Renewable and Sustainable Energy Reviews 79 (2017) 646–655

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A framework to evaluate security of supply in the electricity sector

Erik R. Larsen[a], Sebastian Osorio[b,*], Ann van Ackere[b]

[a] Department of Management, Aarhus University, Fuglesangs Allé 4 DK-8200 Aarhus N, Denmark
[b] University of Lausanne, Faculty of Business and Economics (HEC Lausanne), Quartier UNIL-Dorigny, Anthropole, 1015 Lausanne, Switzerland

ARTICLE INFO

Keywords:
Security of supply
Electricity
Energy security
Framework

ABSTRACT

Security of Electricity Supply (SoES) has become a major concern for regulators and policymakers over the last decade. However, most work focusses either more generally on energy security or on a single fuel. We develop a comprehensive but flexible framework to assess the SoES for a single jurisdiction, taking into the account the specificities of electricity. This framework has two aims: (i) provide a snapshot of the situation to understand current weaknesses and determine what actions are required; (ii) capture the evolution over time to evaluate progress and identify potential problems before they materialise. The framework, based on an extensive literature review, consists of twelve dimensions that are critical for SoES. We develop metrics that capture the state and evolution of each dimension. This framework is intended to be a management information tool for all stakeholders, aimed at organising data and structuring its analysis, to enable monitoring the evolution of the SoES, while also functioning as an early-warning system by flagging potential future problems.

1. Introduction

Energy security (ES) has been a concern for regulators and policymakers since the oil crisis in the seventies [1]. However, security of electricity supply (SoES) has only recently become a major issue. Over the last two decades many countries around the world have developed competitive electricity markets [2], and regional markets are emerging [3], implying an increase in cross-border transmission and trade. Research has thus focussed on the consequences of the deregulation [4] and privatisation of the electricity sector [5], including market design [6,7], market regulation, and providing the right incentives [8].

Over the last few years electricity markets have undergone major changes: decisions to close down nuclear capacity, a shift to renewable energies, insufficient new investments in thermal generation, and the decreasing profitability of utility companies. This has resulted in security of supply becoming a central issue for all the actors of the electricity industry, from consumers, through utility companies to regulators and policymakers; several national regulators have expressed concerns about long-term SoES, e.g., in the UK [9] and in Belgium [10].

The particularities of electricity systems, the changes in the market structure, and the pressure resulting from environmentally driven policies, together with technological innovations over the last thirty years, have also led to a notable change in the technologies used for electricity generation. The significant shift towards gas-fired turbines as the main technology for newly installed conventional generation capacity [8] has, among others, made the European electricity market increasingly dependent on gas imports [11]. Recently, renewable energy technologies have reached a significant share of new installed capacity [12,13]. Regional issues further complicate the situation. For instance, a significant share of Europe's existing generation capacity will soon become obsolete, and thus needs to be replaced [14]. Several countries intend to phase-out nuclear plants, which often represent a non-trivial share of their generation; this will affect future capacity adequacy [15].

These issues need to be understood in the context of environmental factors. For instance, while a move from old generation plants to new gas fired plants typically reduces emissions, the opposite is true when gas fired plants replace nuclear ones [16]. This raises the question of the degree to which renewables can play a role in this replacement. Furthermore, in many countries the grid is more fragile than anticipated, as illustrated by several large blackouts in Europe and the USA [17]. Finally, there is the question of whether consumers are able to understand these issues, and will accept to pay what might be significantly higher tariffs to ensure SoES, generally considered a "non-issue" until blackouts start occurring [18,19]. The magnitude of the economic impact of such events is huge. For instance, the blackout in the U.S.A in 2003 costed between 4 and 10 billion U.S. dollars [20], and according to a study of the Swiss Federal Office of Energy, the cost of a blackout in Switzerland varies between 8 and 30 million CHF per minute [21]. Such estimates do not include less tangible consequences, such as loss of reputation.

* Corresponding author.
E-mail addresses: erik.larsen@mgmt.au.dk (E.R. Larsen), sebastian.osorio@unil.ch (S. Osorio), ann.vanAckere@unil.ch (A. van Ackere).

http://dx.doi.org/10.1016/j.rser.2017.05.085
Received 25 January 2016; Received in revised form 2 May 2017; Accepted 17 May 2017
1364-0321/

Finally, there is the question of time horizon. Investment planning in the electricity system is a long-term process: building new thermal capacity requires at least three years, large hydro might take up to ten years, and the expected lifetime of investments ranges from twenty to more than fifty years. While disruptions to the electricity supply are often attributed to sudden, short term, events (e.g., grid failure, unscheduled plant outage, unexpected demand peak), the true underlying cause is a lack of long-term planning. These disruptions force the regulators to become reactive rather than proactive, preventing them from taking a long-term perspective.

In this paper we develop a framework to assess the level of security of supply of the electricity sector, and its evolution over time, for a single jurisdiction. The term framework refers to a set of principles, ideas, etc., used to form a judgement and reach a decision. Our aim is to provide a framework for regulators, policy makers, utilities and other stakeholders to understand, asses and act on the state of the security of supply of an electricity system.

In legal terms, a jurisdiction is formally defined as "the limits or territory within which authority may be exercised" [22]. In our context, the electricity sector, this refers to a geographical area under the authority of a single regulator, governed by a common set of rules. A jurisdiction may or may not coincide with national borders or with the area under the control of a single system operator. For instance, despite being divided into different areas, each with its own system operator, Germany is considered as a single jurisdiction, because the legislation of its market is determined at the national level [23]. On the contrary, while in the USA the Federal Energy Regulatory Commission (FERC) provides general guidelines and directives to the regional markets, there are well-established, autonomous, regional markets (e.g., PJM, NYISO and ERCOT), each with its own independent system operator and public utilities commission, resulting in very different regulatory frameworks; we therefore consider these regional markets to be jurisdictions. We thus use the term jurisdiction to refer to an area under the control of a single regulator or policy maker.

The paper is organised as follows: first we review the existing literature and outline our framework. Then we develop our framework and the metrics necessary for its evaluation. Next we elaborate on how this framework can be used, and conclude with a more general discussion, including the limitations of the proposed framework.

2. Literature review

Jewell et al. [24] define energy security as low vulnerability of vital energy systems. More concretely, according to the IEA [25], energy security refers to the uninterrupted availability of energy sources at an affordable price. The IEA [26] emphasises the importance of the time-frame: while in the short-term energy security focuses on the ability of the energy system to react promptly to sudden changes within the supply-demand balance, in the long-term it mainly deals with timely investments to supply energy in line with economic developments and sustainable environmental needs. A similar definition is provided by Chester [27], who suggests that the concept is based on ‘reliability’ and ‘adequacy’ at ‘reasonable’ market-determined energy prices. Likewise, Sovacool et al. [28] define energy security as “how to equitably provide available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users” (p. 5846). An extensive review of energy security definitions is presented in Winzer [29]. These definitions illustrate that SoES is a complex concept, with a very broad scope.

Previous work has focused on the conceptualisation of the multiple factors affecting ES, using different approaches depending on the specific fuels analysed, the geographic dimension and the time-horizon under consideration. Other work has focused on specific energy sectors or primary energy sources, (mainly oil, and to a lesser degree gas). Examples include [30–33]. Studies regarding security of oil supply tend to take a global view, while those concerning the gas industry, due to the network aspects, take a regional view [34].

One of the most widely used frameworks, proposed by the APERC [35], defines ES using the four A's: availability, accessibility, affordability and acceptability. Several authors have built on this framework. For instance, Jonsson et al. [36] base their work on the first three A's, focusing on whether energy systems are exposed to insecurity (e.g., infrastructural disturbances), or whether they create insecurity, (e.g., energy used as a “weapon” in geopolitics). Cherp and Jewell [37] build on this definition by discussing whether the four A's deal with the fundamentals of security in the broadest sense. Likewise, Gracceva and Zeniewski [38] propose five properties, strongly related to the four A's, that energy systems should have to ensure supply: stability, flexibility, resilience, market adequacy and robustness. They also identify potential threats to those properties and classify them according to the time-horizon of their impact and the segment of the supply chain that they affect.

Other authors focus on defining the different dimensions of ES, and indicators to assess these, rather than on conceptualising a definition for ES. For instance, Von Hippel et al. [39] propose four major elements that should be included in a definition of energy security: the environment, technology, demand-side management and domestic socio-cultural and political factors. Cherp et al. [40] insist on the need to include environmental factors given the tangible impact of climate change on energy systems. Vivoda [41] adds three further dimensions: human security, international issues and policy aspects. This work [39,41] is closely related to that based on the APERC's four A's [35]. For instance, an environmentally friendly electricity system will gain acceptability from society. Likewise, Kruyt et al. [42] argue that their four dimensions of ES (globalisation, regionalisation, economic efficiency and environmental acceptability) are strongly linked to the four A's. For instance, political embargoes (regionalisation dimension) endanger the accessibility (property) of energy resources.

Several authors focus on evaluating the multiple dimensions of ES. Kruyt et al. [42] provide a review of the available indicators to assess ES in the long-term, while Löschel et al. [43] elaborate on two indicators proposed by the IEA for evaluating the risk of price disturbances and physical availability of fossil fuels. Others develop a single metric for ES by aggregating the indicators used to measure the different dimensions. For instance, Sovacool [28] and Vivoda [41] both calculate a global index to assess the level of energy security in the Asia-Pacific region. The very different nature of the dimensions of ES casts doubts on the usefulness of aggregate indicators: a good performance on one dimension will not necessarily compensate a poor performance on another one; worse, a reasonable overall performance could hide a critical situation on one dimension. Several authors, including [38], are very critical towards the use of indicators due to the simplifications required for their calculation.

Two of the more comprehensive ES frameworks found in the literature are the Model of Short-term Energy Security (MOSES) [44] and the General Energy Assessment (GEA) [40]. The main difference between these two studies is the time frame. While the former focusses on issues affecting ES in the short-term, the latter considers the short- to medium-term. The former considers how an energy system's resilience could mitigate the risks of energy disruptions related to domestic and foreign external factors. The latter proposes three main perspectives (robustness, sovereignty and resilience) to classify threats and mitigation strategies. Thus, while these studies incorporate some aspects of the electricity system, we consider the level of detail insufficient to evaluate the security of electricity supply.

Although the electricity sector and the generation technologies (e.g., hydropower and nuclear power) are included as one element of the ES frameworks previously mentioned [40,44], there is relatively little work focusing specifically on the SoES. In particular, while the Cherp et al. framework [40] includes a wide range of potential threats to energy systems, it only provides a very narrow set of indicators for electricity systems. Furthermore, the impact of renewable energies, which are