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Complexity, uncertainty and ambiguity: Implications for European Union energy governance

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ABSTRACT

Energy security is an ambiguous concept. Growing academic interest has aimed at defining, conceptualising and measuring energy security, often through indicators. Energy policy in the European Union (EU) is not concerned with energy security's ambiguous conceptualisation, nor does it use energy security indicators, but it refers consistently to security as one of its primary aims. In this paper, by analysing the use of energy security both in scientific publications and in EU policy, we argue that the ambiguity of the concept plays a function in the policy process and is only seen as a problem in the academic literature. Building on the uncertainty literature, we conceptualise ambiguity as the type of uncertainty that emerges from complexity. Complexity leads to the existence of multiple representations of a system, which may serve different purposes in the policy process, generating ambiguity. Uncertainty is mobilised to frame energy policy as a matter of security. This has implications for the science-policy interface: on one hand, the analysis suggests that science's aim of providing holistic assessments and clarifications may not serve its desired instrumental purpose in policymaking; on the other, ambiguity allows for materially ineffective policy measures to persist in the name of energy security.

1. Introduction

Energy security has received growing attention in European Union (EU) and United States (US) public policy since the early 2000s, reviving a concept that had been predominant during the oil crises of the 1970s [1]. While persisting as a priority in national agendas, its definition has evolved in time. Up to World War II, energy security was tied to the supply of fuels for the military [1], linking the concept of security to the military narrative. According to Lippman, "a nation is secure to the extent to which it is not in danger of having to sacrifice core values, if it wishes to avoid war, and is able … to maintain them by victory in such a war" [2]. With the oil embargo of the 1970s, energy security became part of political diplomacy and geopolitical concerns. In this context, it referred to the risks of depending on oil imports, and on the vulnerability of oil trade to international diplomacy and political instability in producing countries. With the publication of the report "The limits to growth" (Meadows et al. 1972), security was also tied to the possibility of physical scarcity of non-renewable energy sources. Starting from the 2000s, the term has been increasingly associated with resilience based on a complex systems perspective [1], with the resource scarcity narrative based on concerns for the depletion of fossil fuel reserves [3], and with renewable energy based on the challenges of a renewable transition [4–6]. Challenges and solutions offered by specific primary energy sources, such as gas, coal, uranium, shale gas and variable renewable sources have also contributed to the proliferation of definitions of energy security. In the EU, security concerns became central to the energy policy agenda following the 2005–09 gas and oil disputes between Russia and Ukraine, and between Russia and Belarus [7]. As the electrification of energy systems gradually increases to incorporate a higher share of renewable energy, energy security has also evolved to incorporate dimensions that are unique to electricity, such as the security of transnational grids [8].

The reintroduction of energy security in policy agendas has sparked academic debates that can be grouped under the field of energy security studies. The view that energy is a key input to all economic processes is widespread in these studies [9,10], and in disciplines such as ecological economics [11–13]. Characterisations of energy security range from the availability of primary energy sources [10], to the stability of internal markets [14], to the affordability at consumer level [3]. While availability and affordability are the two dimensions most commonly associated with energy security [3,10,14–18], it has been linked to a number of other aspects, including for example sustainability [3], sovereignty and resilience [1]. The ubiquity of energy security, and its context-dependent nature [18,19], have been the object of a branch of

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security papers exploring the ambiguity of the concept. Ciută [9] explains the multiplicity of definitions of energy security as a result of the fact that “energy security is a complexity model with interlocking segments and levels of interaction” [p. 132]. Energy security studies recognise that the security of modern energy systems has different characteristics than those attributed to the concept in the 1970s, among other factors because of the increased importance of renewable energy, and attempt to handle the multiple dimensions that are associated with this polysemic concept [19], which sometimes mixes technical and colloquial definitions of energy security.

From a policy perspective, the growing focus given to energy security in EU policy from the early 2000s follows a trend of securitisation of energy issues [20], i.e. “a process where governments frame energy as an existential threat to state interests” [21, p.114]. This is in contrast with previous framings of the 1990s, when energy had been mostly relegated to the technical domain, as highlighted by Kuzemko [22] for the case of the UK. Energy security has long been a recurring theme for many national agendas of countries that are poor in primary energy sources, often used as a justification for disparate policy measures. This was highlighted for the US by MIT economist Paul Joskow [23]: “There is one thing that has not changed since the early 1970s. If you cannot think of a reasoned rationale for some policy based on standard economic reasoning, then argue that the policy is necessary to promote ‘energy security’” [p. 7].

From a governance perspective, energy security is used both as a means to mobilise uncertainty and as a material issue. The multiple definitions provided by academia and the overflow of information do not lead to paralysis-by-analysis, as proven by the fact that the concept of energy security is recurrently used in policy. It is due to the very existence of multiple definitions that one may view energy security as characterised by ambiguity. Focusing at the interface between science and policy, there is a clear gap between the conceptualisations and measurements of energy security in academia, and the (non-)issue of ambiguity in policymaking [24].

Although some authors recognise that ambiguity plays a role in policy-making [25–27], scientific literature largely sees ambiguity as a problem and aims at reducing this type of uncertainty. Stirling [27] argues that ambiguity is a type of uncertainty due not to lack of knowledge, but to the existence of “contradictory certainties”. He submits that the real challenge at the science-policy interface is the failure to recognise this type of uncertainty and to reduce all scientific advice to risk assessment. However, this insight has fallen through and scholars that analyse the science-policy interface still argue for reducing ambiguity. We argue that the role of ambiguity in governance is poorly understood and that reducing ambiguity may not always be functional in policymaking. This is in contrast with the predominant view that scientists should work towards the clarification of slippery concepts: Wellstead et al. [28], for example, recognise that policy problems and solutions can be framed in different ways, leading to ambiguity, yet argue that scientists should take a normative stand and support a specific framing in order to reduce said ambiguity.

The aim of this paper is to contribute to a better understanding of ambiguity as distinct from other types of uncertainty, drawing from complexity theory. We use energy security as our empirical reference. We analyse and compare the multiple representations of energy security in scientific literature and in EU policy documents, and assess the level of uncertainty associated with each representation. Even though energy security is recurrently described as an ambiguous concept, to our knowledge no attempts have been made at conceptualising ambiguity in this context, nor to theorise the role of ambiguity in energy governance.

Because the contribution of this paper is primarily theoretical, we first develop a theoretical background that conceptualises ambiguity as the type of uncertainty created by complexity, and we discuss the implications of ambiguity for the science-policy interface. We use text analysis to identify the different types of uncertainty, including ambiguity, mentioned in scientific publications and EU policy documents. Section 3 introduces the materials and methods used. The results (Section 4) show the multiple scales of analysis used to define energy security and the types of uncertainty associated with it. Based on our results, we return to the discussion of how this type of uncertainty does not lead to paralysis in the policy process in the EU context, but rather provides a rationale for materially ineffective policy measures. We conclude the paper by arguing that our finding about the (non-)issue of energy security definitions at the science-policy interface has theoretical implications for the role of ambiguity as distinct from other different types of uncertainty in policy processes, which requires a careful consideration of the limits of holistic assessments in guiding policy.

2. Conceptualising ambiguity

In general terms, energy security is recurrently linked to risk [26], uncertainty [29] and ambiguity [9,16–19,25,26,29–31]. Because of the extensive use of these terms, it is important to clarify their meaning. In this paper, we draw upon the work of Knight, Stirling and Wynne [32–34] on uncertainty, and of Funtowicz and Ravetz, Zellmer et al., Strand, Kovacic and Giampietro [35–38] on complexity.

Knight [32] first introduced the distinction between risk and strict uncertainty in economics in his foundational work in the 1920s, defining risk as a situation in which the possible outcomes are known and the probabilities associated with each outcome can be calculated. Strict uncertainty is defined as a situation in which the possible outcomes are known but the associated probabilities cannot be calculated. We speak of “strict uncertainty” to distinguish the technical definition of uncertainty from the general study of uncertainty, which includes risk, strict uncertainty, ignorance, indeterminacy and ambiguity. In the case of energy security, strict uncertainty can be associated with events such as price volatility [26], and disruptive events such as tsunamis [29], which are known to occur, but cannot be precisely predicted. The novelty introduced by Knight is that uncertainty is conceptualised as a matter of degrees of (lack of) knowledge[1] .

Building on the idea of degrees of uncertainty, Wynne [34] identifies four types of uncertainty: (i) risk, in which the odds are known, (ii) strict uncertainty, in which “we know what we don’t know”, (iii) ignorance, in which “we don’t know what we don’t know”, and (iv) indeterminacy or systemic uncertainty, in which “causal chains or networks are open”. With regard to energy security, ignorance may be associated with geopolitical threats derived from “insecure political and unstable economic environments” [39], as well as with the emergence of new technologies, such as fracking, which introduce unforeseen opportunities and risks. Indeterminacy is associated with systemic changes, or what some authors call phase changes. “Threats like delivery disruptions or global warming of more than 2 °C can be seen as phase changes, because in addition to having a direct impact on consumers they also change the way in which the system works” [13 p.11]. In the context of indeterminacy, uncertainty is irreducible, as systemic changes reduce the possibility of knowing.

Stirling [33] reorganises Wynne’s levels of uncertainty in a 2 × 2 matrix, which ranges from known to unknown outcomes and known and unknown probabilities, and introduces ambiguity as an additional type of uncertainty. Once again, risk is defined as known outcomes and known probabilities, strict uncertainty as known outcomes and

[1] Knight’s definition of risk has been criticised in the literature for not taking into account “how people perceive uncertain phenomena and how their interpretations and responses are determined by social, political, economic and cultural contexts, and judgments” [32 p. 237]. The concept of risk is thus not fully captured by a technical definition of calculable probabilities and effects. Renn et al. [93] criticize the reduction of risk to calculable probabilities for this concept may lead to the use of “technocratic, decisionistic and economic models of risk assessment and management” [p. 234].

unknown probabilities, and ignorance as unknown outcomes and unknown probabilities. According to Stirling, ambiguity is defined as a situation in which probabilities are known but outcomes are unknown. The ambiguity of outcomes is not necessarily due to lack of knowledge, but to the fact that one cannot predict which of the known outcomes will be realised [27], because of divergent and contested perspectives on the justification, severity or wider meanings associated with a perceived threat [40]. In their historical analysis of the evolution of energy security, Cherp and Jewell [1] discuss how the concept has been used to pursue different outcomes. The concept of ambiguity thus suggests that uncertainty may be mobilised to pursue different goals, not because of a lack of information, but because a plurality of representations can be accommodated.

In the context of uncertainty, the linear model of science speaking truth to power is questioned, not only because science may produce incomplete knowledge, but also because social and political threats indicate that decisions cannot be reduced to rational, utility-maximising, get-the-facts-then-act models [41,42]. With regard to energy security, distinguishing between different levels of uncertainty is critical for decision-making. For example, after the Fukushima accident, experts declared that new designs for nuclear power plants took into account the risk of earthquakes [43]. Better designs, however, do not solve the uncertainty linked to the unpredictability of earthquakes and tsunamis. Safer designs refer to advances in the reduction of operating risk at the level of the power plant. Strict uncertainty about earthquake forecasting (higher levels of uncertainty) cannot be factored into new nuclear designs. The undistinguished reference to uncertainty with disregard to the type of uncertainty in question may create a false illusion of control, and a diffuse understanding of the role, and limits, of scientific knowledge in decision-making.

Stirling's reference to open causality and unpredictability invokes complexity. Many authors have studied the implications of complexity for governance and public policy [35,37,44–46]. In this literature, complexity is often defined in opposition to simplicity [37,45], and as a criticism of the instrumental understanding of the system to be governed through the lenses of reductionism, determinism, predictability and mono-causality. Positive definitions of complexity, however, are many and contrasting.

Strand [37] distinguishes between thin and thick complexity, Geyer [47] speaks of reductionist complexity, soft complexity and complexity thinking as a new epistemology of science, and Salthe [48] provides five definitions of complexity ranging from measurable complexity to ontological complexity. Thin and reductionist complexity can be used as a means to recognise "reality" as differentiated and changing. A system is defined as complex if the whole presents emerging properties that cannot be inferred by analysing only the components of the system. The non-linearity and emerging properties of complex systems challenge predictability. Thin complexity departs from the positivist and reductionist use of scientific facts that underpins the linear model of science speaking truth to power. In this case, complexity is also used to reject post-modernism [49], and to postulate the existence of a complex "reality" out there, whose complexity is independent of the observer.

Concepts of thick complexity and complexity thinking, as well as Salthe's [48] insistence on the role of the observer in all definitions of complexity, create an understanding of complexity as a consequence of analytical choices as much as of what is observed. In this view, complexity requires the use of multiple scales of analysis [36,50,51], so that both local rules of interaction between system components and emerging properties of the whole can be observed. These multiple observations, however, are not reducible to one another, leading to the existence of non-equivalent descriptive domains [38,52].

The epistemology of complexity does not refer to knowledge *about* complex systems, but rather yields a relational understanding of knowledge as the correspondence between what is observed and what is modelled, building on Rosen's modelling relation [53]. For this reason, both Salthe [48] and Kovacic and Giampietro [38] refer to Peirce's semiotics [54], the study of signs as a triadic relation between representation, application and interpretation of experiences. That is, knowledge cannot be separated from action. As Strand [37] argues "craftsmanship and tacit quality judgments play an integral part in the process of transformation from a scientific finding to a fact." Rather than the study of systems "out there," complexity is the study of "holons" [55], that is, the relationship between (i) the knowledge generated, (ii) the choice of narratives defining causality between observables [38], and (iii) the choice of a temporal scale of the model, determining how knowledge is updated with experience (as an application of the knowledge itself) [43].

Similar to uncertainty, complexity poses a challenge to the interface between science and policy. Complexity theory is used by many authors to critique the use of reductionist science to guide decision-making [44–46], and is used to encourage more pragmatic, humble, reflexive and adaptive approaches to policy making [37,38,45,56]. Complexity is also used to describe the policy process as affected by negative and positive feedbacks, attractors and path dependence [44,46]. In line with our aim of conceptualising ambiguity and its role in governance, we build on the relational understanding of complexity as a means to critically re-think the implications of limited and contradictory knowledge for decision-making. Semiotics can be used to argue that science plays a role in the creation of emergent complexity [35]. For instance, through technology, scientific research is also a form of intervention in the world [37].

We argue that the contribution of complexity theory consists not so much in the type of science advice that can be derived from the concepts of emergence, non-linearity, open causality, self-organisation, etc. Geyer and Cairney [44] correctly remark that these concepts are newish, as the messiness of policy making has been long studied in political science with no need to make reference to complexity. Rather, we submit that complexity theory is most usefully deployed in questioning the relationship between science and policy. Rather than speaking a more nuanced and complex truth to power, relational complexity makes it possible to analyse the mutual relation between science, scientific truths and power. The linear model relies on the rational use of scientific facts produced by supposedly neutral scientists. Questioning the linear model requires taking a critical stance also with regard to scientific facts and the role of experts. The epistemic pluralism [57] of complexity is an alternative concept to monolithic and unifiable truths of Newtonian science. Therefore, the study of ambiguity may lead to insights about the role of experts.

Building on Stirling's definition of ambiguity as a type of uncertainty, we conceptualise ambiguity as the uncertainty created by the existence of multiple non-equivalent representations of the same issue. Ambiguity is thus not just a matter of different opinions, as may be the case of the rise in the price of oil (perceived as beneficial by oil producers and problematic by oil importers). In linking ambiguity to complexity, we argue that this type of uncertainty is caused by the existence of incommensurability in the knowledge base. That is, although a lot of information can be produced about energy security, there is no univocal way to combine these representations, as can be seen in the proliferation of energy security indicators [17,25,39] and of academic papers dedicated to the conceptualisation of energy security [26,31].

The role of ambiguity in policy has been widely analysed in the literature [33,58–61]. According to Matland [58], ambiguity is necessary to limit conflict (ambiguity of goals), and to define policy when there is uncertainty over the technology needed or over the role that various organisations are to play in the implementation process (ambiguity of means). With reference to the EU, Zahariadis [59] explains that ambiguity is an integral part of the policy making process in contexts where there is a plurality of, often contrasting, interests, a multiplicity and high turnover of actors, and highly bureaucratic systems that cause a fragmentation of the policy process. Shackley and Wynne [62] suggest that ambiguity may not only be preferred over

Table 1
Definitions of energy security from the scientific literature.

Paper	Framing (definition/dimensions) of energy security	Uncertainties	Scales
Bahgat [66]	Security defined differently w.r.t. price: "security involves achieving a state where the risk of rapid and severe fluctuation of prices is reduced or eliminated". W.r.t. technology: "Energy security depends on sufficient levels of investment in resource development, generation capacity and infrastructure to meet demand as it grows". W.r.t. to diversification: "Security of supplies can be enhanced by an overall diversification of supply".	**Risk:** In relation to price volatility: "In respect of price, security involves achieving a state where the risk of rapid and severe fluctuation of prices is reduced or eliminated". Risk of dependence. Threats can be geological or geopolitical.	Global, energy system Long-term
Bielecki [10]	Definition: "reliable and adequate supply of energy at reasonable prices"	**Risk:** "Short-term security covers the risks of disruption to existing supplies due to technical problems, extreme weather conditions or political disruptions. By contrast, the long-term security focuses on the risks that new supplies may not be brought on stream on time to meet growing demand"	Global, national Long-term, short-term
Cherp & Jewell [1]	Three perspectives: sovereignty (political science), robustness (engineering), resilience (economics/complex systems)	**Ambiguity** Energy security challenges are increasingly entangled so that they cannot be analysed within the boundaries of any single perspective	Global, national
Chester [19]	Six aspects: 1) risk management; 2) reliance on imports; 3) strategic use of the term; 4) its temporal dimension; 5) differences between energy markets and 6) how different actors have different perspectives on security	**Risk:** "the risk of interrupted, unavailable energy supplies; the risk of insufficient capacity to meet demand; the risk of unaffordable energy prices; the risk of reliance on unsustainable sources of energy. These risks may be caused by energy market instabilities, technical failures or physical security threats" **Ignorance:** "The meaning of energy security differs over the short, medium and long term because the probability, likelihood and consequences of different risks or threats to supply will vary over time."	International, national Short, medium and long term
Ciuta [9]	Three logics: a logic of war for energy security (what states do war with/over), a logic of subsistence (energy need, complexity model of interacting parts) and a logic of 'total' energy security (ubiquity and reflexivity)	**Risk:** Can also be called "challenges" or "threats" and "vary from market failures and price volatility to investment risks, network disruptions and import dependency". **Ambiguity:** "Energy security clearly means many different things to different authors and actors, and even at times to the same author or actor."	Global and international, energy system
Costantini et al. [64]	Refers to IEA definition "Energy security is defined as the availability of a regular supply of energy at an affordable price" and to the dimensions identified by the European Commission: physical, economic, social and environmental	**Strict uncertainty:** Makes the distinction between reserves and resources: the more the energy system depends on resources, the more uncertain it is. There is great uncertainty about oil supply from Middle East & Africa. Gas supply is less uncertain.	International, national, consumers Short-term and long-term
Hughes [5]	Refers to IEA definition: "the reliable supply of energy at an affordable price". 4 R.s: review of supply and infrastructure; reduce through conservation and efficiency; replace insecure supplies with secure ones through diversification and renewables; restriction of new demand	**Indeterminacy:** In many of the above examples, replacement policies that were introduced to improve energy security have, overtime, become energy-security problems in their own right. This reflects the temporal nature of replacement programs based upon finite supplies, from natural gas to agricultural energy crops.	Global energy market, energy system, consumer
Jansen & Seebregts [31]	Affordably and competitively priced, environmentally acceptable energy end-use services by the term energy services security (ESS)	**Strict uncertainty:** Resilience as a means to reduce uncertainty - "Enhancing societal resilience against long-term price volatility in the face of the strong inertia of national or regional energy systems"	National, regional, society, consumers Long-term
Jun et al. [17]	"Energy security can be defined as a reliable and uninterrupted supply of energy sufficient to meet the needs of the economy at the same time, coming at a reasonable price"	**Risk and strict uncertainty** Related to reliability of supply Dependence of OECD countries on oil supplied from politically unstable regions; increasing energy demands worldwide for the next few decades in line with emerging economies and rapidly growing developing countries; increasing concerns for oil and other fossil fuel depletion, localized geopolitical instability	Global, international dynamics, national
Kiriyama & Kajikawa [29]	A shift from ensuring self-sufficiency of primary energy to diversification of secondary energy supply	**Risk and strict uncertainty:** Risks are quantified: "to appropriately assess the types of risk posed by hazards, we should consider essential societal changes— macro or micro, economic, political, social, environmental, scientific, technological, human health, etc.—taking into account future uncertainties." **Ambiguity:** The degree of ambiguity "resulting from energy security being open to more than one interpretation when bibliometrics are applied" is quantified. Ambiguity here	National, energy system

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Table 1 (*continued*)

Paper	Framing (definition/dimensions) of energy security	Uncertainties	Scales
		arises from the multiple perspectives of energy security literature.	
Kruyt et al. [15]	4 dimensions: availability (geological), accessibility (geopolitical), affordability (economical) and acceptability (environmental)	**Risk:** Supply and disruption risks, political stability risks, price movement risk **Strict uncertainty:** Uncertain reserves estimates	Global, international, energy system Long-term, short-term
Leung [18]	A supply-based definition for China, where the quest is for a "reliable and adequate supply of oil"	**Ambiguity:** 'energy security' is not a self-explanatory concept and researchers should formulate and contextualize it when applying it to a given country. "China's current energy security measures aim at the quest for a 'reliable and adequate supply of oil,' but pay less attention to the maintenance of 'reasonable prices.' It is because 'reasonable prices' per se is an elusive goal and is judged by subjective criteria."	National, energy system Medium to long-term
Mansson et al. [4]	Security has evolved from meaning security of oil supply to including energy carriers. In industrialized countries, "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". Two dimensions: physical and economic	**Risk:** For the case of markets, makes the distinction between specific, systematic and systemic risk. Specific: diversifiable (unique to every exported and supply route); systematic: market risk; systemic: the risk of market collapse.	National, energy system, consumers, industry and service sectors
Natorski & Surallés [65]	Security in the EU framed in terms of energy supply and dysfunctions in global energy markets	**Strict uncertainty:** "These observations were further aggravated by other uncertainties surrounding energy, such as the perspectives for global demand, price volatility, and the actual capacity of producer countries to supply the energy demanded due to the lack of necessary investments." "Uncertainty could be further aggravated by natural disasters or other accidents having a negative impact on energy, especially on prices and accessibility"	Global, EU, national
Sovacool & Brown [16]	4 dimensions: availability, affordability, efficiency and environmental stewardship	**Ignorance:** Difficult to determine the extent to which countries are responding to ES challenges related to climate change **Ambiguity:** As a problem to solve: "This study provides precision, breadth, and standardization to the often ambiguous concept"	Global, national
Sovacool & Mukherjee [25]	5 dimensions: availability, affordability, technology development, sustainability, and regulation	**Ambiguity:** "The concept has become diffuse and often incoherent". "Energy security is integral to modern society, yet its very ubiquity makes it prone to market failure and under-distribution"	Global, national, energy system Short and long term
Sovacool et al. [3]	"How to equitably provide available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users". It has 5 dimensions: availability, affordability, technology development, sustainability and regulation	**Risk:** "The security of supply and the concentration of energy fuels among countries, theories about peak oil, rising prices, and energy poverty, to name only a few, have all become prominent concerns among policymakers and investors"	Global, national
Umbach [6]	Security as a geopolitical issue (security of supply)	**Strict uncertainty:** Of oil production, oil and gas reserves, of investments, of mid-term challenges, of reliance on gas imports	Global, EU Mid to long-term
Winzer [26]	"The continuity of energy supplies relative to demand"	**Ambiguity:** The concept is blurred, elusive, slippery, difficult to define, umbrella term **Risk and indeterminacy:** "Threats like price volatility or marginal rises of global temperature can be seen as small changes in the sense that they have an impact on consumers but don't change the way the system works. And threats like delivery disruptions or global warming of more than 2C can be seen as phase changes, because in addition to having a direct impact on consumers they also change the way in which the system works"	Global, consumers
Yergin et al. [14]	The definition of security depends on the country: can be security of demand, control over strategic resources, concern over price changes, ability to adjust to new global markets, diversification, whether to build new nuclear plants, etc.	**Risk and strict uncertainty:** "The growth of Russia's output slowed substantially last year because of political risks, insufficient investment, uncertainties over government policy, regulatory obstacles, and, in some regions, geological challenges." "The tens of billions of dollars required to bring the industry's output back up to its 1978 peak of 3.5 million barrels per day have not been invested both because of the continuing attacks on the country's infrastructure and work force and because of uncertainty about Iraq's political and	National, energy system

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Table 1 (*continued*)

Paper	Framing (definition/dimensions) of energy security	Uncertainties	Scales
		legal structures and the contractual framework for investment" **Indeterminacy:** "Part of that challenge will be anticipating and assessing the "what ifs." And that requires looking not only around the corner, but also beyond the ups and downs of cycles to both the reality of an ever more complex and integrated global energy system and the relations among the countries that participate in it"	
Yusta et al. [78]	Energy has evolved from supply of affordable energy to a broader concept including: "price stability, diversification of energy resources, energy storage, economic investments, infrastructure protection, political and military power balance, geopolitics, homeland security, energy efficiency, energy markets, sustainability"	**Risk:** "The term "risk" refers to a combination of what can happen, how likely it is, and its consequences. The term "threat' is more related to harmful acts to infrastructure. 'Vulnerabilities" refers to the weakness level of a system to failures, disasters or attacks" "In case an emergency arises decision makers must understand the interdependences in the underlying infrastructure."	Supranational, national, energy system
Zhang et al. [39]	Related to import risks	**Risk:** Four dimensions relating to: external dependence (dependence risks), supply stability (supply risks), trade economy (economic risks) and transportation safety (transportation risks)	Global, international, energy system

knowledge in decision-making, but may also provide more robust scientific tools than those generated by a precise knowledge base. Understanding the function of ambiguity in the policy process has important consequences for the interface between science and policy. Whereas numerous studies argue for more holistic and integrated conceptualisations of energy security [1,25,29], Matland warns against the dysfunctional effects of clarity in policy implementation.

The literature on energy security is replete with examples of paradoxes and inconsistencies that emerge from the multiple definitions of energy security [1,9,25]. According to Sovacool and Mukherjee [25], a paradox arises as "energy security is integral to modern society, yet its very ubiquity makes it prone to market failure and under-distribution" [p. 5343]. That is, complexity is manifested in the multiple, non-equivalent representations, conceptualisations and quantifications of energy security and the resulting heterogeneity of policies. Building on our analysis of energy security, we will return to the theoretical discussion of how ambiguity challenges the relationship between science and policy in the discussion section.

3. Materials and methods

Following our theoretical focus on uncertainty and complexity, we use text analysis to identify how these concepts are articulated with regard to energy security. The aim of this analysis is to identify the multiple representations of energy security across scales, and their level of uncertainty. Both scientific literature and policy documents are analysed. As can be expected, scholarly articles focus predominantly on defining and measuring energy security, and policy documents focus on identifying different policy measures to increase energy security.

For the literature review, twenty-three papers on energy security were analysed, published between 2002 and 2014. The papers are among the most cited on the topic, and provide a comprehensive spectrum of how energy security is assessed in academia. They include perspectives from economics, engineering, geopolitics, policy, technology, political science, finance and geology, and were selected using citation indexes from Web of Science and the snowballing technique [63].

On the policy side, focus is given to the EU, which we chose as case study because (i) energy security has been part of EU policy since the creation of the EU [1,9], (ii) many of the scientific articles analysed aim at informing EU policy [6,26,64–66], and (iii) energy security has been a high priority of the EU policy agenda since the 2008 gas crisis with Russia [1,6,10,14,66].

Three branches of EU documents are considered: the Energy Security Strategy (2014) [67], the Clean Energy for All Europeans package (2016) [68] and energy directives in force [69–72]. Additionally, the 2015 State of the Energy Union report [73] is analysed. The aim of the policy analysis is to obtain an overview of the role played by energy security in EU policy, of which measures have been proposed as a means to increase security, of which issues are seen as problematic and of how uncertainty is handled. Therefore, the policy analysis is not constrained to legal documents, but also includes press releases and fact-sheets [74–77], as they can provide valuable insights into the underlying narratives surrounding energy security in EU policy.

The texts are coded for definitions of energy security and policy measures, scales and dimensions of analysis, as well as uncertainties, risks and ambiguities. The categorisation of energy security into different disciplines, domains, dimensions, pillars and principles is popular in the literature and the terms, often referring to different scales, are sometimes used interchangeably. Without delving deep into this categorisation, our interest lies in the different scales and types of uncertainty. The term scale is used here to refer to geographical dimensions (e.g. city, province, nation, region, world), temporal dimensions (short-term, long-term), and to hierarchical levels of analysis (energy system, energy sector, renewables, wind power, wind farm). There is no 1:1 mapping between geographical dimensions and hierarchical levels of analysis: the energy sector, for example, may refer to a specific country or to the global economy. This broad category of scale is used in this paper to capture the multiple levels of granularity used in the literature to describe energy security. Having identified scales, definitions or dimensions (for academia) and measures (for policy) linked to energy security, the next section discusses the role that complexity plays in the energy security knowledge base, and the role that the ambiguity arising from complexity plays in policy.

4. Representations and uncertainties of energy security

Results start with the analysis of energy security, as approached in literature. Focus is given to the definitions and dimensions used to characterise energy security, as well as the type of uncertainty that is discussed in relation to these dimensions, and to the relevant scales of analysis (Table 1). While the first two columns of the table refer to what was found directly in the text of each article, the third column was added in order to discuss the multi-scalar character of the concept of security. The distinction between risks, strict uncertainty, indeterminacy and ambiguity follows the levels of uncertainty discussed in the theoretical framework. We analyse all types of uncertainty mentioned in the documents in order to show how the general argument for reducing uncertainty is applied indiscriminately to all types of uncertainty, including ambiguity. Stirling [27] argues that whereas risk may be usefully described using scientific assessments, strict uncertainty and ambiguity require humility and the recognition of the limits of scientific knowledge. Limits are not to be confused with lack of validity, but are a request for more modest claims. Responding to our aim of theorising the role of ambiguity in policy processes, we will add to this argument and show that different types of uncertainty have different functions in the policy process.

Energy security is connected by different authors to a large number of dimensions, from availability and affordability to resilience and technological development. These dimensions are linked to different scales, ranging from individual technologies to global economy, climate and reserves. The most common type of uncertainty discussed is risk, which is strongly linked to security discourses. Ambiguity is also mentioned, mostly as a problem to be solved, and different types of uncertainties are identified by different authors, mostly linked to global resources and supply stability [15,17,64,79] and price volatility [31,79]. Natural disasters are also mentioned [26,79]. Following the distinction proposed by Wynne, these events fall under the category of indeterminacy.

The results of the text analysis of policy documents are shown in Tables 2a and 2b. Table 2a refers to direct measures, which are cited in the Energy Security Strategy. Table 2b refers to indirect measures present in wider EU energy policy, linked to energy security as one of many aims. The uncertainties reported in the tables are not mentioned directly in the policies but were identified based on the type of measure proposed.

Looking at the characterization of energy security in science and policy, the results of both tables show that: (i) there is interdependence across scales of analysis, (ii) uncertainty is central to energy security and (iii) ambiguity is treated differently in science and policy.

There is interdependence across scales of analysis in the dimensions of energy security used both in the scientific literature and in policy documents. Energy security is framed as the combination of (i) security of supply (availability and reliability), and (ii) security of demand (affordability). The need to match supply and demand requires handling the interplay of constraints posed by elements external to socio-economic systems, such as the availability of fossil fuels, solar radiation, water courses, and elements internal to socio-economic systems, such as geopolitical concerns, import dependencies, diversification of suppliers, transportation, infrastructure, technologies, distribution and accessibility issues, and price volatility. The external-internal duality permeates energy security definitions. Moreover, energy security applies to multiple hierarchical levels of analysis. Demand issues refer to the distribution of resources at a global, regional and national scale with regard to energy markets, infrastructure and economic sectors, and at the individual level with regard to consumers. As a consequence, the concept of energy security is based on the interdependence between different hierarchical levels of analysis and the external-internal observation duality.

Uncertainty is central to the concept of energy security. Degrees of uncertainty can be seen in the distinction between different threats. Threats coming from price volatility and technical problems are defined as risks to the system. Reliability of supply and geopolitical concerns may be defined as strict uncertainties (known but not quantifiable). Threats such as peak oil, increasing demand and climate change are seen as sources of indeterminacy that may cause changes in the system. Uncertainty is seen as a property of the system with regard to the high dependence of non-oil producing countries on foreign oil, the high level of inertia of the energy system, and the ubiquitous use of energy in economic activities. Risk, strict uncertainty and indeterminacy have a central role in the definition of energy security. Contrary to ambiguity, these types of uncertainty provide a common ground for the definition of energy security for both science and policy.

In policy documents, the interest lies in the sources of uncertainty. Different sources of uncertainty are used as a means to define and classify policy measures. Uncertainty of supply is the most recurrent source of uncertainty mentioned. It is related to import strategies, to market instability and to technological development. Uncertainty of demand is also present and is related to improvements in efficiency, moderating consumption, and reducing carbon emissions. Contingency measures reveal an additional source of uncertainty, related to ignorance. They include protection and back-up infrastructure, reserves of critical energy sources, and contingency planning.

Ambiguity plays very different roles in science and policy. While ambiguity is mentioned in most of the scientific articles analysed, and is often the central motivation for the work of clarification,

Table 2a
Direct measures of energy security in EU energy security strategy [80], their scales and uncertainties.

Pillar	Measures	Scales	Uncertainties
1. Immediate actions aimed at increasing the EU's capacity to overcome a major disruption during the winter 2014/2015 (short term)	Enhance storage capacity, develop reverse flows, develop security plans at regional level, explore potential of LNG	EU, regional, forms of energy, energy system	Risk of disruption
2. Strengthening emergency/solidarity mechanisms including coordination of risk assessments and contingency plans; and protecting strategic infrastructure (short term)	Maintain minimum reserves of crude oil and petroleum products, invest in back-up infrastructure, physical protection of critical infrastructure, contingency planning/stress tests	EU, national, energy sector, forms of energy, energy sector	Contingency measures to reduce ignorance
3. Moderating energy demand (short term)	Speed up measures to achieve 2020 efficiency targets, focusing on buildings and industry	Building & industry sectors	Uncertainty of demand
4. Building a well-functioning and fully integrated internal market (medium to long term)	Discuss decisions at EU level, develop an internal electricity market, build key interconnectors	EU, electricity sector	Uncertainty of supply (market)
5. Increasing energy production in the European Union (medium to long term)	Increase renewables (which will require smart energy grids and storage capacity), carbon capture & storage	EU, national level, forms of energy, energy system	Uncertainty of supply
6. Further developing energy technologies (medium to long term)	Invest in energy research & innovation, financial instruments to leverage greater investments from industry	EU, national level	Technological uncertainty
7. Diversifying external supplies and related infrastructure	Strengthen relationships with existing suppliers, open the way to new sources, accelerate nuclear safety directive, ensure new nuclear plants do not depend on Russian fuel	EU, global, types of energy	Uncertainty of supply
8. Improving coordination of national energy policies and speaking with one voice in external energy policy	Build an energy union, include energy issues in political dialogues	EU	Ambiguity

Table 2b
Indirect measures of energy security in EU energy policy and their scales, grouped under their uncertainties.

Indirect measures	Scales	Uncertainties
Increasing diversification of sources [73,81], investment for a more secure grid [68], bioenergy [68], increasing diversification of supply from third countries [81], reducing energy imports [81], deployment of domestic sources [81], incentives to transmission and distribution operators [82], facilitating cross-border access to new electricity suppliers [83], renewable energy [84] [81], decentralised energy production [84], biomass fuels converted into electricity and heat [84]	EU, international, national Forms of energy, energy system	Uncertainty of supply
Energy efficiency [85] [68], reducing gas imports through efficiency [85], decarbonisation of the heating & cooling sectors [84]	EU, national Forms of energy, industrial sector	Uncertainty of demand
Regional co-operation [81]	Regional and EU	Ambiguity
EU interconnections [82]	EU, energy system	Technological uncertainty
Short term markets and scarcity pricing [82], a well-functioning and transparent energy market [82]	EU, national, energy sector	Uncertainty of supply (market)
Achievement of EU energy and climate policy goals [86]	EU, all economic sectors	Indeterminacy

conceptualisation and/or classification of energy security, the worry about ambiguity is virtually absent from policy documents. Despite the ambiguity of the concept highlighted in the literature, energy security is an important priority in EU policy. This finding is consistent with the study of the use of energy security in the UK [87]. Energy security is mentioned consistently throughout all EU energy policy documents analysed, although less so in the non-legal documents of the Clean Energy for All Europeans package, where, as the name suggests, focus is shifted to consumers.

Ambiguity is used in EU energy policy in a variety of instances. For example, the definition of energy efficiency is linked to a plurality of accounting methods. According to the directive, "energy efficiency means the ratio of output of performance, service, goods *or* energy, to input of energy" [71] [our emphasis]. The metrics used to measure services (e.g. contribution to GDP) and energy (e.g. megaJoules) are not equivalent to each other and generate ambiguity in energy efficiency indicators. Ambiguity is also present in target setting procedures: "Each Member State shall set an indicative national energy efficiency target, based on either primary or final energy consumption, primary or final energy savings, or energy intensity" [71]. Vagueness can be seen in the renewable energy directive of the EU. For instance, the sustainability requirement is defined as: "Biofuel production should be sustainable. Biofuels used for compliance with the targets laid down in this Directive, and those that benefit from national support schemes, should therefore be required to fulfil sustainability criteria" [69].

A distinction should be made between ambiguity and vagueness. Ambiguity is the uncertainty that emerges from complexity, while vagueness refers to the lack of clarity or specificity with which a term is used. Both may be useful in policy processes, and may help generate consensus, but vagueness is a political decision (e.g. the term energy security is used in relation to geopolitical concerns to avoid explicit mention of specific countries and regions, to which different member states may have different relations), and ambiguity has to do with incommensurability in the knowledge base and the governance of uncertainty. Ambiguity makes it possible for a plurality of knowledge claims to be taken into account, extending the political space.

It should be noted that, although the framing of ambiguity is very different in policy and in science, the uncertainty that arises from the presence of multiple perspectives is seen as problematic in some instances also in the policy realm. For example, a high priority for the EU is the coordination of national energy policies, as expressed by the idea of building an 'Energy Union' and including energy security in political dialogues (last pillar of Table 2a). According to Natorski and Surallés, "attempts to frame energy as a security issue in order to gain support for a Common Energy Policy have been of limited effect, precisely because the security framing contributed to the further legitimisation of EU member states' reluctance to cede sovereignty in the energy domain" [65]. This policy measure can be interpreted as the pursuit for the explicit discussion of topics otherwise left vague and ambiguous. Following Matland [58], this instance can be interpreted as a case in which ambiguity of goals is accepted (energy security), in order to reduce ambiguity of means (coordination is needed).

5. Discussion

5.1. Implications of complexity and ambiguity for energy security

The more one digs into the materiality of energy security, the more trade-offs, bottlenecks and lock-ins emerge. With reference to the nuclear power industry in France, Hecht [88] argues that policy effectiveness relies on material effectiveness. That is, the ability to deliver on material changes legitimizes policy, and the use of scientific evidence. In the case of energy security, this relationship seems to lean not on effectiveness but on uncertainty. Material effectiveness is elusive in the context of complexity because of non-linearity and open causality, and policy relies on ambiguity.

Uncertainty can be explained with reference to the complexity of energy systems. Comparing the current state of the EU's energy system with the measures in EU documents, it becomes clear that (i) some energy security measures play minor roles in the overall energy system, neglecting larger lock-ins, and can be better understood as performing a symbolic role; (ii) measures targeting different components or stages of the energy system may generate important trade-offs and systemic changes. For example:

- Technical security: increasing renewables may present challenges for electric grid control due to the higher penetration of variable sources into the electricity system [89];
- Market security: a higher integration of renewables in the electric grid may also lead to increased prices for consumers due to feed-in-tariffs. In Germany, for example, an increase in renewable electricity generation led to lower prices for electricity producers and higher prices for consumers [90];
- Nexus security: biofuels may increase energy security but pose threats to food security, as documented extensively in the literature (see, for example, [91]);
- Geopolitical security: decreasing reliance on imports may decrease security threats caused by geopolitical issues, such as the Russian gas halts, but may also reduce diversification of supply routes and sources, making the system more vulnerable in times of unexpected crises. This is referred to as import availability [4];
- Environmental security: domestic production of energy carriers may increase local environmental impacts, such as water contamination;
- Technological security: increasing the use of nuclear power may improve the security of electricity supply but pose other concerns, both of plant security and uranium dependence.

Many of these trade-offs are acknowledged in the policy documents analysed. The directives analysed mention grid control problems caused by the increase in renewable energies, the dependence on fossil fuels for transport, and the possible impacts of biofuels on food production [69].

The recurrent reference to risks, threats and urgency are means through which the lack of effectiveness in energy governance is recast as a security challenge. We argue that uncertainty (in the form of risk, strict uncertainty and indeterminacy) is mobilised to frame energy governance in terms of security. In this context, the use of a plurality of policy measures, and the inconsistencies or trade-offs that arise from such plurality reinforce the uncertainty element of energy security. Ambiguity is thus functional to this mode of governance, and the multiple representations that are produced by the scientific knowledge base reinforce the construction of energy security as a challenge of uncertainty, which requires governing.

Ambiguity in this context makes it possible to avoid a paralysis in decision-making due to higher level uncertainties, and makes it possible to form coalitions between different actors and discourses. By linking all of the above measures to energy security, the complexity of the issue is compressed to allow for decisions to be taken. Energy security is almost always bundled up within a mix of justifications which tend to include climate change and economic growth, as can be seen for example in the recast proposal for renewable energy directive of 2016: "Moreover, renewable energy is also emerging as a driver of inclusive economic growth, creating jobs and reinforcing energy security across Europe" [86]. Here, ambiguity is used both to group measures together (ambiguity/vagueness of means), and to group targets such as security and economic growth (ambiguity/vagueness of goals).

5.2. What does ambiguity imply for science advice to policy?

Recognising the relevance of ambiguity in decision making, the discussion is now directed to how this affects the science-policy interface. Clarifying the concept of energy security would mean showing inconsistencies between representations, indicators and associated measures. Therefore, reducing ambiguity may make scientific advice less useful to governance. This observation runs counter to some of the ethos of science for policy, which is manifested in the goals of increasing clarity [25], providing a holistic view [25,29], putting boundaries on the term [26], distinguishing between different logics of energy security and investigating their political and normative consequence [9].

A recurrent recommendation is that uncertainty should be analysed and communicated [5,39,78]. The results presented here, however, suggest that the communication of uncertainty at the science-policy interface needs to take into account what type of uncertainty one is dealing with. While risks, indeterminacy and ignorance are flagged as problematic in policy, ambiguity plays a different role. Before aiming to reduce ambiguity, it is important to take into account which policy processes may be affected, and even disrupted, by reducing ambiguity. "For example, the call for clear, explicit, and consistent goals contradicts much of what is known about how legislation is passed" [52, p.147].

Matland [58] argues that ambiguity is a means to reduce conflict and hold together coalitions. The use of energy security as a recurrent justification for a wide range of measures indicates that the term is used to form coalitions, or mobilise existing ones. Meritet [92], for example, highlights how energy security measures and discourses in France are very different to those in other EU countries, given the role played by nuclear power. Ambiguity thus helps maintain coherence at the EU level, glossing over national differences.

The analysis of the role of ambiguity in policy processes shows that ambiguity is not a deficit of knowledge, and that therefore it is not a matter for scientific experts to "solve." These considerations open the debate about the role of science and science advice to policy in the context of complexity and uncertainty. Policy recommendations in the energy security literature are varied, ranging from "the institution of a consultative process towards broadly accepted (…) fuel-specific premiums" [31], the provision of a detailed analysis of risk [39], and definitional clarity [19], to the support of "multilateral approaches and concrete cooperation models" [6], "anticipating and assessing the 'what ifs'" [14], diplomatic and economic dialogues [66]. While we are sympathetic to these suggestions, we refer to relational complexity to argue that through ambiguity, multiple knowledge claims and multiple sources of expertise are brought to bear on the policy process. Policy is informed not only by scientific evidence, but also by political, economic and social considerations. Ambiguity makes it possible to maintain a dialogue with a wide range of actors, including but not limited to scientific experts. We argue that it is important to take into account who would benefit and who would loose from the clarification of ambiguity, and to assess what is at stake behind different uses of the term.

6. Conclusion

In this paper, we refer to energy security as an entry point to theorise the role of ambiguity in governance. Energy security is an ambiguous term, with many competing and contradictory definitions. We use complexity theory to argue that the multiple definitions refer to non-equivalent representations of energy security, and cannot be reconciled or unified without losing relevant information. We conducted a text analysis of academic publications and policy documents to compare which types of uncertainty are mobilised, with a particular focus on ambiguity, defined as the type of uncertainty arising from complexity.

Many authors have focused on reducing the ambiguity of definitions of energy security and have provided broad definitions that can capture its multiple facets [16,17,26,31]. On the other hand, the definition of energy security does not necessarily arise as a problem in EU public policy. This incongruence between science and policy is not a problem *per se*. Academia has different interests than policy, and what can be interesting from a research perspective (conceptualising an ambiguous term) may not be a priority in policymaking. Moreover, the interactions between science and policy are rarely direct (with scientific evidence guiding policymakers), and the effects of conceptualisation literature can be diffuse [9], in helping to advance a field that may eventually have impacts on policies. Since we relied only on secondary information through text analysis, the differences in the treatment of ambiguity between science and policy would benefit from further research based on primary data through, for instance, interviews with both scientific experts and policy-makers.

The results and discussion suggest that it is important to pay attention to what is at stake before clarifying ambiguities at the science-policy interface. This critical reflection should by no means be understood as a call for irresponsible politics or post-factual decision-making. Rather, it is important to understand the "network of artefacts, knowledges and institutions" [62, p.257] that constitute energy governance before prescribing good practice. To this purpose, we rely on a relational understanding of complexity, which relates representation to the institutions and the uses of knowledge. Returning to the debate raised by Wellstead et al. [28] about the need to reduce ambiguity, we argue that from a complexity point of view, reducing ambiguity would entail (i) a normative choice of some scientific facts over others, and (ii) a poor understanding of how plural and ambiguous knowledge is used in policy processes, which would widen the gap between science and policy, rather than closing it. In contrast, discussing the role of ambiguity in policy can help manage this gap and may foster an environment for better dialogue between science and policy.

Declarations of interest

None.

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References

[1] A. Cherp, J. Jewell, The three perspectives on energy security: intellectual history, disciplinary roots and the potential for integration, Curr. Opin. Environ. Sustain. 3 (2011) 202–212, https://doi.org/10.1016/j.cosust.2011.07.001.
[2] W. Lippmann, U.S. Foreign Policy: Shield of the Republic, Little, Brown & Co., Boston, 1943.
[3] B.K. Sovacool, I. Mukherjee, I.M. Drupady, A.L. D'Agostino, Evaluating energy security performance from 1990 to 2010 for eighteen countries, Energy 36 (2011) 5846–5853, https://doi.org/10.1016/j.energy.2011.08.040.
[4] A. Månsson, B. Johansson, L.J. Nilsson, Assessing energy security: an overview of commonly used methodologies, Energy 73 (2014) 1–14, https://doi.org/10.1016/j.energy.2014.06.073.
[5] L. Hughes, The four' R's of energy security, Energy Policy 37 (2009) 2459–2461, https://doi.org/10.1016/j.enpol.2009.02.038.
[6] F. Umbach, Global energy security and the implications for the EU, Energy Policy 38 (2010) 1229–1240, https://doi.org/10.1016/j.enpol.2009.01.010.
[7] P. Vahtra, Energy security in Europe in the aftermath of 2009 Russia-Ukraine gas crisis, in: EU-Russia Gas connect, Pipes, Polit. Probl. (2009) 159–165.
[8] S. Moore, Evaluating the energy security of electricity interdependence: Perspectives from Morocco, Energy Res. Soc. Sci. 24 (2017) 21–29.
[9] F. Ciută, Conceptual notes on energy security: total or banal security? Secur. Dialogue 41 (2010) 123–144, https://doi.org/10.1177/0967010610361596.
[10] J. Bielecki, Energy security: Is the wolf at the door? Q. Rev. Econ. Finance 42 (2002) 235–250, https://doi.org/10.1016/S1062-9769(02)00137-0.
[11] N. Georgescu-Roegen, The Entropy Law and the Economic Process, Harvard University Press, Boston, 1971.
[12] C.A.S. Hall, K.A. Klitgaard, Energy and the Wealth of Nations, Springer, New York, Dordrecht, Heidelberg, London, 2012, https://doi.org/10.1007/978-1-4419-9398-4.
[13] V. Smil, Energy transitions: History, requirements, prospects, Praeger, Santa Barbara, 2010.
[14] D. Yergin, Ensuring energy security, Foreign Aff. 85 (2006) 69–76.
[15] B. Kruyt, D.P. Van Vuuren, H.J.M. De Vries, H. Groenenberg, Indicators for energy security, Energy Policy 37 (2009) 2166–2181, https://doi.org/10.1016/j.enpol.2009.02.006.
[16] B.K. Sovacool, M.A. Brown, Competing Dimensions of Energy Security: an International Perspective, (2010), https://doi.org/10.1146/annurev-environ-042509-143035.
[17] E. Jun, W. Kim, S.H. Chang, The analysis of security cost for different energy sources, Appl. Energy 86 (2009) 1894–1901, https://doi.org/10.1016/j.apenergy.2008.11.028.
[18] G.C.K. Leung, China's energy security: perception and reality, Energy Policy 39 (2011) 1330–1337, https://doi.org/10.1016/j.enpol.2010.12.005.
[19] L. Chester, Conceptualising energy security and making explicit its polysemic nature, Energy Policy 38 (2010) 887–895, https://doi.org/10.1016/j.enpol.2009.10.039.
[20] C. Strambo, M. Nilsson, A. Månsson, Coherent or inconsistent? Assessing energy security and climate policy interaction within the European Union, Energy Res. Soc. Sci. 8 (2015) 1–12, https://doi.org/10.1016/J.ERSS.2015.04.004.
[21] J. Wilson, A securitisation approach to international energy politics, Energy Res. Soc. Sci. 49 (2019) 114–125.
[22] C. Kuzemko, Politicizing UK Energy: What Speaking Energy Security Can Do, (2013).
[23] P. Joskow, The US energy sector: prospects and challenges. 1972-2009, Dialogue Can. Philos. Assoc. 17 (2009).
[24] L. Sébastien, T. Bauler, M. Lehtonen, Can indicators bridge the gap between science and policy? An exploration into the (Non)Use and (Non)Influence of indicators in EU and UK policy making, Nat. Cult. 9 (2014), https://doi.org/10.3167/nc.2014.090305.
[25] B.K. Sovacool, I. Mukherjee, Conceptualizing and measuring energy security: a synthesized approach, Energy 36 (2011) 5343–5355, https://doi.org/10.1016/j.energy.2011.06.043.
[26] C. Winzer, Conceptualizing energy security, Energy Policy 46 (2012) 36–48, https://doi.org/10.1016/j.enpol.2012.02.067.
[27] A. Stirling, Risk, precaution and science: towards a more constructive policy debate, EMBO Rep. 8 (2007) 309–315.
[28] A. Wellstead, P. Cairney, K. Oliver, Reducing ambiguity to close the science-policy gap, Policy Des. Pract. 1 (2018) 115–125, https://doi.org/10.1080/25741292.2018.1458397.
[29] E. Kiriyama, Y. Kajikawa, A multilayered analysis of energy security research and the energy supply process, Appl. Energy 123 (2014) 415–423, https://doi.org/10.1016/j.apenergy.2014.01.026.
[30] A. Below, Obstacles in energy security: an analysis of congressional and presidential framing in the United States, Energy Policy 62 (2013) 860–868, https://doi.org/10.1016/j.enpol.2013.07.013.
[31] J.C. Jansen, A.J. Seebregts, Long-term energy services security: What is it and how can it be measured and valued? Energy Policy 38 (2010) 1654–1664, https://doi.org/10.1016/j.enpol.2009.02.047.
[32] F.H. Knight, Risk, Uncertainty and Profit, Hart, Schaffner and Marx, New York, 1921.
[33] A. Stirling, Keep it complex, Nature 468 (1993) 1029–1031.
[34] B. Wynne, Uncertainty and environmental learning: reconceiving science and policy in the preventive paradigm, Glob. Environ. Change (June) (1992) 111–127, https://doi.org/10.1016/0959-3780(92)90017-2.
[35] S. Funtowicz, J.R. Ravetz, Emergent complex systems, Futures 26 (1994) 568–582, https://doi.org/10.1016/0016-3287(94)90029-9.
[36] a.J. Zellmer, T.F.H. Allen, K. Kesseboehmer, The nature of ecological complexity: a protocol for building the narrative, Ecol. Complex. 3 (2006) 171–182, https://doi.org/10.1016/j.ecocom.2006.06.002.
[37] R. Strand, Complexity, ideology and governance, Emergence 4 (2002) 164–183.
[38] Z. Kovacic, M. Giampietro, Beyond "beyond GDP indicators": the need for reflexivity in science for governance, Ecol. Complex 21 (2015) 53–61, https://doi.org/10.1016/j.ecocom.2014.11.007.
[39] H.Y. Zhang, Q. Ji, Y. Fan, An evaluation framework for oil import security based on the supply chain with a case study focused on China, Energy Econ. 38 (2013) 87–95, https://doi.org/10.1016/j.eneco.2013.03.014.
[40] A. Stirling, Risk, uncertainty and precaution: some instrumental implications from the social sciences, in: F. Berkhout, M. Leach, I. Scoones (Eds.), Negot. Chang. Edward Elgar, London, 2003, pp. 33–76.
[41] S.O. Funtowicz, R. Strand, Models of science and policy, Biosaf. First-holistic approaches to risk Uncertain, Genet. Eng. Genet. Modif. Org. (2007) 263–278.
[42] R.A. Pielke, When scientists politicize science: making sense of controversy over the Skeptical Environmentalist, Environ. Sci. Policy 7 (2004) 405–417, https://doi.org/10.1016/j.envsci.2004.06.004.
[43] F. Diaz-Maurin, Z. Kovacic, The unresolved controversy over nuclear power: a new approach from complexity theory, Glob. Environ. Change 31 (2015) 207–216, https://doi.org/10.1016/j.gloenvcha.2015.01.014.
[44] R. Geyer, P. Cairney, Handbook on Complexity and Public Policy, Edward Elgar, Cheltenham, 2015.
[45] R. Geyer, S. Rihani, Complexity and Public Policy: a New Approach to 21st Century Politics, Policy and Society, Routledge, Oxon and New York, 2010.
[46] G. Morçöl, A Complexity Theory for Public Policy, Routledge, London and New York, 2012.
[47] R. Geyer, Can complexity move UK policy beyond "Evidence-Based policy making" and the "Audit culture"? Applying a "Complexity cascade" to education and health policy, Polit. Stud. 60 (2012) 20–43, https://doi.org/10.1111/j.1467-9248.2011.00903.x.
[48] S.N. Salthe, Development and Evolution: Complexity and Change in Biology, MIT Press, Boston, 1993.
[49] D. Byrne, Complexity Theory and the Social Sciences: an Introduction, Routledge, London and New York, 1998.
[50] V. Ahl, T.F.H. Allen, Hierarchy Theory: a Vision, Vocabulary, and Epistemology, Columbia University Press, New York, 1996.
[51] Z. Kovacic, Investigating science for governance through the lenses of complexity, Futures (2017), https://doi.org/10.1016/j.futures.2017.01.007.
[52] R. Rosen, Anticipatory Systems, Pergamon Press, Oxford, 1985.
[53] R. Rosen, Life Itself: a Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life, Columbia University Press, New York, 1991.
[54] C.S. Peirce, Collected papers. Vol. VI, Harvard University Press, Boston, 1935.
[55] T.F.H. Allen, T.B. Starr, Hierarchy Perspectives for Ecological Complexity, University of Chicago Press, Chicago, 1982.
[56] R. Strand, S. Cañellas-Boltà, Reflexivity and modesty in the application of complexity theory, in: A. Guimaraes Pereira, A. Guedez Vaz, S. Tognetti (Eds.), Interfaces between Sci. Soc. Greenleaf Publishing, Sheffield, 2006.
[57] S.D. Mitchell, Unsimple Truths: Science, Complexity and Policy, University of Chicago Press, Chicago, 2009.
[58] R.E. Matland, Synthesizing the implementation literature: the ambiguity-conflict model of policy implementation, J. Public Adm. Res. Theory 5 (1995) 145–174, https://doi.org/10.1093/oxfordjournals.jpart.a037242.
[59] N. Zahariadis, Ambiguity and choice in European public policy, J. Eur. Public Policy 15 (2008) 514–530.
[60] S.O. Funtowicz, J.R. Ravetz, Uncertainty and Quality in Science for Policy, Kluwer Academic Publishers, Dorcrecht, 1990, https://doi.org/10.1016/0921-8009(92)90014-J.
[61] A. Smith, A. Stirling, Moving outside or inside? Objectification and reflexivity in the governance of socio-technical systems, J. Environ. Policy Plan. 9 (2007) 351–373, https://doi.org/10.1080/15239080701622873.
[62] S. Shackley, B. Wynne, Global warming potentials: Ambiguity or precision as an aid to policy? Clim. Res. 8 (1997) 89–106, https://doi.org/10.3354/cr008089.
[63] S. Jalali, C. Wohlin, Systematic literature studies, Proc. ACM-IEEE Int. Symp. Empir. Softw. Eng. Meas. - ESEM' 12 (2012) 29, https://doi.org/10.1145/2372251.2372257.
[64] V. Costantini, F. Gracceva, A. Markandya, G. Vicini, Security of energy supply: comparing scenarios from a European perspective, Energy Policy 35 (2007)

210–226, https://doi.org/10.1016/j.enpol.2005.11.002.
[65] M. Natorski, A.H. Surallés, Securitizing moves to nowhere? The framing of the european union's energy policy, J. Contemp. Eur. Res. 4 (2008) 70–89.
[66] G. Bahgat, Europe's energy security: challenges and opportunities, Int. Aff. 82 (2006) 961–975, https://doi.org/10.1111/j.1468-2346.2006.00580.x.
[67] European Commission, European Energy Security Strategy, Brussels, 2014, https://doi.org/10.1007/978-3-531-19201-7.
[68] European Commission, Clean Energy for All Europeans, Brussels, 2016.
[69] European Parliament, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources, European Parliament, Brussels, 2009, https://doi.org/10.3000/17252555.L_2009.140.eng.
[70] European Parliament, Directive of 2009/72/EC of the European Parliament and of the Council of 13 July 2009 Concerning Common Rules for the Internal Market in Electricity, European Parliament, Brussels, 2009, https://doi.org/10.1126/science.202.4366.409.
[71] European Parliament, Directive 2012/27/EC of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency, European Parliament, Brussels, 2012.
[72] European Parliament, DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 on the Deployment of Alternative Fuels Infrastructure, European Parliament, Brussels, 2014.
[73] European Commission, State of the Energy Union 2015, Brussels, 2015.
[74] European Commission - Press release, Clean Energy for All Europeans – Unlocking Europe' S Growth Potential, (2016).
[75] European Commission, Providing a Fair Deal for Consumers (MEMO/16/3961), (2016).
[76] European Commission, Putting Energy Efficiency First: Consuming Better, Getting Cleaner (MEMO/16/3986), (2016) http://europa.eu/rapid/press-release_MEMO-16-3986_en.htm.
[77] European Commission, Achieving Global Leadership in Renewable Energies (MEMO/16/3987), (2016), pp. 30–33 http://europa.eu/rapid/press-release_MEMO-16-3987_en.htm.
[78] J.M. Yusta, G.J. Correa, R. Lacal-Arántegui, Methodologies and applications for critical infrastructure protection: state-of-the-art, Energy Policy 39 (2011) 6100–6119, https://doi.org/10.1016/j.enpol.2011.07.010.
[79] M. Natorski, A.H. Surrallés, Securitizing moves to nowhere? The framing of the european union's energy policy, J. Contemp. Eur. Res. 4 (2008) 71–89.
[80] European Commission, European Energy Security Strategy, (2014), https://doi.org/10.1007/978-3-531-19201-7.
[81] European Commission, Regulation of the European Parliament and of the Council on the Governance of the Energy Union COM(2016) 759 final/2, 0375, (2017).
[82] European Commission, Regulation of the European Parliament and of the Council on the Internal Market for Electricity, 0379, (2017).
[83] European Commission, Proposal for a Directive of the European Parliament and of the Council on Common Rules for the Internal Market of Electricity (recast) COM (2016) 864 final/2, (2017).
[84] European Commission, Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy From Renewable Sources (recast) COM(2016) 767 final/2, 0382 (COD), (2017), pp. 1–116 http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016PC0767R%2801%29.
[85] European Commission, Proposal for a Directive of the European Parliament and of the Council Amending Directive 2012/27/EU on Energy Efficiency, (2016).
[86] European Commission, Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the Promotion of the Use of Energy from Renewable Sources, Brussels, 2017.
[87] E. Cox, Opening the black box of energy security: a study of conceptions of electricity security in the United Kingdom, Energy Res. Soc. Sci. 21 (2016) 1–11, https://doi.org/10.1016/j.erss.2016.06.020.
[88] G. Hecht, Technology, politics, and national identity in France, in: M.T. Allen, G. Hecht (Eds.), Technol. Power, MIT Press, Boston, 2001, pp. 253–294.
[89] G. Boyle, Renewable Electricity and the Grid: the Challenge of Variability, Earthscan, 2007 (Accessed November 6, 2017), https://books.google.es/books?hl=en&lr=&id=q3IAkdbntiwC&oi=fnd&pg=PR5&dq=grid+security+intermittency&ots=fa84Bd5lnD&sig=tbK1vvs9skR-7n1pDW5WFt7QOxw#v=onepage&q=gridsecurityintermittency&f=false.
[90] F. Paraschiv, D. Erni, R. Pietsch, The impact of renewable energies on EEX day-ahead electricity prices, Energy Policy 73 (2014) 196–210, https://doi.org/10.1016/j.enpol.2014.05.004.
[91] R.L. Naylor, A.J. Liska, M.B. Burke, W.P. Falcon, J.C. Gaskell, S.D. Rozelle, K.G. Cassman, The ripple effect: biofuels, food security, and the environment, Environ. Sci. Policy Sustain. Dev. 49 (2007) 30–43, https://doi.org/10.3200/ENVT.49.9.30-43.
[92] S. Meritet, French perspectives in the emerging European Union energy policy, Energy Policy 35 (2007) 4767–4771, https://doi.org/10.1016/J.ENPOL.2007.04.010.
[93] O. Renn, A. Klinke, M. Van Asselt, Coping with complexity, uncertainty and ambiguity in risk governance: a synthesis, Ambio 40 (2011) 231–246, https://doi.org/10.1007/s13280-010-0134-0.
[94] B.K. Sovacool, J. Axsen, S. Sorrell, Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design, Energy Res. Soc. Sci. 45 (2018) 12–42, https://doi.org/10.1016/j.erss.2018.07.007.