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Methodology for energy security assessment considering energy system resilience to disruptions

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ABSTRACT

In this article, a methodology for energy security assessment in terms of energy system resilience to disruptions is presented. The methodology serves as an integrated framework towards the evaluation of energy security, which directly refers to energy system resilience. The proposed model expands the conventional energy system modelling tools with the ability to model the energy system in the environment of stochastic disruptions. Furthermore, the methodology provides an energy security metric, whose main goal is to quantitatively estimate energy security for future development scenarios or pathways of the energy system in terms of its resilience. The methodology is based on the analysis of emerging threats, disruptions and associated consequences to energy systems combined with the energy system modelling tool OSeMOSYS. Furthermore, the model with its characteristics and modelling algorithm are described, the main strengths and limitations are indicated, and potential future developments and applications of the methodology are discussed. An illustrative case study for Lithuanian energy system, including fuel supply, electricity and district heating, is carried out to demonstrate the applicability and capabilities of the methodology. Three scenarios constructed according to different targets of renewable energy, which are being considered in the project of new National Energy Independence Strategy of Lithuania, demonstrate the potential impact of renewables development on energy security.

1. Introduction

Energy security plays a considerable role in the economic growth and social welfare in any country. Most of our nowadays activities and well-functioning of modern societies and economies depend on a reliable and efficient supply of energy. Unexpected disruptions in energy systems can have both an economic and social cost. As a result, energy security has become a key theme not only in the European Union (EU) but also worldwide long time ago. The latest strategic European Commission's (EC) documents [1–5] emphasize the importance of diversifying sources of energy and ensuring energy security as well.

Related to these policy documents, a number of projects have been launched within EU to deal with energy security analysis directly or catching some aspects of this topic. The SECURE project directly referred to energy security and was targeted to build a comprehensive framework that considers all the issues related to the topic of security of supply [6]. The REACCESS project aimed to generate, make available and disseminate many aspects of which one was the capability to analyse the availability and security of each supply corridor/region through a suitable methodology based on the security indicators [6]. One of the objectives of the MILESECURE-2050 project was an analysis of policies, trends and existing scenarios from the national to the worldwide level upon energy security and energy transition [6]. The EUSUSTEL and SESAME projects focused on European electricity sector. In the EUSUSTEL project, a comprehensive analysis of the future European demand and generation of European electricity and its security of supply was carried out, while the SESAME project focused on the securing the European electricity supply against malicious and accidental threats [6]. The REFENS project focused on the preparation of a descriptive map of the various risks to a secure energy future for Europe in the medium to long-term horizons and aimed at developing a methodical framework for quantifying the security of energy system [6]. A bunch of quantitative risk indicators, some of which directly relate to energy security indicators, were developed within the NEEDS project, which focused on energy sustainability issues [6]. Completed and ongoing projects have complemented various high level EC policy documents, which emphasize the relevance and importance of energy security. In the Integrated Roadmap of the European Strategic Energy Technology Plan (SET-Plan), security of supply together with competitiveness and sustainability are pointed out as three overarching

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Abbreviations

BC	Baseline Cost
CHP	Combined Heat and Power
EC	European Commission
ECI	Energy Cost Increase
EMP_E	Energy Modelling Platform for Europe
ESC	Energy Security Coefficient
ESL	Energy Security Level
EU	European Union
FC	Final Cost
IEA	International Energy Agency
NEIS	National Energy Independence Strategy
OSeMOSYS	Open Source Energy Modelling System
RES	Renewable Energy Sources
SET-Plan	European Strategic Energy Technology Plan
TDC	Total Discounted Costs
UE	Unserved Energy
UEA	Unserved Energy Amount
YS	Year Split

energy and climate policy objectives and is one of the main challenges energy system is facing [5].

Energy security and climate change are seen as two main goals of achieving decarbonisation, which directly refers to energy transition [7]. However, meeting the requirements for energy security coupled with decarbonisation is a challenge [8]. Thus, energy security aspects should be addressed when examining the transition to a low-carbon energy system also with decarbonisation pathways.

The first conference "Energy Modelling Platform for Europe" (EMP-E), which took place at the EC in Brussels, Belgium on May 17–18, 2017, had highlighted key themes, such as the Energy Union, its transition, transparency, scenario definitions and the SET Plan. EMP_E aims to initiate a long-term forum for exchanging research, development and practice of energy system modelling in Europe, also to improve the efficiency of research in the area [9]. However, energy security factor in the energy transition was not addressed thoroughly, though it was not the primary objective of the EMP_E. Consequently, this article contributes to the EMP_E initiative presenting a methodology for an energy security assessment to fill the gap between the necessity of this type of analyses.

For that, a clear definition of energy security is critical, since energy security is a concept rather than a policy or a strategy [10]. Energy security is a complex, multifaceted and evolving concept [11–19], however, it still resists a commonly-accepted definition [20–25].

Detailed reviews of energy security definition also reveal that the term energy security is often understood differently, is contextual and dynamic in nature [11,13,17,19,25]. The most common concepts behind the energy security definitions are "reliable and uninterrupted supply", "reasonable or affordable price", "energy availability", "diversity", etc. Even so, such important concepts as "threat", "risk", "disruption", "robustness", "vulnerability", "resilience" do not get enough attention when defining, conceptualizing or assessing energy security. Advanced review of energy security definitions and dimensions [10] points out that resilience has occurred in almost one-third of the discussed literature, however, Cherp & Jewell [13] state that the concepts of risk and resilience do not receive proper treatment in the related literature. More importantly, Cherp and Jewell [26] proposed to analyse energy security from three perspectives: sovereignty, robustness and resilience, which is also pointed out in Refs. [27,28]. This concept later was elaborated and analysed in Refs. [13,27], where energy security is defined as "low vulnerability of vital energy systems". This definition directly reflects energy system resilience since vulnerabilities of vital energy systems are combinations of their exposure to risks and resilience [13,29,30].

According to Azzuni & Breyer [10], resilience means the ability of energy system to withstand diverse disruptions without experiencing change in the energy security baseline, the capacity to tolerate disruption and continue delivering energy services. The coherence of resilience and vulnerability was analysed in Ref. [31] as well. Gracceva & Zeniewski [32] identified five key systematic properties of energy security, which also included resilience and robustness concepts.

We adopt the energy security definition proposed by Cherp and Jewell [13] and agree that energy security is not only the ability of energy system to supply energy to consumers under reasonable conditions and acceptable prices, but energy system should also be able to cope with or to resist potential disruptions arising due to technical, natural, economic, socio-political and geopolitical threats. Energy security in a similar way was also defined by Valentine [33], which distinguishes three criteria, such as availability, affordability and resilience.

Energy security concept, which is used in the presented methodology, is not in contradiction with the definition of the International Energy Agency (IEA), which defines energy security as "the uninterrupted availability of energy sources at an affordable price" [34] and has some common aspects, such as "reliable supply" and "reasonable price" with other definitions, which dominate in the literature. However, energy system resilience approach offers some merits over conventional dimensions of energy security assessment, which are discussed in more detail in Refs. [13,35]. The methodology presented in this article particularly considers the aspect of energy system resilience to disruptions, which directly refers to the level of vulnerability.

Many studies so far have been proposed to evaluate, assess and analyse energy security. Some of them evaluate energy security by employing indicator approach [36–43], use energy system modelling techniques for future energy security [32,44–50] or take into account other aspects of the energy system. Risk assessments may also be applied in this field [51–56] and the proposed methodology relates to that context as well. However, this approach is not widely used in the energy security evaluation and it is demonstrated that risk techniques are not the best way of constructing and quantifying energy security indexes [56].

Energy security in terms of energy system resilience to disruptions is still not analysed in its full extent providing an integral measure for energy security. Some of energy security literature provides recommended measures or metrics for resilience, which are mostly based on indicators or indexes. One of the most commonly used indicators for energy security in terms of resilience is diversity index. This index as resilience measure was applied in many studies [27–31,36,57–60], mostly using Shannon-Wiener index and Herfindahl-Hirschman index. More applications of these diversity measures were also employed towards energy security assessments [61–65]. Energy intensity as a resilience measure of energy security is also quite commonly applied [22,27,28,30,48,49,66], usually expressed as the ratio of the total primary energy supply and the gross domestic product. Other indicators employed to measure resilience in terms of energy security cover capacity and reserve margins [21,28–31,36,39,57,67], storage level [28,30,67,68], supply/demand ratio [31,36,48,67], import dependency [22,66], flexible demand, efficiency and adequacy [21,36,59,60,67].

Although the indicators enable to assess various aspects of energy security using the resilience concept, however, we agree with Cherp & Jewell [29] that an indicator is rarely a direct measure of a risk or a resilience capacity since the energy system is very complex and dynamic in nature. Nevertheless, construction of indicators measuring energy security may be based on a high degree of subjectivity and represent a wide spectrum of focus issues [11,69]. Additionally, various metrics for energy resilience were introduced by Roege et al. [70],