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Research article

Updating energy security and environmental policy: Energy security theories revisited

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ABSTRACT

The energy security theories are based on the premises of sufficient and reliable supply of fossil fuels at affordable prices in centralized supply systems. Policy-makers and company chief executives develop energy security strategies based on the energy security theories and definitions that dominate in the research and policy discourse. It is therefore of utmost importance that scientists revisit these theories in line with the latest changes in the energy industry: the rapid advancement of renewables and smart grid, decentralization of energy systems, new environmental and climate challenges. The study examines the classic energy security concepts (neorealism, neoliberalism, constructivism and international political economy) and assesses if energy technology changes are taken into consideration. This is done through integrative literature review, comparative analysis, identification of 'international relations' and 'energy' research discourse with the use of big data, and case studies of Germany, China, and Russia. The paper offers suggestions for revision of energy security concepts through integration of future technology considerations.

1. Introduction

Energy security is one of key parameters for assuring a stable development of countries and regions. Today energy demand has been growing faster than ever, particularly in the developing countries, making energy security is an integral part of national security. Energy security is also an important element and the source of interdependence in international relations (de Mattos Fagundes et al., 2016). There is a close interlink between energy policy (energy governance) and dominant ideologies through which groups of stakeholders debate key energy issues (Victor Valentine et al., 2017). This interlink has major implications in the event of energy transitions that reveal how energy systems function and how they may develop in the future (Tarasova, 2018).

Energy security, as perceived by international development organizations and national policies, often focus on fossil fuels, while neglecting energy equity and environmental sustainability (Moore, 2017). This is particularly a problem for the developing countries. Therefore integration of energy governance and energy security perspectives is required to understand and address the difficulties of a just energy transition in the context of the standard energy trilemma (Zaman and Brudermann, 2018). At the same time, energy policy should avoid excessive securitization of all energy issues (Leung et al., 2014).

Energy security issue emerged on the political agenda in the early 20th century (Bennear and Stavins, 2007a). However, energy security concepts were included in the research discourse only in the 1960s. Further interest of researchers in this subject had a wave-like nature, following changes in the energy markets. In recent years the energy security concept has experienced a revival, with a renewed interest from researchers, managers and policy makers (Månsson et al., 2014).

The term 'energy security' has evolved accordingly. If in 1970s and 1980s the researchers gave the top priority to a stable supply of cheap oil, despite the restrictions and price manipulations of exporting countries (Hay, 2009). Some attention was given to the need for better management of energy enterprises, included state-owned (Chocklin, 1993), and for more effective management of energy technology (Coates, 1977). In the 2000s attention was paid to ensuring equal access of all social groups to safe energy sources and reducing negative impact of the energy sector on the environment (Cherp and Jewell, 2011) and climate (Nyman, 2018).

The approaches to energy security vary depending on a discipline in which this concept is used: the theoretical analysis of energy security can be found in both social sciences and liberal arts (in political science, international relations and economics), and in natural sciences (in math, physics) (Månsson et al., 2014). The social scientists usually focus their energy security research either on the analysis of international (geopolitical) relations and policy analysis (Kessler and Kessler, 2017) or on discursive and contextual dimensions of politics (Teräväinen et al., 2011; Ciut and Klinke, 2010). A number of studies underline the interdisciplinary approach to energy security (Månsson, 2014;

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Cipollaro and Lomonaco, 2016).

The classic approach is to assess the four key parameters of energy resources: their availability, accessibility, affordability and acceptability (Wang et al., 2018a; Kruyt et al., 2009), of which availability and affordability seem to be more significant in terms of impact on other elements of energy security (Ren and Sovacool, 2014). The main energy security elements that are usually included in the definition of the term are resource nationalism (Childs, 2016), secure supplies of affordable energy resources, diversification of energy sources in the energy mix and through different suppliers, secure energy and fuel transportation (transit) and corresponding infrastructure, prospective geopolitical and market changes, and *threats that are caused by or have an impact on the energy supply chain* (Winzer, 2012). The traditional national security concepts today merge with more recent concepts of human rights and individual security, energy justice and sustainable development (Sovacool, 2016).

Dayer and Trombetta claim that energy security implies *continuous access to various forms of energy in sufficient quantity and at affordable prices* (Dyer and Trombetta, 2013). This definition is similar to the International Energy Agency's (IEA) long-term energy security understanding: *uninterrupted availability of energy sources at an affordable price*. The short-term IEA approach to energy security underlines *the ability of the energy system to react promptly to sudden changes in the supply-demand balance*. New research in energy security also takes account of environmental and social aspects (Energy Supply Security. O, 2014). Other researchers define energy security as *assuring citizens', state, societal and economic protection from energy shortages (deficit) and blackouts, provision of quality energy resources* (Senderov and Smirnova, 2012). A more compound and, at the same time, wider definition by Cherp and Jewell, states that energy security is *low vulnerability of vital energy systems* (Cherp and Jewell, 2011).

Markovska et al. argue that the top 10 energy security challenges are decarbonising the world economy; enhancing the energy efficiency and energy savings in buildings; advancing the energy technologies; moving towards energy systems based on variable renewables; electrifying the transport and some industrial processes; liberalizing and extending the energy markets; integrating energy sectors to Smart Energy Systems; making the cities and communities smart; diversifying the energy sources; and building more biorefineries (Markovska et al., 2016). There are other security concerns, including *terrorism or more mundane forms of crime, such as fraud, in management of nuclear waste* (Vander Beken et al., 2010), and nuclear power generation more generally. This positions energy security at the interlink of three perspectives: sovereignty, robustness, and resilience, of which the last one covers technology changes (Valdés Lucas et al., 2016).

These challenges listed above better reflect the relation between energy and security and should be better analyzed within energy security concepts (Johansson, 2013). Moreover, various aspects of global competition for energy resources, wide application of renewables (Garcia-Gusano and Iribarren, 2018), interdependence of the economies and energy systems (infrastructure), climate change (Wang et al., 2018b) and environment impact issues, as well as technological innovations (Victor Valentine et al., 2017) in the energy sector are also considered in the studies on the topic.

Many researchers admit that the existing multiple understandings of energy security and underlying concepts are rather vague and contradictory (Sovacool, 2011; Chester, 2010). There are several obstacles that prevent the formulation of a single universal approach to energy security, as each country or non-governmental actor has its own, subjective perception of the issue that may change with the evolution of social and other conditions (Valentine, 2011; Escribano Francés et al., 2013). Governments and organizations may choose the energy security concept that justifies their policy and actions (Korin and Luft, 2009), which leads to the manipulation with the term. In this interpretation energy security can be compared to Rorschach inkblot test: you see what you want to see (Sovacool, 2011). Due to a number of problems in the approach and understanding of energy security, energy security policy and energy security management also remain an under researched subject (Radovanović et al., 2018). This makes researchers call for reconceptualizing the process and practice of energy policy itself (Victor Valentine et al., 2017).

Despite the relatively high number of publications on energy security, there are a number of remaining research gaps. First, more future research is required *to link the de-coupled areas of energy security, access and climate change* (Goldthau, 2011). Second, many previous studies rely on one-sided definitions of energy security focused on particular technical and economic aspects, while overlooking social and political elements such as good governance. Moreover, many energy security publications focus only on a particular sector, an individual state, or a specific technology (Sovacool, 2013). Unlike earlier studies this paper is not devoted to energy security of particular countries (Zeng et al., 2017) and regions (Chalvatzis and Ioannidis, 2017), is not focused on particular energy segment (Nyman, 2017) or a single energy security concept (Bompard et al., 2017). This paper focuses on the theoretical approaches to energy security from the perspective of International Relations theory and offers outcomes that may be applied to any country and the entire industry within the realms of the four key energy security concepts.

Although there are many publications on energy security, most of them relate to the analysis of particular countries, inter-country relations, regional and global energy security difficulties. Very few studies attempt to conceptualize energy security, analyze this phenomenon through the prism of key energy security concepts, and none attempt to revisit those concepts in a comprehensive manner in the light of new developments in the energy industry. The paper aims to bring more clarity to *a dizzying variety of fragmented and contradictory interpretations of energy security in scholarly and policy literature* (Tarasova, 2018) by examining and revisiting the four major theoretical approaches developed in the realm of International Relations theory (Victor Valentine et al., 2017). The hypothesis is that energy security concepts are based on outdated security paradigms and do not reflect the meaningful energy trends that have surfaced over the last three decades (Brown et al., 2014). As energy theories have their practical application, i.e. are used in international, national and corporate energy management and policy-making, neglecting the latest developments involves high costs (Kessler and Kessler, 2017). Moreover, the transformations of energy security may transform the international system itself (Nyman, 2017).

2. Methods

The methods of this study include comparative analysis of the major energy security concepts in international relations that was performed though an integrative literature review for a mature topic – 'energy security', followed by critique and reconceptualization based on the expanding knowledge base of energy systems and energy industry and a more diversified understanding of the concept (Torraco, 2005).

The theoretical groundwork publications, mainly books, were selected for analysis of key energy security concepts in International Relations theory. Further, the analyses was limited to the contemporary debate related to energy security theory To this end, only research and review articles, books chapters, encyclopedia and editorials published in 2000–2018 were chosen through ScienceDirect, Web of Science (through big data algorithms), and Google Scholar using keywords listed in Annex 1, Table 1. Of all ScienceDirect research and review articles and editorials on international relations 535 containing 'energy security' as keywords were selected. Based on analysis of these publications, four energy security concepts were chosen: neorealism, neoliberalism, political economy and constructivism (Victor Valentine et al., 2017; Mohapatra, 2017; Keohane, 1984).

ScienceDirect is among the largest databases that contains a good collection of publications in Social Sciences and Humanities and the Elsevier's platform of peer-reviewed scholarly literature featuring over

3800 journals and 37 000 books. This database was accessed by corporate subscription with access to full texts.

In contrast, Web of Science (WoS) yields much less results. Out of 38 448 publications related to 'international relations' 175 contain 'energy security' as keywords (the majority of which relate to particular countries, regions or projects; many published in journals with very low visibility/impact factor). For example, out of 20 459 publications that contain 'energy security' as keyword, only two articles also contain 'neorealism', 12 'neoliberalism', three 'constructivism', and 256 'political economy'. Of these publications about two thirds relate to climate change (a growing topic in energy security studies) and country cases. The top cited 10% of WoS publications related to 'energy security' were analyzed with the use of proprietary text mining system iFORA. This was done to compare the mainstream international relations and energy research discourse on energy security. A similar systematic approach was suggested by Sovacool and Brown (2010), who applied a meta-survey of existing literature to identify energy security concerns.

Although Google Scholar yields too many results for manual processing, the results are sorted by relevance (unlike in ScienceDirect), and the top selected sources contain the core theoretical contributions, mainly books and monographs. Only the top papers/books sorted by relevance were selected for review from this database, and it was possible to read/preview many books through GoogleBooks.

Further, after four mainstream energy security concepts were selected for analysis, the following keywords were applied: 'neorealism energy', 'political economy energy', 'constructivism energy' and 'neoliberalism energy'. As the high number of results suggests, the selected publications are overwhelmingly related to adjacent research areas. The high number of papers also suggested a need for automated analysis in addition to manual search and review. It is also obvious that the majority of publications that databases contain, were made in the period selected for analysis (2000–2018).

Of those publications selected in the databases by keywords, the most relevant for the scope of the study were selected for an in-depth analysis based on the focus of the paper: either a theoretical paper related to energy security or a paper that applies energy security concepts to reality.

Case-studies of the energy security policy in Germany, China and Russia are used to test the hypothesis and reflect on the interlink between energy security concepts and energy policy. The same approach has been taken by Winzer (2012), who used "a stylized case study for three European countries to illustrate how the selection of conceptual boundaries … determines the outcome". The three countries selected for analysis represent the various approaches to energy security policy-making discussed below. The information base for case studies included energy policy documents and official information from government agencies, where available, as well as research papers.

Further development of energy security debates and analysis in the last two decades introduced more technology insights, as well as the concepts of resilience and flexibility (Cherp and Jewell, 2011), but the underlying theories remained unchanged. The research novelty of the present study is a revision of existing energy security concepts with a view to update them and bring in line with contemporary energy technology developments that open many more options for energy production and use. It is an attempt to marry the new technology trends and considerations (foresight) and the dominant energy security concepts.

3. Energy security concepts

There four energy security concepts that dominate in the International relations theory: neorealism, neoliberalism, constructivism and political economy. Each of the research strings offer a different view on the key energy security elements, actors, and priorities.

The energy security concepts that have traditionally focused on fossil fuels (their availability, control of these resources and their transportation routes) should also encompass various other energy resources, including the rapidly growing renewables, available in most locations. At the same time, the rapid technological changes in the energy sector could radically change the future energy outlook and these have to be accounted for. The switch to renewables, such as solar technology, has some positive environmental and climate effects, as well as improves in energy security, especially in the developing world (Adenle et al., 2015). Energy future studies can be useful for understanding how to assure energy security by managing technical, economic and policy changes related to energy supply and use (Nilsson et al., 2011).

3.1. An overview of energy security concepts

Arguably the majority of researchers working on energy security place it in the **neorealist** discussions. They focus on the energy policy of the states in the context of national interests and security, military confrontation and regional conflicts (Daddow, 2017). Military and forceful actions to assure energy security are among the key research subjects in neorealism (Baldwin, 1993). Kalicki and Goldwyn view energy security only in the context of the national security. They believe that energy challenges the country faces should be better reflected in its foreign policy strategy (Kalicki et al., 2005). Similarly, Kokoshin provides a typology of global energy-related political risks and looks into balancing the interests of the key world energy actors (Kokoshin, 2012).

Realism is an approach to international politics that has a long historical tradition and numerous variants. It focuses on the actual state of the world, takes as given that the key actors are self-interested states, and that they interact in an anarchic setting, one in which there is no central authority to enforce order. As a result, states seek power and what emerges is a conflict-ridden world in which the balance of power is the only basis for order. The perspective has problems and limitations but few analyze international politics without focusing on the distribution of power (Stein, 2015).

Control over natural resources located in oceans draws increasing attention of neorealists. According to Nincic the interstate conflicts over access to fossil fuels will be inevitable as the future oil and gas reserves are situated offshore, and their extraction depends on the outcomes of the debates over the border delimitation in the global ocean (Nincic and Kolin, 2009). Wilson considers maritime security to be the key condition for ensuring reliable energy delivery as that former should ensure addressing illegal activity and emergency situations at the territory covering over two thirds of the Earth's surface and 80% of transport routes (Wilson, 2012).

Neorealist researchers believe that national interests should dominate energy policy, and bilateral deals should dominate over multilateral contracts. In most cases it is understood as strengthening of the state control over natural resources, primarily in resource-rich countries. Russia and Venezuela are usually cited as examples of the countries that pursue 'resource nationalism'.

Securing sufficient energy import is of paramount importance as the energy supplies are highly competitive. Multinational energy agreements similar to those existing in the European Union have their limitations, including quotas and other energy delivery obstacles, and, therefore, will subsequently become less attractive. Acting alone is better than facing the complexity of coordination where the interests of the importing states tend to prevail due to market failures (Elving, 2014).

A string of research focuses on structural security changes related to energy interests Moran and Russell believe that the risk of a global military conflict is minimal despite the ongoing local conflicts (Moran and Russell, 2009). In any case, the struggle for access to energy resources remains the most likely reason for escalating violence. High dependence of the world economy on oil and gas increases the risk of

both local and regional confrontation that could possibly grow into a global one. Given fierce competition for energy resources and technologies among states, conflicts are inevitable and lead to boosting military capacities, complicating international cooperation. Military aspects of energy security are also noticeable in the domestic competition for energy exports rent in fossil fuel rich countries. Related problems in energy security may lead to terrorist attacks (Klare, 2008).

Opposite to neorealism is **neoliberalism** that focuses on international cooperation and the non-state actors. As the states are unable to control energy prices, the energy policy is made by transnational corporations, financial institutions, think tanks, mass media, and terrorist and criminal organizations that may have a significant impact on the global energy system and even disrupt regular economic activity of individual states (Baldwin, 1993).

The emergence of global energy market and the decrease in the number and intensity of conflicts lower the likelihood of 'resource wars'. According to Fettweis the global energy system that was developed in recent decades is suitable for all major market actors regardless of their resource assets size (Fettweis et al., 2009). Consequently, they are not interested in a military conflict that could destabilize the global or regional energy trade. Moreover, high costs of military operations and related political problems do not justify the takeover of oil and gas fields, as buying oil and gas at the market would be much cheaper and easier. As Goldthau and Witte point out, market forces that shape today's supply and demand, determine the volume of investments, and ultimately the future of the world energy. Institutions are of key importance in this system (Goldthau and Witte, 2009).

Neoliberals pay special attention to the role of international institutions in shaping the global energy industry (Newell and Phillips, 2016). Firstly, they can intervene in instances of market failures and in cases of extraordinary situations (i.e. economic problems or disasters). Such interventions happened in 1970-ies in the course of the oil crisis by the Organization of the Petroleum Exporting Countries and the International Energy Agency. Secondly, the institutions improve information transparency and increase trust among global energy actors, such as the International Energy Forum. Thirdly, the institutions (World Trade Organization and the Energy Charter Treaty) are designed to establish rules and standards for international energy cooperation that are based on interdependence theory proposed by Keohane and Nye (2001). The market assures secure energy supplier through competition, and interdependence guarantees cooperation. The reverse side or the side effect of international cooperation is energy terrorism whose main target is energy infrastructure (Koknar, 2005). Further debate places 'energy security' in the context of 'securitization' phenomenon that appeared due to international relations actors' recognition of three types of challenges: assuring energy supplies; assuring secure energy extraction, transportation and consumption; and improving energy efficiency for environmental, economic and social purposes (Debrouwer, 2008).

Unlike neorealists, neoliberals believe that the relationship between the energy market actors and energy security gains should not be perceived as a zero-sum game. One outcome of this cooperation that resulted in higher energy security is the global oil market. A key remaining challenge for energy security is assuring further development of liberal energy (Goldthau and Witte, 2009).

Constructivists offered to make person an object of security, and widen the range of actors involved in assuring security for all individuals (Gheciu and Wohlforth, 2018). This string of research suggests that the basic features of international relations, including energy-related, are unsteady. International relations and economic well-being are created and reproduced by the actors involved. The same phenomena, including energy security threats, can be interpreted differently by different actors of international relations (Buzan and Wæver, 2003). At the same time, assessments and rules of the game are subject to change as a result of interaction and information dissemination.

Energy problems are considered 'unstructured problems' with many uncertainties, fundamental disagreements and resistance from vested interests (Hoppe, 2010). This suggests that top-down rationalist approach alone is not suitable and has to be replaced or complemented with others, which offer "second-best" policy mechanisms (Bennear and Stavins, 2007b) or out of the box solutions, especially at the time of transition (Fouquet and Person, 2012).

The energy security approach in constructivism underlines the need to see and pursue common interests and shared values, to sustain communications, interpersonal contacts and trust in overcoming conflicts, including energy-related ones. Constructivists believe that frames ("construction of temporarily fixed meanings by establishing chains of connotations among different linguistic elements") shape and promote specific understandings of the world, also in energy policy-making, typically seen as defined by technical and economic frames (Kazantsev and Sakwa, 2012).

International political economy school considers energy to be one of the secondary power structures that play a key role in supporting the four primary structures: security, finance, production and knowledge. Today there is a competition between the four primary structures of power and the winners are often market actors, not states (Ocelik and Osička, 2014). According to Strange, energy research requires a new, mixed approach that fully takes into account the impact of policy factors on the energy markets and, vice versa, the impact of these markets on policy (Strange, 2004). The central issue here is finding the optimal balance between the state and the market that should be identified through a structural analysis of power execution in a particular society. Researchers of this school discuss international energy relations in terms of power, political rivalry, and different types of state governance in place (Dyer and Trombetta, 2013).

As noted by Markusson et al., "different liberal capitalisms could be supported by different clean fossil technologies", while "illiberal or more egalitarian regimes remain possible alongside particular, perhaps radically re-envisioned, versions of clean fossil" (Markusson et al., 2017).

Researchers emphasizing the geopolitical approach focus on countries struggling for access to energy resources. States establish direct or indirect control over certain fossil fuel reserves or energy transportation routes, and promote the geographical diversity of energy export or import to ensure national security. Energy geopolitics proponents Pascual and Zambetakis note that the largest energy importers depend on oil (the US) and gas (the EU) imports and seek to diversify suppliers. They acknowledge the geopolitical aspects of national energy strategies and name economic reasons for politicization of world energy. The authors point to the lack of elasticity of the global oil market due to high dependence of some countries on exports and others on imports of hydrocarbons (Pascual and Zambetakis, 2010).

Most energy security studies are based on a combination of several theoretical concepts discussed above. Many authors acknowledge both the influence of government actors and the conflict potential embedded in the competition for access to energy resources that are typical for neorealism, as well as the significant role of international institutions and global markets that fit the neoliberal paradigm. Some of them also admit the influence of ideas that shape the perception of energy security issues, that later feed in policy decisions (Stoett, 1994). For instance, Yergin identified ten principles of energy security that are important for all actors: diversification, security margin, high-quality and up-to-date information, co-operation between supplier and consumer countries, widening the influence of IEA through inclusion of China and India, stability of infrastructure and entire supply chain, well-functioning markets, energy efficiency (that also helps reduce impact on the environment), ensuring investment flow, and the advancement of new technologies (Yergin).

3.2. A comparison of energy security concepts

Modern studies of energy are often characterized by theoretical

Table 1
Characteristics of the theoretical approaches to energy security.

Theoretical approach/ character-ristics	Neorealism	Neoliberalism	Constructivism	International political economy
Level of issue consideration (cooperation/isolation)	The national interests dominate ("resource nationalism"); Each state acts on its own, however bilateral agreements are possible; Cooperation is relatively beneficial	States cooperate on energy issues; Cooperation is beneficial for all actors	The main features of international relations are created and reproduced by the actors themselves; The benefits of cooperation are subjective	The combined approach, that fully takes into account the impact of policy factors on the energy markets and the impact of these markets on policy; The combination of state and market-driven approaches
Key aspects of energy security	Military confrontation and conflicts over energy resources (fossil fuels); Ensuring sufficient fossil fuel imports	Market forces determine the development of the world energy sector; Ensuring secure fossil fuel supplies	Different interpretations of the problem by various players, assessments and behavior rules depend on the interactions and the information flows	Energy is a secondary power structure that ensures the four primary power structures: security, finance, production and knowledge
Main actors	States	Non-state actors*	States and non-state actors	States and non-state actors
National priorities	National power	Economic well-being	Depend on the interpretation of players	Depend on policy-making in a particular economy

Note: * Non-state actors include transnational companies, financial institutions, think tanks, media, terrorist organizations, and international institutions.

eclecticism. The differences between neorealists and neoliberalists have levelled-off. These two classical schools are successfully supplemented with alternative approaches – constructivism, international political economy, and neomarxism. With the advancement of international energy relations modern theoretical constructs will be complemented with new strings of research. Characteristics of the four theoretical approaches to energy security discussed above are summarized in Table 1.

Each of the described approaches has its advantages and limitations. Neorealism and Neoliberalism clearly assign the leading roles to either states or non-state actors, while underscoring the diversity of the modern world. In overestimating the value of either of the sectors (government or private) these theories are limiting the cooperation benefits within and across the national borders.

Constructivism and International political economy seem to be more balanced in terms of key stakeholders, but they postulate the ever-changing nature of energy security decisions. While in Constructivism these depend on subjective interpretation of each of the actors, in International political economy energy security prepositions may shift due to changing political priorities. Therefore, these two approaches lack the stability and predictability of energy security considerations.

In conclusion, one may note that neither of the described classical energy security concepts covers the diversity of international energy relations that have fundamentally changed since the 1970s. These concepts presume that fossil fuels dominate the world energy balance, while renewable sources are hardly noticeable and are not a significant factor for energy security. Today it is hard to ignore that renewables are the fastest growing segment of the global energy sector and this trend is expected to continue (Waterson, 2017). Some countries that have previously been net exporters of fossil fuels plan switching to electricity export in the long term (Farnoosha et al., 2014).

The ideological theoretical differences are further exacerbated by the difference in research approaches by scholars of difference scientific disciplines, and this has been acknowledged. Cherp and Jewell have identified three distinct perspectives on energy security: the 'sovereignty' perspective grounded in political science; the 'robustness' perspective grounded in natural science and engineering; and the 'resilience' perspective grounded in economics and complex systems analysis (Cherp and Jewell, 2011).

The analysis of the top 10% of highly cited international relations papers (closely related to political science and integrated with policy-making), indexed in the Web of Science, performed for this study, show a great variety of areas that focus on energy security (Fig. 1). There are large nodes that are disconnected with each other, i.e. there is no cross-fertilization among papers tackling various aspects of energy security from the international relations perspective. The most read research is centered around national security, energy prices, resource curse, resource security, industrial policy, conventional weapons and East Asia. This picture shows a marked difference with the energy security research topics discussed in energy journals (Fig. 2).

The top 10% of highly cited energy papers, indexed in the Web of Science, show us a great variety of areas that focus on energy security (Fig. 2). The top cited research papers on energy security are very disperse and cluster around the following nodes: power system, microgrid frequency, lithium-ion battery-battery management system-long life cycle, renewable energy (generation), wind speed, energy efficiency, load demand, SOC estimation, conventional technologies, flue gas, and a variety of smaller nodes. All of these nodes, that represent a gigantic picture, are interconnected. Behavioral change and deterministic approach are, perhaps, the only large node of research that links energy and international relations researchers.

Moreover, the time period from basic research findings to the development of energy applications and technologies has dramatically shortened (Technology transfer. Exec, 2016). Therefore, today's research and development may have an impact on energy markets in the short to medium term perspective (Adams et al., 2016). Disruptive

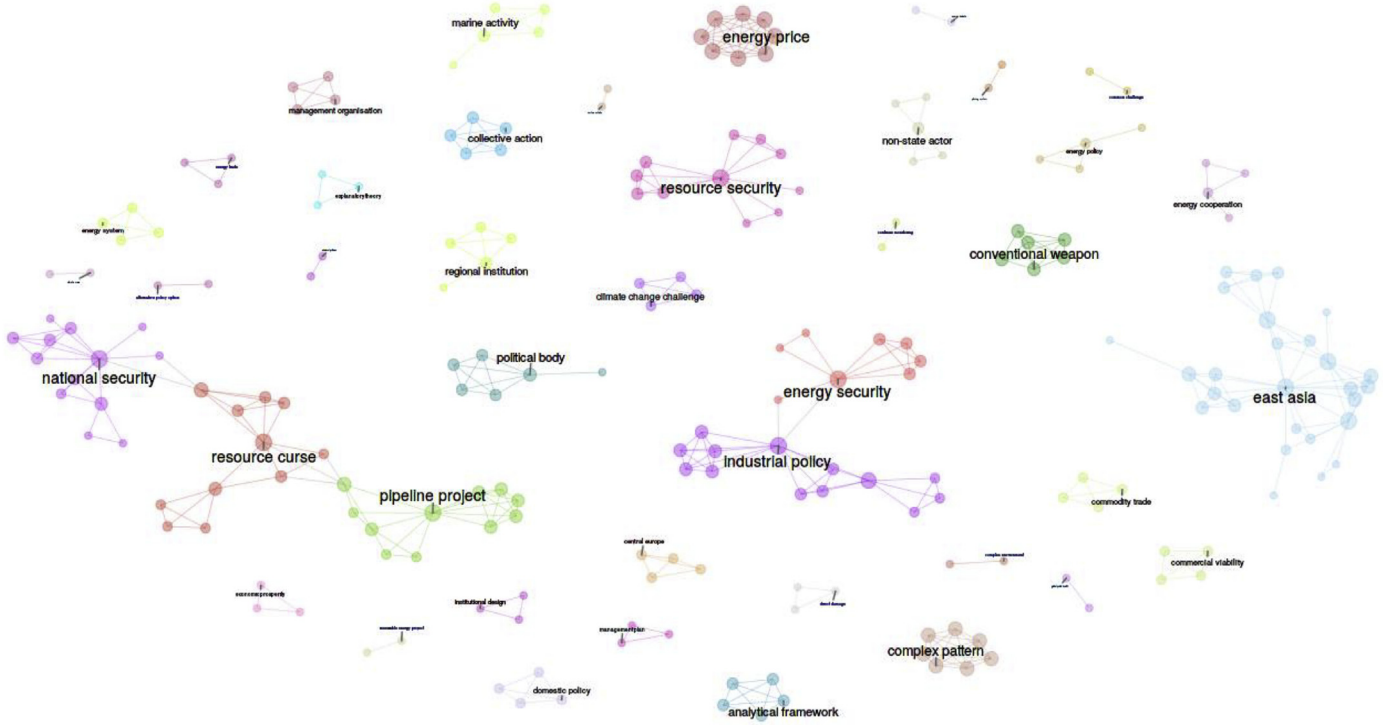

Fig. 1. Semantic map of the top cited publications in 'International relations', Web of Science, featuring energy security (2010–2015).

energy technologies that appear on the market are capable of introducing new energy sources that are acceptable from the socio-political, community and market perspective (Wustenhagena et al., 2007). These technologies include, inter alia, hydrogen energy (Ekins, 2010), economically justifiable energy storage systems (at the price of US$100 per kW/hour) (NREL, 2016) and entirely new energy infrastructures.

The classic theoretic prepositions are linked with energy issues that are mostly relevant for the developed countries. At the same time, as much as 40% of the world population in developing countries still uses wood and other basic bioenergy resources, adding new elements to the energy security concept, such as access to clean fuels and technologies for cooking, and electricity (IEA, 2017).

Often overlooked are market forces that have significantly affected the development of world energy outlook over the past decades. This has resulted in the formation of a fluid, competitive and truly global market with free trade of large volumes of oil, gas and electricity across

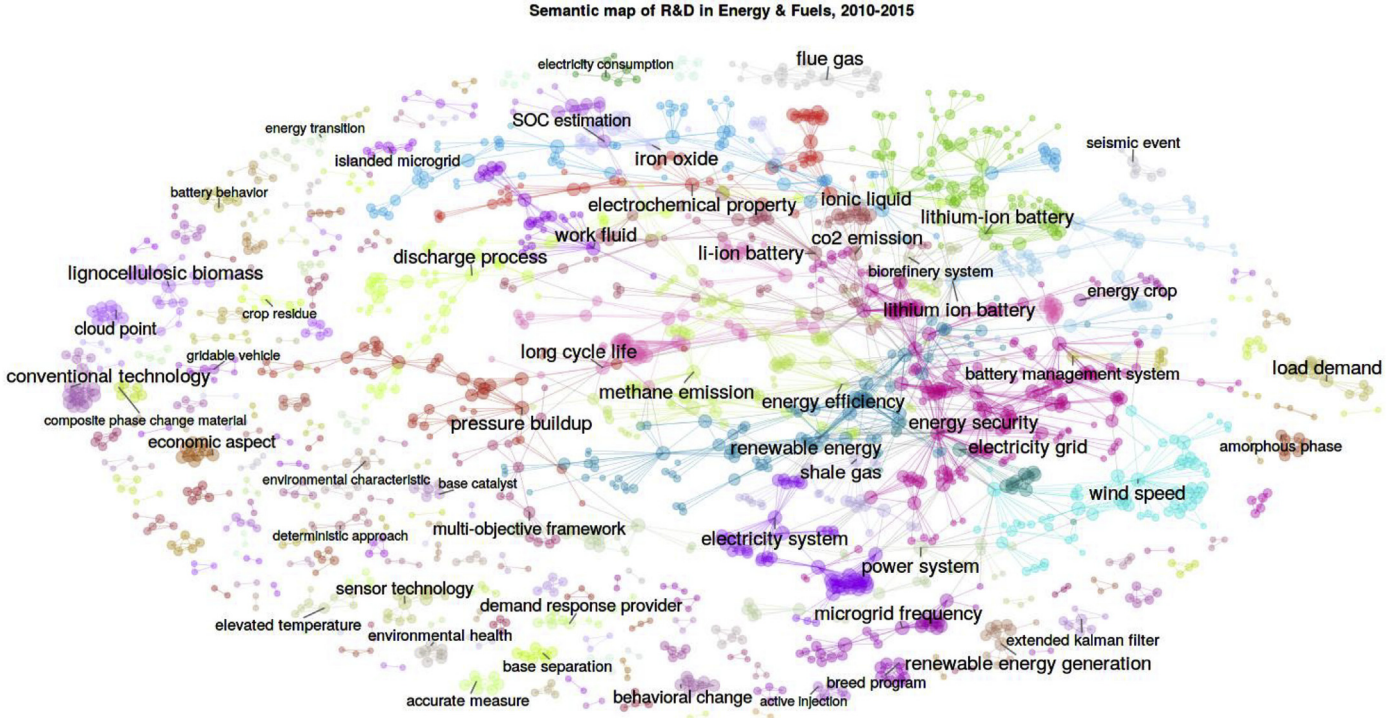

Fig. 2. Semantic map of the top cited publications in 'Energy and Fuels', Web of Science, featuring energy security (2010–2015).

borders (Newell and Phillips, 2016). These changes lead to former net importers exporting fossil fuels, and new trade routes appearing. Some countries and regions have become self-sufficient through adding a large share of renewables in their energy mix, or becoming "renewable energy research and innovation hubs as well as build up a renewable energy technology export industry" (Yao et al., 2018). Decentralization of energy supply is led by consumers' self-generation and the establishment of micro and mini-grids (García-Olivares, 2015). Deploying community-based small-scale renewable power plants in combination of low cost energy efficiency measures also contributes to energy security and poverty reduction, specifically for rural and vulnerable households (Laldjebaev et al., 2018).

4. The place for energy technology in energy security concepts

As it was shown, the classic international relation concepts of energy security take into consideration a multitude of internal and external factors that are necessary for a stable operation of energy systems. However, the future energy technology shifts and breakthroughs, such as discovery and commercialization of new energy sources, radical cheapening of existing renewable energy and energy storage technologies and other uncertainties, are not taken into consideration (Smits et al., 2011). The foresight studies usually mark such factors as 'weak signals', 'wild cards' and 'black swans' (Miles et al., 2016). The reserve also holds true: future energy studies should incorporate a much stronger political and institutional analysis (Daddow, 2017).

4.1. Suggestions on integration of future technology consideration in energy security concepts.

Most of energy security concepts take into consideration the disruptions in the supplies of (predominantly fossil) energy resources, but do not take into consideration the appearance of disruptive innovations that are capable of changing the energy outlook in a few decades. The existing concepts made a certain move in this direction by attributing high importance to externalities. However, the list of externalities lacks revolutionary technological changes that may be identified, for instance, with the use of technology foresight instruments.

Energy technology foresight has become a widely used practice in most developed and certain developing countries, including the European Union, BRICS countries and more (Proskuryakova, 2017). Research and technology foresights in the energy sector are developed in the framework of foresight (forecasting) systems; science, technology and innovation policies; as well as strategic planning for informed decision-making, including the decisions on science and technology priority-setting in the energy sector (Proskuryakova and Filippov, 2015).

The energy foresight studies differ in scope, principles of organization, and the use of outcomes. They could be implemented at international, national and corporate levels. All of the studies may be devoted to the analysis of energy security perspectives. National energy-related science and technology foresights may be used for identifying the approaches to overall security in the energy sector, as well in particular energy segments, such as the *Outlook for shale gas and tight oil development in the U.S.* by the US Energy Information Administration (Sieminski, 2013), and *Roadmap to achieve energy delivery systems cybersecurity* by the US Department of Energy (Roadmap to achieve energy, 2011).

The foresight studies on advanced, in particular, low-carbon energy technologies contribute not only to addressing climate change and economic development issues, but also energy security. For instance, the APEC Energy Demand and Supply Outlook (Energy Demand and Supply, 2013) identified key energy policy factors of APEC member-states, including assuring energy security, the overall economic effects necessary for energy sector development and the need to provide for sustainable development. The experience of Delphi survey undertaken in the course of the first national Foresight study in Poland "The Scenarios of Technological Development of Fuel and Energy Sector for National Energy Security", implemented on the request of the Polish Ministry of Economy, was analyzed by Czaplicka-Kolarz et al. (2009). The study allowed identifying future development directions for the energy sector until 2030, a list of key energy technologies of strategic importance, as well as corresponding roadmaps for their implementation.

Shell has been developing world energy scenarios since 1990-s, and already in its early reports the company was underlining that there is no alternative to sustainable development that will allow finding answers to multiple global challenges. In 2005 the consequences of negative and hardly foreseen events such as terrorist attacks and high-scale corruption deals (i.e. Enron case) were forecasted. In scenarios with a 40 year time horizon the company offers a fork between an absence of efficient state policy in energy efficiency (with consequent rapid depletion of natural resources and corresponding climate change problems), and policy directed towards assuring energy security while minimizing environmental impact.

International Renewable Energy Agency (IRENA) approaches energy security through replacement of fossil fuel imports with renewable energy generation that will have an impact on the energy and trade balance structure. IRENA experts estimate that the G7 countries would save USD275-315 bn per year in 2012–2030 due to increasing the share of renewables in their energy balance (Roadmap for a renewable e, 2016). The Agency uses some elements of foresight studies, including non-linear scenario analysis.

The reviewed examples prove that foresight studies (including science and technology foresights) often take into account energy security issues. However, the forecasted changes and breakthrough in energy research and development are not taken into consideration in the major energy security concepts, which limits their applicability. The suggested revisions of energy security concepts through integration of a technological foresight are given in Table 2.

The common new elements in all energy security concepts should be the consideration of new energy sources, primarily renewables (Contribution of renewable, 2007). Their production, transportation and use patterns differ radically from those of fossil fuels. The countries will focus more on transmission of power, improving the speed and efficiency (minimizing losses), rather than transportation of fossil fuels by pipelines and tankers. A more equal distribution of renewables throughout the planet (as compared with hydrocarbons) will change the notions of 'resource rich' and 'resource poor' countries (Yao et al., 2018).

The competition for primary energy resources will be substituted by the competition for energy conversion and storage technologies, high-speed energy transmission systems and smart-grid solutions. This will require countries to correctly assess the global market potential and domestic capabilities, to concentrate the always limited financial resources on priority R&D areas.

4.2. The cases of Germany, China and Russia

To test the suggestions in Table 2, three cases of national energy policy are reviewed below. It is described how Germany, China and Russia respond to their energy security challenges within the boundaries of the described energy security concepts and beyond, encompassing future energy technologies through science and technology foresight.

In Germany that is in the middle of a very ambitious energy transition, *the Energy Security of Supply Act* permits the enactment of regulatory acts to restrict sales, purchase or use of goods (demand restriction related to quantity and time), or permit them only for certain priority purposes. The government regulated that companies should assume individual responsibility for backup solutions to ensure supply security for their energy facilities. Companies that have fuel-switching

Table 2
Suggestions on integration of technological foresight in energy security concepts.

Theoretical approach/ character-ristics	Neorealism	Neoliberalism	Constructivism	International political economy
Type of energy resources	Various types of renewables (solar, wind, geothermal, biomass, hydrogen, etc.) should be taken into consideration.			
Technological advancements	Development of national champions that produce own energy technologies and equipment, and provide energy services	International cooperation in basic research (for ex. advancement of mega-science projects) that will trigger changes towards the new technological order in the world energy	Multiple-actor energy R&D programs suffer from actors' diverse interpretations of technologies prospects	The state sets minimal security standards for existing and future energy facilities and technologies that are observed by market actors; These standards may become more stringent or loose with the appearance of new threats and new energy sources
Level of technology studies, including foresight	Science and technology energy foresight at national level	International foresight studies and foresights for world regions	States, companies and research centers develop their own science and technology foresights and provide for security of suggested solutions	Foresight studies are performed by various actors for pragmatic purposes - to maximize benefits (profits); the aim is to persuade partners, competitors and the market that one's vision is correct and one's products will be in demand years ahead
Level of technological foresight consideration	Development of national centers of excellence capable of making a breakthrough and advancing national capabilities	Foresight studies are planned with participation of international experts and consideration of best international experience	The decision to use or neglect the available science and technology studies and technologies is made by each actor independently, based on their strategic documents and priorities	The state assures permanent monitoring of energy technology trends and 'weak signals' that are early markers of substantial future changes. The national systems of energy technology monitoring and foresight is set up by states and used by other national actors.
National priorities	Support to traditional energy sources (fossil fuels, nuclear), and advancing technologies for their use	Support to new economically and technologically feasible energy technologies that spread fast at the world market	International organizations, states and companies set their own priorities based on own requirements and limitations	The state seeks to maximize the profit derived from energy technologies, therefore the support goes to easily scalable technologies with short pay-back period, or to technologies with high added value

capability would use it in the case of a gas supply emergency (Energy Supply Security, 2014).

The security of electricity and gas supply through power grid and pipelines to the population is a core objective of the *German Energy Act (EnWG)* and it also makes up a large part of the Bundesnetzagentur's work. The challenges of *Energiewende* and the increase in volumes of European power trade represent additional loads on the country's electricity grid and gas supply networks.

In accordance with item 13(1) and 14(1) of the EnWG the electricity distribution system operators are authorized and obliged to address any threat or breakdown in the electricity supply network through the adoption of system-related and market-related measures. After waiting all pros and cons of the nuclear energy – its role in meeting the growing demand, providing a pathway towards the decarbonization of the world's major economies and environmentally risks (possible nuclear accidents and radioactive waste) (Prăvălie and Bandoc, 2018) – 8.4 GW nuclear power stations were shut down in 2011 and it was decided to decommission additional 12 GW of nuclear power by 2022 (Energy Supply Security, 2014). This loss of capacity will be offset by energy efficiency/energy saving, renewables, and natural gas, as well as more frequent interventions by grid operators. One major assumption behind the successful implementation of *Energiewende* is that future technologies (i.e. energy storage, smart grid, etc.) will be developed and put on the market.

As energy security is in mutual interest of all EU member-states, cooperation between countries is considered desirable. The European energy market was based on the principles of states' interdependence and energy companies' competition. Its common energy market fits into the neoliberal approach to energy security. A competitive energy market is meant to increase energy security problem through lower prices and costs, thereby making supplies less critical.

The German energy plans are in line with the overall European Energy Security Strategy (released in May 2014) and its targets, such as increasing energy efficiency and reaching the 2030 energy and climate goals. Another target is to increase energy generation in the EU and to diversify suppliers and routes. The biggest challenge for EU supply security is that more than half of all energy demand is covered through imports: crude oil (over 90%) and natural gas (66%) for the amount of over EUR1 billion per day (European Energy Security, 2014). Many EU member-states, including Germany, import their energy from a single supplier, i.e. natural gas from Russia. Although Russia has proven to be a reliable partner, this dependence is potentially subject to politically or commercially motivated supply disruptions or infrastructure failure.

The EU Green Paper "Towards a European strategy for the security of energy supply", adopted by the European Commission in 2000, was developed to address the risks associated with the ever increasing external dependence for energy (The EU Green Paper). In 2014 38 EU and other European countries carried out energy security stress tests where they simulated one to six months energy supply disruption scenarios related to Russian natural gas imports to the EU. The exercise revealed that if all countries cooperate with each other consumers would be supplied even in the worst case scenario by redirecting energy across the EU. Thereafter, the Energy Community countries developed regional energy security preparedness plans that were adopted in 2015.

To address the technology aspects the European Energy Security Strategy is closely linked with the EU Strategic Energy Technology Plan. New energy technologies will be required to reduce the emissions by 80% until 2050, build a common smart grid, integrate distributed renewable energy facilities in the energy system (da Graça Carvalho et al., 2011).

The German Federal Ministry of Education (BMBF) and research undertakes science and technology foresight exercises to address future societal challenges, including those in the energy sphere in 2007–2009 and 2012 (Hightech and Innovation., 2018). Previous studies were performed by Fraunhofer ISI back in 1990-ies and also included the suggestion for national policies and possible follow-up security

problems (Cuhls, 2015).

Energy security was put forward by China's policy makers in 1990s and reflected in the country's 10th Five-Year Program (FYP) (2001–2005). The goal was to optimize the energy mix while sustaining the overall energy security. The 10th FYP established the strategic petroleum reserves for emergency cases to ensure national petroleum supply security, as well as storage schemes by individual enterprises (Wu, 2014). Other way to lower heavy dependence on oil imports was to enhance domestic coal gasification and nuclear power development, as well as boosting domestic oil and gas extraction. Another goal was to diversify oil and gas imports. To this end, China aimed at import of hydrocarbons from many different suppliers, contribute to the setup of a regional energy security system and investing in overseas oil business.

The strive to mitigate economic and environmental problems associated with boosting energy consumption has become the top priority and led to multiple low-carbon policies since 2005, displaying a mixture of authoritarian and neoliberal environmentalism (Lo, 2015). The key energy security challenges in the 11th FYP (2006–2010) cover increasing energy demand and energy imports, continuous increase of the strategic petroleum reserves, and enhancement of the overseas sea-lane transportation security (Wu, 2014). For an increase in domestic hydrocarbon extraction, new technologies will be required for the exploration of unconventional hydrocarbon resources such as coal-bed methane and shale oil.

In the 12th FYP (2011–2015) the energy security priorities included exploration of unconventional hydrocarbons, rational energy use - energy conservation, diversification of energy supply and a more active use of renewables. Today China is leading in domestic and overseas investments in renewable energy and related technologies, and dominated the renewable energy equipment manufacturing (Slezak, 2017). Moreover, the analysis shows that the country has more ‘efficiency losses’ than ‘efficiency gains’ resulting from carbon transfers. The situation could be changed with new policies and technologies, as well as stricter technology standards for carbon intensive productions (Jiang et al., 2015).

To this end, China has performed several foresight exercises in 2002–2009 that have identified priority (critical) technologies (Technology Foresight Repo, 2003). Outcomes these studies were integrated in the National science and technology development plans. The criteria for the selection of technologies included achieving their domestic production not least for increasing energy security (Chen, 2010).

In Russia the key document in energy security is the *Energy Security Doctrine of the Russian Federation*. The document treats national energy security as part of national security that includes assuring quantity (volume), quality (economic feasibility and reliability) and efficiency (logistics) of energy supply to consumers. The national energy security threats are divided into domestic economic (low level of investments, depletion of fossil fuel reserves, dependence on equipment imports, lack of energy saving gains), social-political (ethnic conflicts, labor conflicts at energy enterprises, malfunctions and terrorist acts at energy facilities), man-made (accidents at power supply facilities), natural (earthquakes, floods, hurricanes, etc.), and external economic and foreign policy (sanctions, etc.) (Energy Security Doctrine, 2011). Although the hydrocarbon receipts will shrink twofold in the national 2040 budget (The Energy Research Insti, 2016), it is planned to further increase hydrocarbon exports at international markets, increasingly exporting also energy equipment and technologies (Bushuev et al., 2012).

The solutions that are offered by the document are modernization of the equipment and technologies used in the energy sector, increasing energy efficiency, and exploration of new hydrocarbon deposits. Moreover, it is planned to undertake thorough analysis of energy resources (including renewables) available in Russia's regions to ensure their self-sufficiency and lower energy transportation volumes. To this end, it is planned to set up hybrid facilities based on renewables and diesel in Russia's regions located behind the polar circle. Previously these were entirely dependent on expensive diesel generation. More prospective energy technologies are reflected in the National Science and Technology Foresight until 2030 (Grenenuyk et al., 2014) and the sectoral energy technology foresight (Foresight of science and, 2016). Some priority energy technologies identified in these documents were selected based on energy security considerations.

To sum up, Germany is continuing its energy transition path, where energy efficiency and renewables have long occupied a central place. For Russia and China a more substantial increase in energy efficiency and the advancement of renewables today also seems inevitable, despite little attention in the past. The main rationale for China is its boosting energy demand and major environmental damage, and for Russia – the need to increase international competitiveness, lowering budget costs for energy consumption in energy-poor regions and unstable hydrocarbon exports (tough competition, low prices and depletion of traditional reserves). The Germany (like other EU countries) and China striving to diversify suppliers are bad news for Russia, the only fossil fuel exporter. Clearly, all three countries will require new technologies to address their energy security issues.

Germany has an ubergoal to diversify its energy mix by substantially increasing the share of renewables, and, decreasing the dependence on imported fossil fuels. Its policies are within the boundaries of neoliberalism with some elements of constructivism. China is the largest energy consumer that is aiming to diversify its energy import in terms of contractors/countries, while also increasing domestic production of all types of fuels (including renewables). Its policies are predominantly constructivist with some elements of neorealism (Mori, 2018). Russia has an old school neorealist approach to energy security (Kropatcheva, 2014) with some elements of political economy (Kropatcheva, 2012). It has been predominantly relying on the domestic production of fossil fuels for own consumption and budget revenues from export (Geels, 2014).

Despite the variety of approaches to the definition of energy security, the cases of Germany, China and Russia show that countries are equally trying to improve their energy security by increasing energy efficiency, reducing the vulnerability of the energy system and enhancing power grid stability, aiming at resource self-sufficiency at national and regional level. In some cases stability is more important for energy security than performance indicators, as well as economic and environmental costs.

5. Conclusion

The classical energy security concepts – neorealism, neoliberalism, constructivism and international political economy – are based on the premises of sufficient and reliable supply of fossil fuels at affordable prices. Fossil fuels were considered to be the most reliable and most wanted energy resources, centralized systems – the predominant energy generation schemes, and energy infrastructure to remain unchanged in the long-term. Today with the rapid advancement of renewables and smart grid, decentralization of energy systems, new environmental and climate challenges the basic elements of energy security should be questioned and revisited.

More specifically, all concepts should master technological advancements. The proponents of neorealism that place resource nationalism at the center, should support national champions that produce own energy technologies and equipment, and provide energy services. Neoliberals may prefer to support international cooperation in basic energy research. Constructivists need to overcome diverse interpretations of technologies prospects in multiple-actors energy R&D programs. Policy-makers that have international political economy views should set minimal security standards for existing and future energy facilities and technologies that are observed by market actors.

Energy technologies should also be assessed in terms of new energy sources that may become available (i.e. hydrogen, nuclear fission), new faster ways of energy transportation, new energy storage options and

other areas that may become evident in the course of foresight studies that are already applied at national and sectoral level in Germany, China and Russia.

All of these advancements impact on the reliable supply of energy resources at affordable prices.

Neorealists should invest in the development of the national centers of excellence. Neoliberals plan foresight studies are planned with participation of international experts and consideration of best international experience In case of a constructivist approach, the decision to use or neglect the available science and technology studies and technologies is made by each actor independently, based on their strategic documents and priorities. The international political economy policies rely on national systems of energy technology monitoring of energy technology trends and 'weak signals' that are early markers of substantial future changes.

Energy security studies have a direct impact on national and international energy policies. Therefore, it is of utmost importance to see that energy security concepts are constantly scrutinized in order to reflect the fast changes that occur in research and development. Technology foresight provides evidence to decision-makers and researchers who want to foresee future shifts in the energy sector and social-economic areas that determine its development. Foresight studies of various energy resources characteristics (economic, technological, policy regulation, etc.) is an inherent element of contemporary energy security policy and planning.

The policy-makers and managers will continue to have divergent views on the national energy priorities. While neorealists will primarily focus of hydrocarbons (including their more efficient use and unconventional deposits) and advanced nuclear technologies, neoliberals will support any new energy technologies that are economically and technologically feasible and have good prospects at the world market. In constructivism international organizations, states and companies set their own priorities based on own requirements and limitations. Under international political economy the policy support will focus on easily scalable technologies with short pay-back period, or to technologies with high added value.

International relations and energy researchers' discourse of energy security differs markedly: the papers with highest impact in both disciplines focus on very different topics that are hard to match. While international relations research treats the various energy security issues separately, energy research represents an interdependent set of studies with a vast variety of focus areas. An interdisciplinary approach to energy security, combining the natural and social sciences ideas and tools, would definitely enrich the debate on energy security.

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Appendix A

This Appendix shows the number of articles and book chapters found in the literature review exercise and the keywords used for literature search.

Table 1
Keywords used for literature search

Keywords	No. of results as of 26.04.2018		Notes
	Total	2000–2018	
ScienceDirect (*review and research articles, Encyclopedia and book chapters*)			
Energy security	113 634	94 097	
International relations theory + energy security	535	218	A substantial part of papers refer to application of energy security theory to some practical energy issue (i.e. climate change in China or gas supply in the EU), to measuring energy security, and other practical aspect. Conceptual papers were only considered for Literature Review in this paper.
Energy security + Neorealism	1	1	One paper on global politics
Energy security + Realism	61	50	Some papers relate to other sectors or areas, i.e. IT, culture and education. A number of paper touch upon various energy segments, i.e. natural gas transportation, electric vehicles, carbon capture and storage, radioactive waste.
Energy security + Neoliberalism	211	206	The papers contain many country cases, such as Ecuador, Kenya, Mexico and other. National policy discourses are also analyzed (i.e. Poland and Russia). Some papers are devoted to adjacent sectors. i.e. food and water security, climate change, social security and medicine, etc.
Energy security + Neorealism	109	66	Many references belong to articles in Encyclopedia
Energy security + political economy	1003	824	A lot of publications refer to practical application of political economy theory to various economic aspects, such as environmental labeling, tourism, transportation or even teacher management reform
Energy security + Constructivism	16	14	Some publications are related to other research areas, such as tourism and health services. Some publications are related to business and management, as well as education. One Encyclopedia entry. A few papers pickle Russian energy policy.
Google Scholar (*excluding patents*)			
International relations theory + energy security	38 700	17 800	

(*continued on next page*)

Table 1 (*continued*)

Keywords	No. of results as of 26.04.2018		Notes
	Total	2000–2018	
Energy security + Neorealism	2200	2100	
Energy security + Neoliberalism	7270	7020	
Energy security + Political economy	77 700	21 000	
Energy security + Constructivism	5270	5150	

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