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Review

Assessing energy security: An overview of commonly used methodologies

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ABSTRACT

This paper provides an overview of methodologies used for quantitative evaluations of security of supply. The studied material is mainly based on peer-reviewed articles and the methodologies are classified according to which stage in the supply chain their main focus is directed to, as well as their scientific background. Our overview shows that a broad variety of approaches is used, but that there are still some important gaps, especially if the aim is to study energy security in a future-oriented way.

First, there is a need to better understand how sources of insecurity can develop over time and how they are affected by the development of the energy system. Second, the current tendency to study the security of supply for each energy carrier separately needs to be complemented by comparisons of different energy carrier's supply chains. Finally, the mainly static perspective on system structure should be complemented with perspectives that to a greater extent take the systems' adaptive capacity and transformability into account, as factors with a potential to reduce the systems vulnerabilities. Furthermore, it may be beneficial to use methodological combinations, conduct more thorough sensitivity analysis and alter the mind-set from securing energy flows to securing energy services.

1. Introduction

In recent years the concept of 'Energy Security' has experienced a revival, with a resurging interest from academia as well as policy makers. The meaning and focus of the concept have varied over time and between different disciplines, although some issues have remained firmly on the agenda. For example, the perceived threats to national security due to dependence on a few oil producing regions and supply routes have been a concern and an issue for politicians and scholars since the early twentieth century [1]. However, some security scholars have tried to broaden the analysis by including new threats and actors in the analysis and deepening the perspective by approaching it through the lens of human security[1] [2], a concept originally put forward by UNDP [3]. From a situation when energy security used to be almost synonymous with 'security of oil supply', analyses now also often focus on other energy carriers such as natural gas, as well as renewable energy [4].

In order to curb greenhouse gas emissions and mitigate climate change, renewable energy is expected to increase its share in the global energy mix, see e.g. Ref. [5]. However, there are fundamental differences between renewables and fossil fuels and therefore the security features of low-carbon systems are likely to differ from those of current systems. For example, a move from tapping stocks to managing flows from variable production may require new methods to evaluate the ability to manage demand. Furthermore, a new energy mix may motivate methods to compare different energy carriers and/or supply chains. Also, changed trade patterns and altered or new dependencies between different parts of the system may require methods to study dynamic and structural changes within the system.

Although the term 'energy security' is widely used, the interest in methodology development for evaluating energy security has been less pronounced. This may partly be a result of the sometimes multiple, vague and often diverging meanings of the concept. Strengthening the methodological understanding would be helpful for improving energy security analyses. A first step is to develop a better understanding of the strengths and weaknesses of existing methodologies for evaluating energy security and assess if there are

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[1] The human security paradigm questions the traditional notion of the state as the referent object that is to be secured. Instead the focus is on the level of security of individuals, emphasising humans' access to basic necessities and their well-being. In this mind-set an important policy goal is to reduce energy poverty by guaranteeing the entire population access to basic energy services.

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important aspects that current methods do not capture, thus motivating further methodological development. In such a broad field as energy security, several methods are needed in order to study different aspects and different temporal scales.

To investigate this, we carried out a review of existing quantitative methodologies used to assess the level of energy security in society. Previous reviews of this area have mainly addressed the use of indicators to measure different dimensions of energy security, see e.g. Refs. [6–8]. Such reviews provide valuable information but only cover a subset of the techniques that have been used to date and only treat a limited set of aspects concerning the relationship between energy and security. Furthermore, reviews of indicators mainly address the issue of 'what' to measure, but 'how' and 'why' are as important to consider in order to understand what level of security that can be considered adequate as well as how different systems can be compared and how different policies and strategies impact on energy security, not least in relation to other societal objectives. For example, we may need to improve current methods to assess interactions between interrelated policy areas, for example in the water, energy and food security nexus. The concentration on quantitative methodologies in this paper is a way to limit the size of the study, but does not imply that we think that they are generally preferable to other methodologies and we recognise that quantitative parameters can only capture certain aspects of energy security.

2. Definitions of energy security

Chester [9] described the concept of energy security as 'polysemic' and 'slippery', referring to its tendency to symbolise multiple dimensions at the same time. One underlying cause may be the variation in different stakeholders' perception of what security means and how to reach a desirable level. Some of this variation can probably be explained by differences in how stakeholders value the importance of different parameters, such as decentralisation of supply and energy intensity [10], and national differences, such as whether the country of the stakeholder is resource-rich or a net importer [11] and whether the emphasis in the country is on market solutions or state involvement. There can also be different priorities and opportunities in industrialised and developing countries. In the latter case, energy security tend to be more closely connected to provision of energy access to the poorest in rural areas and, in urban areas, access for the rapidly expanding industry and service sectors [12]. Another explanation for variation is the scientific background of researchers with, for example, political scientists, engineers and complex system analysts often approaching energy security as an issue of sovereignty, robustness and resilience, respectively [13].

Energy security itself is also dynamic, since the perspective may depend on the timeframe analysed. For example, those analysts studying longer timeframes tend to value stability over cost-effectiveness [14]. Overall, the differences in perspectives and priorities have contributed to a debate among scholars on how energy security will change over time and how best to respond to this change [15]. Johansson [16] proposed that a distinction can be made between: i) when the energy system is analysed as an object that is exposed to threats, commonly referred to as 'security of supply' or 'security of demand', and ii) when the energy system works as an agent that generates or enhances (in)security, for example caused by a perceived political or economic value. Thus, the focus of energy security studies and the weights assigned to different factors affecting security will depend on the purpose of the specific analysis. It is therefore improbable, and perhaps undesirable, for researchers to agree upon one single definition and interpretation of energy security.

Winzer [17] reviewed 36 definitions of energy security and he argued that it should be separated from other policy goals, e.g. goals related to economic efficiency and sustainability, by defining it as "the continuity of energy supplies relative to demand", thus narrowing the concept to security of supply. Using this definition, a secure supply chain is a vital requirement in order to deliver the required energy services. The chain can be complex and involve many steps, such as extraction, transportation, conversion, distribution and final use. The chain can also stretch over long distances and across national borders. As an example, crude oil can be extracted in a remote country, transported by oil tanker to a refinery and then distributed by truck to a petrol station. The end user only experiences the final steps, filling up and driving the car. However, researchers and policy makers may be interested in exploring different parts of the upstream supply chain to identify root causes of insecurity, bottlenecks and interactions with other policy domains.

A variety of factors can be considered possible threats or risks that can either deliberately or accidentally lead to disturbances in the flow of energy. However, two interrelated dimensions that consumers are interested in securing can be distinguished [18]: a physical dimension, sometimes referred to as available, reliable and/or accessible energy supply, and an economic dimension that incorporates aspects such as price volatility and affordability.[2] These dimensions are connected, since physically unreliable supply or resource scarcity may affect prices. Low or volatile prices may also reduce investments in infrastructure and production facilities and thus affect the physical dimension, sometimes referred to as supply destruction. Markets should thus be designed so that prices can act as a mediator between producers and consumers and indicate a situation of future scarcity or oversupply.

Although physical and economic dimensions of energy security are frequently emphasised in the definitions it is not common to specify, for example, when high prices should be considered a threat to security. That is, most definitions highlight dimensions and perspectives but do not define thresholds. For the purposes of this overview we do not attempt to formulate a new definition of security of supply. We are interested in the broader research field and not further elaborations of certain security features. Instead we merely note that a variety of definitions exist, but common denominators are generally related to physical and/or economic characteristics.

3. Method and analytical framework

The overview is based on material collected in 2011–2013, searching scholarly databases for peer-reviewed articles using keywords such as 'energy security' and 'security of supply'. Criteria for inclusion were studies of methodological interest, such as generic, state-of-the-art and/or novel methodologies used to evaluate security of supply. We also used snowballing (i.e. pursuing references within references) and, for comprehensiveness, included a few non peer-reviewed reports in this study. Thus, there may be methodologies that have been used to assess security of supply that are not included as authors may use another nomenclature, or if they have not been cited. Furthermore, as the focus of this article is to review methodologies and not individual articles only a limited amount of studies that use the same methodology has been included. Articles in which energy security is mainly discussed, described or studied qualitatively were not included.

[2] Some researchers distinguish between several dimensions, for example by using the 4-A classification, i.e. availability, accessibility, affordability and acceptability, see e.g. Refs. [7,19].