is currently underway in Finland. It is a response to global megatrends and roadmaps, including climate change, the Paris agreement to limit the global warming, increasing competition for fossil fuels among Asia's emerging economies, and European Union (EU) visions such as the 2050 Roadmap to a Resource Efficient Europe and the low-carbon objectives of the Energy Roadmap 2050 (see (Lund, 2007; Van den Bergh, 2008; EU Commission, 2011)).

These roadmaps make it necessary for Finland, as well as other EU member states, to rethink long-run targets and policies in the domain of energy. The policy challenges call for a new approaches to energy research, such as systems thinking approaches that respond to the inability of normal disciplinary science to deal with multidimensional complex problems as outlined by the Intergovernmental Panel on Climate Change (IPCC) (Metz, 2007). There is need to develop and organize interdisciplinary international studies, which recognize these new long-run challenges of energy policy in the context of global energy sector changes (Aalto, 2011; Aalto and Korkmaz Temel, 2012; Kaivo-oja et al., 2014; Luukkanen et al., 2015; Vehmas et al., 2016).

In addition to decades of prominent technical global energy and emission studies through complex scenario analysis such as Nakicenovic et al. (2000), scenario analysis methods have often been used by policy makers and in strategic foresight as an instrument to manage uncertainty and to support the shaping of long-term policies and decision-making (Enzer, 1971, 1972; Bañuls and Turoff, 2011).

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* Corresponding author.
E-mail addresses: juha.panula-ontto@utu.fi (J. Panula-Ontto), jyrki.luukkanen@utu.fi (J. Luukkanen), jari.kaivo-oja@utu.fi (J. Kaivo-oja).

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Cross-impact methods have been used in conjunction with energy scenario construction (see e.g. (Al-Saleh, 2009; Medina et al., 2015; Vögele et al., 2017)). The cross-impact approach can be seen as a systems modeling approach, using mainly expert-sourced data in lieu of statistical or empirical data in model construction. Cross-impact methods, as modeling and analysis approaches, fall in between empirical data-driven computational models and argumentative systems analysis. They exhibit a high degree of disciplinary heterogeneity and focus on expert-sourced soft system knowledge (Weimer-Jehle, 2006), making them exceptionally applicable in foresight-oriented modeling.

Typically, complex systems are very challenging to analyse (see (Andersson et al., 2014)). The process of building a cross-impact model of such complex systems has the advantage of partitioning and modularizing the complexity. Instead of trying to intuitively assess the dynamics and operating logic of the entire system and its interaction web, the human expertise mobilized for the modeling can be used to assess individual system aspects and components and their bilateral relationships. Starting from a conceptual-level and argumentative system model, the cross-impact approach provides a tool for going further, proceeding towards a more formal and systematic model of the analysed system. A more formal system model can then undergo a computational transformation to reveal non-obvious, emergent characteristics of the system. Cross-impact modeling is also a way to go beyond argumentative systems analysis in modeling cases where data-driven models are not feasible due to lack of empirical data and difficulties in quantification of essential system characteristics.

The cross-impact approach can be thought to be relatively strong, compared to the data-driven approaches, when there is a lot of variety and heterogeneity in the utilized theoretical or methodological approaches. The cross-impact methods provide possibilities to analyse systems, which have too complex interactions to be meaningfully analysed by mere qualitative reasoning (Weimer-Jehle, 2006; Helmer, 1981; Gordon and Hayward, 1968b; Bañuls and Turoff, 2011; Thorleuchter and Poel, 2014; Medina et al., 2015). Several different modeling languages and computational processes of varying complexity have been proposed for the analysis of complex interactions between system components and processes, based on mostly expert-sourced data. These approaches have shared characteristics and overlapping utilization areas, but are referred to by various labels by different authors. Labels such as structural analysis (Godet et al., 1991, 1994), morphological analysis (see Ritchey (2006)), and cross-impact analysis (Gordon and Hayward, 1968b; Gordon, 1994; Honton et al., 1984; Weimer-Jehle, 2006), all refer to approaches for doing expert-based systems modeling.

In this study, we utilize the *Express Cross-Impact Technique (EXIT)* (Panula-Ontto et al., 2016), (see also (Panula-Ontto, 2016b, Panula-Ontto and Piirainen, 2017)) in foresight-oriented analysis of the Finnish energy system. EXIT takes a model of statements or *hypotheses* describing a hypothetical or future state of the modeled system, and the valuations of the direct supporting or negating interactions between the hypotheses as its input. From this information, the EXIT computational process mines the valuations for *indirect* impacts in the system model. Together, the direct (input) interactions and the indirect (computed) interactions can be used to valuate the *emergent* or *systemic* interactions between the hypotheses describing the system, accounting for the influence the different system parts and processes have on each other through the system's complex web of interactions. This information helps understand the system and the relationships of its parts better and serves to identify those that are pivotal. Identification of the most important parts with highest systemic leverage is useful in intervention point evaluation in strategic decision-making. The EXIT input data can be collected in expert workshops or in a multi-stage expert survey process. The EXIT approach can help organisations and agencies in the boundary work between policy, strategy and knowledge about the future (Steen and Twist, 2013).

The aims of the study described in this paper were to

1. Recognising emerging challenges related to increasing wind and solar penetration, formulate a specific, compact set of system descriptors relevant to the near-term future of the Finnish energy system
2. Model and valuate the direct interactions of this set of essential system descriptors using the EXIT modeling language, based on an expert group process supplying the necessary inputs
3. Discover the internal dynamics of the modeled system, using the EXIT computational process to valuate the indirect impacts extant in the system, and to gain understanding of the systemic relationships between the descriptors and the emergent system characteristics
4. Identify the critical system aspects from the perspective of the EL-TRAN project premise, to support and facilitate the process of defining different paths for strategic policy actions in the long-run electricity market policy in Finland

The study is also a trial of the EXIT cross-impact approach in the high-level modeling case of a complex energy system. It demonstrates the use of the EXIT approach in this domain, using a relatively small and high-level set of system descriptors. The built system model, and the transformation performed on it, illustrate the possibilities of investigating the emergent and systemic properties of systems in a cross-impact setting. The trial study lays a basis for more extensive modeling efforts in the domain, using the same approach.

2. Methodology

The modeling and analysis of the Finnish energy system undertaken in this study is based on the EXIT approach, which falls into the category of cross-impact analysis approaches. The cross-impact approach could be described as a high-level systems modeling approach, with emphasis on utilizing expert-sourced inputs, and capacity to use heterogeneous theoretical and methodological approaches in the definition of the characteristics of the model. The different cross-impact modeling and analysis methods diverge in terms of their modeling languages and the nature of their analytical output. What is referred to as cross-impact analysis is really a family of methods for modeling and analyzing systems and problem complexes. The best-known methods are Gordon's cross-impact method (Gordon and Hayward, 1968b; Gordon, 1969, 1994), SMIC (Godet et al., 1991, 1994), BASICS (Honton et al., 1984), (see also Luukkanen, 1994), MICMAC (Godet et al., 1991, 1994), KSIM (Kane, 1972) and the cross-impact balances approach (Weimer-Jehle, 2006). The cross-impact approach has been utilized and further methodologically developed in many projects and studies, and it already has a relatively long history in systems analysis and various foresight applications (see (Gordon and Hayward, 1968a; Gordon, 1969; Turoff, 1971; Dalkey, 1971; Kane, 1972; Blackman,1973; Godet, 1976; Bloom, 1977; Martino and Chen, 1978; Nováky and Lóránt, 1978; Kaya et al., 1979; Burns and Marcy, 1979; Ishikawa et al., 1980; Brauers and Weber, 1988; Godet et al., 1991, 1994; Gordon, 1994; Jeong and Kim, 1997; Weimer-Jehle, 2006; Choi et al., 2007; Pagani, 2009; Thorleuchter et al., 2010; Agami et al., 2010; Bañuls and Turoff, 2011; Bañuls et al., 2013)).

The cross-impact method used in this study, the EXIT method ((Panula-Ontto et al., 2016), see also (Panula-Ontto, 2016b; Panula-Ontto and Piirainen, 2017)), is a computational technique for processing a model consisting of expert input about the direct impacts that different events, phenomena, drivers and forces have on each other. The computational aspiration of EXIT is to use the information of the model to compute how the network of effects works, and how the system descriptors affect each other *systemically*, over the complex network of effects. An event, phenomenon, driver or force considered in a particular cross-impact analysis setting can be called in a more generic fashion a *system descriptor*, a *cross-impact item*, or a *hypothesis*, as is done in EXIT. The method is useful for comparing the cross-impact items in terms of the magnitude of their total (direct + indirect) effect