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Event-related stresses in energy systems and their effects on energy security

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ABSTRACT

Energy systems change over time as events, such as grid failures, new energy sources, and extreme weather conditions, occur, often affecting the system's energy security. Understanding events, their causes, and how they are handled, can help a jurisdiction and its energy stakeholders develop better, evidence-based energy policy.

This paper employs a definition of stress in combination with systems analysis to specify methods for explaining the states through which an energy process, chain, or system passes in response to an event and how this response results in energy security improving, deteriorating, or being maintained. The definition uses three dimensions-availability, affordability, and acceptability-derived from the International Energy Agency's definition of energy security to show when and how a system's energy security will change. Examples are used to illustrate the application of the methods.

1. Introduction

All jurisdictions are associated with an energy system responsible for converting and transporting different types of energy from various sources to meet the demands of its energy services. The system and its sources and services are all subject to events – anticipated and unanticipated – which can potentially affect both the system and the energy security of the jurisdiction. Understanding these events and how they are handled can offer further insight into the functioning of the jurisdiction's energy system and the conditions under which the supplies, prices, and environmental impacts of the energy used to meet the demands of its services—that is, its energy security—can improve, deteriorate, or be maintained.

The majority of research in energy security has for the most part focused on the development of indicators or dimensions and their application to nation-states or specific energy chains within an energy system. At the national level, recent examples of this research include an analysis of energy security in the Asia-Pacific region using 11 dimensions, each associated with a number of attributes [45]; an examination of 10 countries using 16 dimensions of energy security (some of which consider the underlying energy system of each jurisdiction) [41]; an evaluation of energy security performance for 18 countries from 1990 to 2010 using five dimensions broken down into 20 components and 20 metrics [40]; a synthesized list of 320 simple and 52 complex indicators of energy security based on surveys, a workshop, and research interviews [39]; an integrated energy strategy based on a conceptual system model to deal with energy challenges in China [29]; and recommendations for the implementation of and energy strategy for the Republic of Croatia [36]. Examples of research examining specific energy chains include a study of three indicators of energy security as a part of social indicators of sustainability for the assessment of nuclear power in the UK [42]; a detailed examination of natural gas and its contribution to energy security in the UK [37]; a review of China's coal usage in light of carbon-emission constraints and its replacement with natural gas [26]; projections of future oil development in China [28]; a development of a broadened typology to describe an interconnection between energy and security [21]; and a focus on supply relative to demand as the principal view of energy security [47]. There appears to have been little work done with respect to the events that can change an energy system and, consequentially, its energy security.

One notable exception to this was a presentation given by Stirling on how events can change energy security in an energy system [43]. The approach enumerates the places where an event can occur (inside or outside the system) and its temporal characteristics (short-term or long-term); from this, methods for four "energy-security dynamics" are developed (their classification is shown in Table 1).

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Table 1
The four dynamics of energy security (from Ref. [43]).

	Short-term (shock)	Long-term (stress)
External to system	Resilience	Robustness
Internal to system	Stability	Durability

In this, temporal characteristics refer to the time taken for an event to occur: shock events are those which occur immediately or very rapidly and are considered transient (such as a grid failure), while stress events are gradual, occurring over a lengthy period and are enduring (such as annual emissions reduction targets). External events are those that take place outside the system and are beyond its direct control, whereas internal events occur within the system and can be controlled by it. In either case, if the system's response prevents the effects of the event from reaching its energy suppliers or services, or both, the system is said to be resilient (external-shocks), robust (external-stresses), stable (internal-shocks), or durable (internal-stresses). If the system is unable to handle the event, the energy security of those services using the system can be compromised.

An alternative approach to explaining events and event handling in an energy system and the resulting effect on a system's energy security is to examine its processes and the conditions under which an event will cause a process—and possibly the entire system—to reach a tipping point and change from one state to another. By measuring the outcome of an event relative to a metric, a better understanding of the event's impact can be obtained rather than using imprecise terms such as "gradual" or "very rapid"; moreover, such measurements allow the magnitude and long-term effects of the event to be considered. Knowing an energy system's event-handling characteristics allows for the development of policy targeting specific parts of the system to improve energy security.

This paper presents a set of methods for defining, measuring, and explaining how energy security can change as events cause stresses that affect a jurisdiction's energy system. The methods employ a process model which defines the internal processes of an energy system and the indicators required to measure changes to the system. From this, a generic set of event-handling characteristics applicable to any process within the system are developed and specified in terms of definable and measurable stresses associated with the event, their effects on the process, and, potentially the system. The utility of the method is demonstrated with examples.

2. Energy systems, energy security, and energy policy

An energy system is intended to meet the energy demands of a jurisdiction's energy services by supplying them with energy. Since the system itself is only responsible for converting and transporting energy, its demands for energy are supplied by external sources. Moreover, the system must meet certain regulations, specified by regulators, to minimize its impact on the environment. The relationship between the system and its external entities is shown in Fig. 1.

Internally, an energy system has one or more energy chains consisting of conversion and distribution processes leading from a source to a service; the length and complexity of a chain depends upon its energy inputs and the intended demand. If the energy input is a primary energy source, it usually requires conversion into a secondary energy product which can be distributed to energy services for subsequent conversion into tertiary energy. Shorter chains are possible; for example, using a secondary, rather than a primary, energy source.

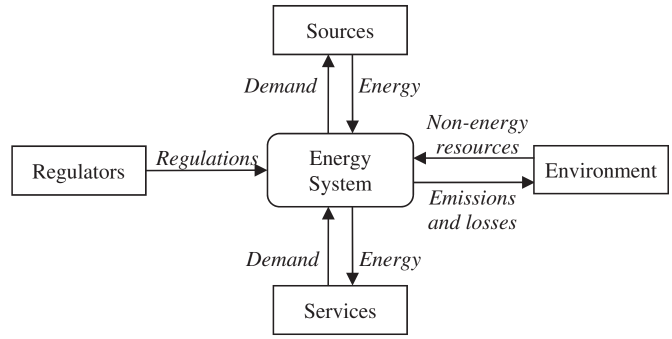

Fig. 1. An energy system and its external entities (from Ref. [43]).

Each process in the chain, whether it handles conversion or distribution, is associated with seven flows. A flow is a logical connection between entities (i.e., processes, energy sources, or energy services), describing the components—such as demand, cost, energy, or emissions—passing between them; it gives no indication about how the component is actually moved. The various flows in Fig. 2 are defined as follows:

1. The $Demand_{IN}$ flow is from a downstream process or energy service requesting energy from the process; it indicates the quantity of energy required.
2. The process attempts to meet the demand specified in $Demand_{IN}$ with the quantity of energy requested; this is indicated by the $Energy_{OUT}$ flow.
3. The $Demand_{OUT}$ request should be met with a flow of energy, $Energy_{IN}$, supplied by an upstream process or energy supplier.
4. All processes (conversion or distribution) exhibit a degree of inefficiency and as a result release emissions or losses, or both to the environment; these are specified by the process's $Environment_{OUT}$ flow. These inefficiencies mean $Energy_{IN}$ is always greater than $Energy_{OUT}$, regardless of the process.
5. In addition to the $Environment_{OUT}$ flow, a process can also require non-energy resources from the environment; indicated by the $Environment_{IN}$ flow.
6. Finally, most jurisdictions (or organizations responsible for the process) have regulations intended to control the actions of the process; these regulations are specified in the $Policy_{IN}$ flow.

An energy chain is constructed from interconnected processes. The first $Energy_{IN}$ comes from an energy supplier, while the last $Energy_{OUT}$ is intended to meet the $Demand_{IN}$ of an energy service. In most, if not all, cases, the output of a conversion process feeds into a distribution process, which in turn feeds into another conversion process. A linear energy chain taking primary energy to meet tertiary energy demand is shown in Fig. 3.

More complex chains can have processes that accept multiple $Energy_{IN}$ flows from more than one upstream process or produce multiple $Energy_{OUT}$ flows, with potentially different types of $Energy_{OUT}$ to various downstream processes, or do both. Similarly, a

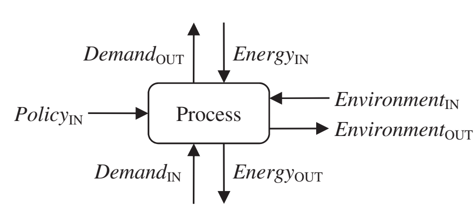

Fig. 2. A generic energy process.