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Technology, business model, and market design adaptation toward smart electricity distribution: Insights for policy making

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ABSTRACT

The transformation of the electricity sector towards a sustainable energy supply and use has a disruptive potential for infrastructure and utilities. The spread of digital technologies, renewable energy, and prosumers requires a swift and well-guided adaptation of the electricity distribution industry to smart grid technologies and related business models. This paper, based on the large technical systems (LTS) conceptual framework, investigates the complex evolution and company and market design adaptation needs. Challenges and opportunities are analyzed through nine multi-stakeholder workshops, held in two EU member states (Germany and Portugal) in 2016–2017, engaging distribution system operators, researchers, academics, and integrated utility companies. The results indicate considerable uncertainty for distribution system operators regarding the value of large-scale smart meter rollouts. Also, a corporate culture with resistance to change is observed, challenging the integration of novel technologies and processes. Traditional regulation is seen as a barrier to smart grid investments, and is associated with job losses and knowledge destruction. Policy-makers can benefit from these insights on the dynamics of DSOs, which can contribute to public policy design and market reform which traditionally has often been mainly concerned about operational efficiency in a steady-state, stable economy.

1. Introduction

The transition towards a low-carbon energy sector is currently a priority in most countries, recently reinforced through the Paris agreement signed in 2015 at the 21st Conference of the Parties (COP 21). Many European countries have set targets for the share of renewable energy: Germany, for example, aims to reach a share of 35% renewable energy by 2020, while Denmark and Sweden have set 50% as a target (Anaya and Pollitt, 2015). Commonly envisioned transition paths include the integration of the heating and mobility sector into the electricity sector on the consumption side (sector coupling). The generation of electricity is expected to gradually shift from centralized thermal power plants to distributed energy resources (DER), which either feature high energy efficiency levels, due to combined heat and power generation, or are based on renewable energies, and thus carbon-free during operation, such as wind turbines and solar photovoltaic modules (Castro and Dantas, 2017; Palensky and Dietrich, 2011; Pereira and Silva, 2017).

Smart grids will play a key role in integrating these distributed energy resources and their associated flexibilities, increase energy and economic efficiency, and empower customers (European Commission, 2012), which is why the European Union (EU) prompted its member states to ensure the rollout of intelligent metering systems (European Commission, 2009a). These developments can be expected to strongly impact electricity distribution system operators (DSOs), their grid operations, and the role of network infrastructures in the future (Lavrijssen et al., 2016; Pereira et al., 2018a).

While there has been some general discussion on challenges and opportunities for DSOs in a smart grid future (BMWi, 2014; Droste-Franke et al., 2012; Lavrijssen et al., 2016; Siano, 2014), few insights on recent developments and on how DSOs face this transition can be found in the literature (Pereira et al., 2018b). This research aims to contribute

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to a more detailed understanding of the ongoing sociotechnical transition dynamics impacting the electricity distribution industry in the European Union. The research design implemented in this study frames the distribution industry adaptation dynamics as an evolving Large Technical System (LTS). Implementing the LTS conceptual framework in this regard proves particularly useful as its initial conceptualizations were derived from the appearance and evolution of electricity networks between 1880 and 1930 (Hughes, 1983). Now, one century later, the analysis of the complex processes underpinning the power sector, and the changing role of distribution infrastructure, are yet again critical. Particularly for electricity distribution, technological innovations, including distributed generation, electricity storage and demand response, supported by public policy agendas with ambitious decarbonization, decentralization, and digitalization goals; and changing consumer profiles are pressuring stable and reliable distribution systems. In this context it becomes relevant to dedicate efforts for understanding this adaptation process, for Hughes:

> “the effort to explain the change involves the consideration of many fields of human activity, including the technical, the scientific, the economic, the political, and the organizational. This is because power systems are cultural artifacts.” (Hughes, 1983, p. 2).

As a result of this approach, this paper presents empirical insights on the challenges and opportunities that the sociotechnical transition towards smart grids and distributed energy resources represent for DSOs, and for the transformation of the electricity distribution industry in the European Union. The analysis conducted encompasses technology, business model, and market design aspects, for existing contributions in the literature often focus on the specificities of a single dimension. By doing so, we aim at providing a complementary perspective to the following areas of action focused on the electricity distribution industry adaptation dynamics. Firstly, the growing discussion focusing on the regulatory models to be applied on DSOs in the future (ACER and CEER, 2017; CEER, 2015, 2014), as well as the ongoing discussion on the most adequate electricity market design for the EU as part of the Clean Energy for All Europeans policy proposals (Council of the European Union, 2017a, 2017b, 2017c; European Commission, 2016a). Secondly, the efforts in understanding the role of smart grid and distributed generation technologies in a changing electricity system and the opportunities and benefits these represent (Gangale et al., 2017; Giordano et al., 2013, 2011; Giordano and Fulli, 2011; Hall and Foxon, 2014; Krishnamurti et al., 2012; Ruiz-Romero et al., 2014). Lastly, the importance of identifying the most adequate business model innovation approach and capabilities needed to realize the added value possible from new technologies and enabling policies (Helms, 2016; Nisar et al., 2013; Reuver et al., 2016; Shomali and Pinkse, 2016).

The findings presented result from a series of nine multi-stakeholder workshops, conducted in 2016 and 2017, engaging experts in the field, in Germany and Portugal, as two representative EU member countries. Participating stakeholders include experts from research, academia, and industry exposed to both the national and European context on the energy transition. This research was developed within the scope of the project *“The Electricity Sector Transition – Transnational Experiences from DSOs and Cooperatives”* jointly developed by the Energy for Sustainability Initiative (EfS), University of Coimbra, Portugal, and the Institute for Future Energy Consumer Needs and Behavior (FCN) at the E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany.

The remainder of this paper is organized as follows. Section 2 provides background information on the large technical systems conceptual framework, and on the business model, legislative aspects, and technology developments that influence DSOs. Section 3 describes the research design, after which Section 4 presents and discusses the findings. Finally, Section 5 summarizes the main challenges and opportunities identified, whereas Section 6 draws conclusions and provides policy implications and recommendations.

2. Background

2.1. Large technical systems conceptual framework

Large Technical Systems (LTS) encompass a complex network of assets and technologies, organizations, and legislative elements, implemented to deliver critical services to society (Bijker et al., 2012; Ewertsson and Ingelstam, 2004; Hughes, 1987). As a conceptual framework of analysis it focuses on achieving a greater understanding of the interaction and evolution of its elements, aiming at delivering an integrated view of its complex evolution and adaptation (Davies, 1996). In LTS, adaptation and development are driven by the occurrence of reverse salients and critical problems. A reverse salient occurs when an existing or new component operates out of sync with the overall system elements. In the case of electricity distribution, for instance, the growing diffusion of small-scale distributed generation from solar PV and wind technologies represent such reverse salients, challenging the traditional operation of the networks and the regulatory and business operations traditionally in place. Acting upon reverse salients and the challenges they create for the system is what enables transitions in LTS.

The transition-oriented conceptual foundations of LTS have led to two noteworthy streams of knowledge development. Firstly, its direct applications for the understanding of changes in large technical system-based industries, such as those operating energy networks (Bolton and Foxon, 2015; Hasenöhrl, 2018; Markard and Truffer, 2006; Palm and Gustafsson, 2018), water infrastructure (Dobre et al., 2018), and telecommunication, food, and transportation (Davies, 1996; Vleuten, 2018), to name just a few. Secondly, its contribution to the evolving field of enquiry on sociotechnical sustainability transitions (Farla et al., 2012), and its specific analytical approaches, such as the Multi-Level Perspective (MLP) (Geels, 2002; Rip and Kemp, 1998), and the Triple Embeddedness Framework (TEF) (Geels, 2014), which have been used to design policy for a low-carbon development across technologies, firms, industries, and regions.

Furthermore, the relevance of LTS as a conceptual framework has been recently reinforced given its ability to facilitate the understanding not only of the systems’ development and growth, but also of reconfiguration in mature systems, as is the case for electricity distribution (Sovacool et al., 2018). Understanding the recent adaptation dynamics towards a smart and sustainable electricity distribution industry in the EU benefits from this conceptual approach, as its original aim was specifically to study infrastructure-based, capital-intensive industries (Truffer et al., 2010). Considering this, the LTS conceptual framework provides a sensible approach for understanding the sociotechnical transitions in electricity distribution, particularly the changing roles and responsibilities of electricity distribution system operators (DSOs). Therefore, it enables to develop insights for policy making that consider business model, legislative, and technological challenges, as well as opportunities.

2.2. The business model of incumbent DSOs

For the EU, ‘*distribution system operator’ means a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity*. (European Commission, 2009a). For this service of general economic interest, DSOs are remunerated through a regulated tariff. While this description might sum up the incumbent role of DSOs in the past quite well, it falls short when it comes to the recent developments in the context of the sustainable energy transition.

The traditional, asset-focused task of operating, maintaining, and developing distribution grid assets already extends to the operation of smart metering devices, with the DSO becoming a data hub operator (Eurelectric, 2010). The diffusion of distributed generation and storage