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A systemic approach to assessing energy security in a low-carbon EU energy system

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HIGHLIGHTS

- Develops a framework for a comprehensive and systemic assessment of energy security.
- Develops a scenario analysis to identify the structural changes of a Low-Carbon energy system.
- Assesses the implications of a Low-Carbon EU energy system on energy security.
- Provides foundations for more detailed analysis of climate change/energy security nexus.

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ABSTRACT

Until now, the complex relationship between energy security and climate change has been addressed using a partial understanding of security, one that is based on simplified indicators such as import dependence or fuel mix diversity. As a consequence, the synergies and trade-offs between climate change and energy security policies have not been systematically explored according to a wider understanding of the latter concept. The purpose of this article is to resolve the resulting knowledge gap by proposing a theoretical approach to energy security that is consistent with its multi-dimensional nature, taking into account the whole energy supply chain. Five key 'systemic' properties of energy security will be identified – namely, stability, flexibility, adequacy, resilience and robustness. The paper proposes a novel framework to assess energy security and uses this framework to develop a comprehensive approach to the interactions between climate change policies and energy security. The impact of a low-carbon scenario on one of these five properties (long-term robustness) will be assessed using a complex multi-regional energy system model. The results demonstrate how this scenario induces structural changes along the whole energy supply chain, revealing dynamic vulnerabilities and trade-offs that are not adequately accounted for by existing indicator-based assessments. Finally, the paper provides solid foundations for further analysis of these trade-offs using more detailed sectoral models.

1. Introduction

In recent years a wide range of policies has been introduced in Europe to pave the way towards a low carbon energy system, with the dual objectives of combating climate change and breaking "the cycle of increasing energy consumption, increasing imports and increasing outflow of wealth created in the EU to pay energy producers" [1].

Security of supply, sustainability and competitiveness are the three complementary pillars/goals of the European energy policy [2]. As stated in [3] "these goals are part of the same strategy. Work to achieve one should help deliver the others." The current EU climate and energy targets were designed to be mutually supporting and there are indeed synergies between them. But, as recently recognized by the European Commission there is also a risk that climate-focussed energy policies, if not properly designed, can affect energy security and bring about extra costs, as they support technological and market solutions designed to achieve a different policy objective [4]. Therefore, "the 2030 framework must identify how best to maximise synergies and deal with trade-offs between the objectives of competitiveness, security of energy supply and sustainability" [4].

A key challenge in meeting this objective lies in the different 'natures' of energy security and climate change mitigation. Because GHG mitigation is measurable in a relatively straightforward way, it is clear whether policies are heading in the right direction. On the other hand, even without being set in the context of sustainability, security of energy supply is an inherently complex topic: as underlined by most of the recent literature, much of the discussion

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is "conducted without a clear idea of the dimensions of energy security and their relative significance" [5–8]. In contrast to other energy policy objectives, there is no obvious or universally accepted measure of supply security [9], for two key reasons: (a) energy security is a product of many diverse attributes, from the diversity of gas imports to the capacity margins in the power sector; therefore, it needs to be assessed from a systemic perspective that takes all of these attributes into account [10]; (b) energy security is a product of the interactions and interdependencies of a complex system, one "whose properties are not fully explained by an understanding of its component parts" [11].

The purpose of this article is three-fold: first, to identify methodological deficiencies in existing indicator-based assessments of the links between climate change and energy security and, secondly, to develop a novel theoretical approach to energy security that is consistent with its polysemic and multi-dimensional nature. This requires a 'systemic' understanding of energy security that takes into account the whole energy supply chain and categorises the multitude of threats that may affect the capacity of this supply chain to deliver energy services to end-users. In so doing, the properties of a "secure" energy system will be identified – namely, stability, flexibility, adequacy, resilience and robustness. Thirdly, the methodological requirements deemed crucial for adequately assessing the interactions between a low-carbon and secure energy supply chain will be applied in practice by assessing the implication of a low carbon energy system in Europe by using a complex multi-regional energy system model (TIAM).

2. Assessing the interactions between energy security and climate change policies; a review

The debate on the interaction between energy security and climate change policies is typically framed in terms of the trade-offs and synergies between the two policies. Many studies argue that optimal policies, which can mitigate climate change and enhance security at the same time, are possible (e.g. [12–14]). Others contend that the two goals are often fundamentally at odds [15]. Evidence can be presented for both sides, as considerations of energy security have sometimes trumped climate change commitments and sometimes not [10].

Framing the energy security/climate change policy nexus in terms of synergies and trade-offs creates a compelling case for quantification. Most studies combine a model-based scenario analysis with a set of indicators, which can help to operationalise and hence assess a system as complex as the energy supply chain. Designed to reduce complex phenomena to simple terms and functions, indicators are widely used to abstract from the energy system a few key parameters to give an overall indication of its level of security (for an overview see [13,16,17]). Yet despite their ability to simplify complex phenomena, indicators suffer from some key weaknesses that challenge their actual usefulness as policy instruments. Indeed, the debate about the effect of climate change policies on energy security strategies may defy resolution precisely due to the methodologies that are typically applied in both sides of the argument. Often a handful of parameters to represent 'energy security' and 'climate change' are selected for comparison and analysis under a set of different long-term energy scenarios. But whereas the essence of climate change mitigation policies can indeed be reduced to a desire to control the amount of carbon emitted by humans into the atmosphere, energy security – given its conceptually elusive and multi-dimensional nature – is not so easily reducible to a single property. The consequence is that the existing literature presents at least one of the following shortcomings:

First, energy security indicators are signals useful in conveying condensed information about the state of an energy system, particularly about its potential vulnerabilities. As such, their essence is to simplify what would otherwise be a complex phenomenon defying quantification, because the complexity of energy systems hides multiple dynamic vulnerabilities [18]. The consequence is that a number of studies purporting to explore the interactions between climate and energy security policies end up evaluating the impact of climate policies on only a sub-set of factors that may or indeed may not capture the essence of energy security (e.g. [19]).

Secondly, energy security is a "property of the energy system" [20], therefore an adequate assessment must include all the significant elements of the system and emphasize the relations and interactions between them [21]. It is this interaction of different components that determines the capacity of the energy system "to tolerate disturbance and to continue to deliver affordable energy services to consumers" [22], acting as a cushion to dampen the impacts of a threat [13]. By their very nature, indicators are unable to assess the energy system's *response* to adverse events, i.e. the vulnerability of the system in terms of the actual consequences of energy insecurity, despite claims to the contrary in [13,23,24]. This is because indicators cannot capture the chain of substitutions triggered by an adverse event along the whole supply chain, and hence processes such as primary energy substitutions or demand elasticities go unaccounted for. Indeed, even the most sophisticated analyses of the interactions between energy security and mitigation policies are ultimately based on variables which are *proxies* of the vulnerability of the system [13,25].

A direct consequence of these weaknesses is that many indicator-based assessments often focus on diversity as a desired state for energy systems, making the degree of diversification the *de facto* measure of energy security [26]. For instance, energy security is represented by an index combining import dependency, commodity dependency and energy intensity in [27], by an indicator of diversity of primary energy sources and import dependency in [28], and by the diversity of fuel source mix in electricity in [29]. However, there exist many other dimensions of supply security that extend beyond the issue of diversity alone [30]. Indeed, according to [31] energy security is related to different types of incomplete knowledge: risk, uncertainty, ambiguity, ignorance; each type requiring a different analytical armoury (see Table 1). But the rationale for focusing on diversity is only under the condition of ignorance, i.e. when sources or modalities of the threats are unknown.

Moreover, options to increase diversity means investing in alternatives whose lack of penetration in the energy system may be due to poor performance; thus, enlarging their contributions often incurs some penalty [33]. A key limit of indicators is that they cannot provide insights on this key issue of the costs and benefits of alternative levels of energy security [9,34], which can then be benchmarked against climate targets. Two interesting exceptions on this respect are [35,36], who assess the economic cost of two specific threats, oil price hikes and oil scarcity, with and without a climate policy, as well as the economic costs of not exploiting fossil fuels versus suffering through climate change.

Finally, the indicator-based approach is particularly prone to view energy security as a distinctly supply-side phenomenon. This is the case in several studies where the energy security implication of mitigation scenarios are assessed by looking at aspects such as the market concentration in competitive fossil fuel markets and pipeline-based gas import for regulated markets [37,38]; the structure of global oil and gas production and trade [14]; or a wide set of indicators related to oil and gas resources and production, market concentration and energy trade [13,16,24]. Studies that narrowly focus on supply side-aspects