

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/338445998>

Renewable energy and geopolitics: A review

Article in *Renewable and Sustainable Energy Reviews* · April 2020

DOI: 10.1016/j.rser.2019.109547

CITATIONS

12

READS

556

3 authors:



Roman Vakulchuk

Norwegian Institute of International Affairs

52 PUBLICATIONS 98 CITATIONS

[SEE PROFILE](#)



Indra Overland

Norwegian Institute of International Affairs

156 PUBLICATIONS 781 CITATIONS

[SEE PROFILE](#)



Daniel J. Scholten

Delft University of Technology

35 PUBLICATIONS 290 CITATIONS

[SEE PROFILE](#)

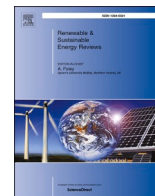
Some of the authors of this publication are also working on these related projects:



CADGAT Central Asia Data Gathering and Analysis Team [View project](#)



Central Asia Data Gathering and Analysis Team (CADGAT) [View project](#)



Renewable energy and geopolitics: A review

Roman Vakulchuk^{a,*}, Indra Overland^a, Daniel Scholten^b

^a Center for Energy Research, Norwegian Institute of International Affairs (NUPI), C.J. Hambros Plass 2D, Postboks 7024 St. Olavs Plass, 0130, Oslo, Norway

^b Delft University of Technology, Faculty of Technology, Policy and Management, Jaffalaan 5, 2628BX, Delft, the Netherlands

ARTICLE INFO

Keywords:

Renewable energy
Geopolitics
Energy security
Energy transition
Critical materials
Petrostate decline
Literature review

ABSTRACT

This article reviews the literature on the geopolitics of renewable energy. It finds that while the roots of this literature can be traced back to the 1970s and 1980s, most of it has been published from 2010 onwards. The following aggregate conclusions are extracted from the literature: renewable energy has many advantages over fossil fuels for international security and peace; however, renewable energy is thought to exacerbate security risks and geopolitical tensions related to critical materials and cybersecurity; former hydrocarbon exporters will likely be the greatest losers from the energy transition. Many of the reviewed publications share some weaknesses: a failure to define “geopolitics”; an unwarranted assumption that very little has been published in the field previously; limited use of established forecasting, scenario-building or foresight methodologies; a lack of recognition of the complexity of the field; a lack of theorisation. Most authors do not distinguish between the geopolitical risks associated with different types of renewable energy, and only a few distinguish clearly between the geopolitics of the transitional phase and the geopolitics of a post-energy transition world. A disproportionately large part of the literature is dedicated to critical materials and cybersecurity, while only a small part concerns the decline of former fossil fuel powers. Among those publications that do discuss the decline of fossil fuels, there is also an over-focus on oil producers and a lack of attention to the countries that rely heavily on coal, for example Australia, China, Germany, Indonesia, Poland and the United States.

1. Introduction

According to Jacobson et al. [1], hindering global warming from rising above 1.5 °C will require reaching 80% zero-emissions energy by 2030 and 100% by 2050, and much of this should be achieved through the increased use of renewable energy. This, in turn, inspires a steadily growing literature on a range of questions concerning the geopolitical consequences of the transition to renewable energy. Will the world become more secure if renewable energy is adopted on a large scale? Can electricity transmission be used as a foreign policy instrument or weapon similar to how oil and gas resources have been used in the past? Will renewable energy leaders such as China, Denmark and Germany strengthen their positions in world affairs? How likely is a backlash from declining petrostates during the transition phase?

This article reviews, systematises and aggregates the existing research on the geopolitical consequences of the transition to renewable energy. For the purpose of this article, “geopolitics” broadly concerns the connection between geography, space and the power of states, and the scope of the article is limited to the literature that deals explicitly

with the consequences of the growing use of renewable energy for the power of states, international conflict or energy security (a more detailed discussion of the term “geopolitics” is presented in the next section). Publications dealing with domestic issues and conflicts related to renewable energy, or those that cover international relations but not power, conflict or energy security, are outside the scope of this article.

In the next section, we further define the field. Then we proceed by briefly going into the history of the literature, finding that it is actually older than many recent publications claim. After that, we review the core themes covered by the literature: (1) the overarching questions of the peace potential of renewables, (2) the potential geopolitical winners and losers in the energy transition, (3) the impact of renewable energy on international relations, (4) critical materials, and (5) cybersecurity. Finally we summarise the literature’s strengths and weaknesses and conclude with some observations and suggestions for future research to address gaps.

Relevant publications for this review were identified by searching for literature from the period 1950–2019 in Crossref, Dimensions, Google Scholar, ISI Web of Science and Scopus. The following search string was used: “(geopolitic* OR energy security OR security OR conflict) AND

* Corresponding author.

E-mail address: rva@nupi.no (R. Vakulchuk).

<https://doi.org/10.1016/j.rser.2019.109547>

Received 8 June 2019; Received in revised form 7 October 2019; Accepted 30 October 2019

Available online 7 January 2020

1364-0321/© 2019 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

List of abbreviations

GeGaLo	The Index of Geopolitical Gains and Losses
HVDC	High-voltage direct current
ICMM	The International Council on Mining and Metals
IEA	The International Energy Agency
IISD	The International Institute for Sustainable Development
IRENA	The International Renewable Energy Agency
LNG	Liquefied natural gas
MENA	Middle East and North Africa
NASA	The National Aeronautics and Space Administration
NSF	The National Science Foundation
OECD	The Organisation for Economic Co-operation and Development
VUCA	Volatility, uncertainty, complexity, ambiguity

(renewable energy OR renewables OR alternative energy OR electricity OR solar energy OR wind energy OR biofuels OR energy transition OR stranded assets)".

2. History of the field

2.1. Defining the field

Considering the abundance of literature on geopolitics and on renewable energy, it is necessary to define these terms. The definitions have implications for which works are to be included and excluded from the review.

For "renewable energy", we adhere to the definition of the International Energy Agency (IEA), which views it as "energy that is derived from natural processes that are replenished constantly [such as] solar, wind, biomass, geothermal, hydropower, ocean resources [tidal and wave], and biofuels, electricity and hydrogen derived from those renewable resources" [2].

"Geopolitics" is somewhat harder to define. Initially, it was conceived as "a deterministic causal relationship between geography and international relations focused on the permanent rivalry, territorial expansion and military strategies of imperial powers" (Overland [3], p. 36; see also Ó Tuathail [4], Mahan [5]; Ratzel [6]; Mackinder [7]; Haushofer [8]; Spykman [9]; Kissinger [10]; Brzezinski [11]).

Over time, however, geopolitics started to "denote the influence of geography on the power of states and international affairs more broadly, with less emphasis on determinism and more on the strategic importance of natural resources, their location, transportation routes, and chokepoints" (Overland [3], p. 36). The late 1990s saw the rise of critical geopolitics (Agnew [12]; Ó Tuathail and Dalby [13]; Amineh [14]). Since then, the main divide within the field has been between classical and critical geopolitics (Dodds [15]; Flint [16]; Moisiso [17]; Agnew [12]; Painter and Jeffrey [18]). In a critical geopolitics perspective, "[g]eographic arrangements [are seen as] social constructions that are changeable over time depending on political, economic and technological changes" (Amineh [14], p. 24). However, for the purpose of this paper, we stick to a more conventional understanding of the term "geopolitics": "great power competition over access to strategic locations and natural resources" [Overland [19], p. 3517].

Having thus defined both "renewable energy" and "geopolitics", we delimit our review to works that cover issues that fall within those definitions. This means that other bodies of literature have been intentionally excluded. First among those are more theoretical works that focus on the conceptualization of geopolitics in general and are not directly related to energy. Second, we exclude works on the geopolitics of fossil fuels that only briefly touch upon renewable energy (Bromley [20]; Clingendael [21]; O'Sullivan [22]; Hoegsli [23]).

Third, we do not cover works on the geopolitics of climate change and the environment, topics that have received a great deal of attention (e.g. Dalby [24–31], Dalby and O'Lear [32], O'Lear [33], Chaturvedi and Doyle [34], Harmer [35]). Those studies span considerably more broadly than ours. While they sometimes also concern renewable energy, they do not focus on it. We would argue that the geopolitics of climate change and the environment deserves to be classified as its own field, related to, but sufficiently distinct from the geopolitics of renewable energy not to be covered here.

Fourth, we do not cover works that emphasize the development, system integration and market diffusion of renewable energy technologies, policies to support them or their domestic politics (Aklin and Urpelainen [36], Gallagher [37], Haas et al. [38], Scoones et al. [39], Tellam [40]; Verbong and Geels [41]). Their emphasis is on achieving the energy transition, not its geopolitical implications.

Fifth and finally, we have not included the energy security literature that is solely occupied with the concept of energy security (definitions, frameworks, and operationalizations), for example Sovacool and Mukherjee [42] or Winzer [43], or that applies it only to fossil fuels. While we leave them out, we would still like to acknowledge the theoretical and empirical richness of these works, whose lessons the literature on the geopolitics of renewables could benefit from. For example, by relating notions of space and territoriality to renewable energy (e.g. Stoeglehner et al. [44]; Bridge et al. [45]), political geography has highlighted many important considerations that energy security and geopolitical analyses should take into account.

2.2. Origin of the literature

From the late 1950s onwards, the energy geopolitics literature mostly dealt with the interface between international affairs and petroleum resources (e.g. Ireland [46], Conant and Gold [47], Klare [48, 49], Barnes and Jaffe [50], Harris [51], Yergin [52], Krane and Medlock [53]). This topic received considerable attention from the academic community as well as the media. It was often included in the curricula of university courses in international relations, global governance, foreign policy, security studies and energy studies. As of 2018, oil and gas still dominated the geopolitics research agenda, receiving much more attention than renewables (see Table 1).

Solar and wind power installations started expanding exponentially from around 2006, and the geopolitics of renewable energy received increasing attention from the expert and academic communities from around 2010 onwards. Many of the resulting publications highlight the novelty of this topic (e.g. Scholten and Bosman [54], Goldthau et al. [55]); however, it is not as new as one might think. In 1972, the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) [56] argued that solar power was of strategic importance to the United States and that solar energy utilisation would inevitably have environmental, social and political consequences that needed to be understood. In 1974, Williams [57] noted that the large-scale adoption and use of solar energy would avoid the international energy crises associated with the consumption of fossil fuels. In 1980, the California Academy of Sciences [58] prepared a report for the US Federal Emergency Management Agency on how renewable energy could lessen US energy vulnerabilities and the likelihood of war. The authors stated:

Table 1

Searches for geopolitics, oil and renewable energy (11 September 2018).

	Search string A: "geopolitic* AND oil", in title, keywords, or abstract 2016–2018	Search string B: "geopolitic* AND renewable energy", in title, keywords, or abstract 2016–2018
ISI Web of Science	131	23
Scopus	100	38

Current US energy systems (fuels and electricity) are highly vulnerable, due to requirements for imported resources and due to the centralised nature of the systems themselves. Dispersed, decentralised and renewable energy sources can reduce national vulnerability and the likelihood of war by substituting for vulnerable centralised resources (p. 2).

The positive impact of renewable energy on the global economy and international security was also stressed by Omo-Fadaka in 1980 [59] and Shea in 1988 [60].

2.3. Resurgence of the topic

As we saw in the previous section, US scholars and experts were the first to raise the issue of the geopolitics of renewable energy in the 1970s and 1980s. However, after the year 2000, Northern European researchers came to dominate the field. Northern Europe is where the widespread use of modern renewables – initially wind and solar power – first took off. It is therefore not surprising that scholars based in Germany and the Benelux countries were among the pioneers in the study of renewable energy geopolitics. In Germany, this included Krewitt et al. [61], Westphal [62], Casertano [63], Westphal and Droege [64], Huebner [65], Strunz and Gawel [66]; in the Benelux countries it included Crikemans [67], Scholten and Bosman [54,68], De Ridder [69], Sweijts et al. [70] and Scholten [71]. One of the most comprehensive works in the field is the edited volume by Scholten [71] with 12 chapters focusing on various aspects of the issue area and most of the contributors based in the Benelux countries or Germany. Within a few years, Nordic academics joined the debate, reinforcing its distinct Northern European flavour (see Månsson [72], Overland [19], Tynkynen et al. [73]).

The high level of activity among Northern European researchers was partly driven by the ministries of foreign affairs in Finland, Germany, the Netherlands and Norway initiating and funding relevant research. The issue also gained attention in Spain where the Ministry of Defence published a report on the topic (see Ministerio de la Defensa [74]).

The German Federal Foreign Office and the Ministry of Foreign Affairs of Norway were particularly active, joining forces with the International Renewable Energy Agency (IRENA) to support a major international analytical initiative from 2016 to 2017 (O'Sullivan et al. [75]), leading on to the formation of the Global Commission on the Geopolitics of Energy Transformation under IRENA in 2018. The Commission's findings were published in 2019, and its prominent membership – including Anatoli Chubais, Joschka Fischer, Pascal Lamy, Maria van der Hoeven – drew further attention to the field (IRENA [76]).

3. Core themes

There are some recurrent core themes in the literature on the

geopolitics of renewables. First, will increased use of renewable energy stabilise international energy relations or not? In other words, what is renewable energy's peace and conflict potential? Within this area, critical materials and possible competition over them receive special attention. Second, which countries are the potential winners and losers in a transition to renewable energy? Third, what are the overall consequences of renewable energy production for international relations in general (i.e. beyond the energy domain)? Sections 3.1–3.5 address these questions and Table 2 presents a summary of the main geopolitical ideas about fossil fuels and renewables expressed in the literature.

3.1. More conflict or more peace?

One of the main divides within the literature on renewable energy and geopolitics relates to the security implications of renewable energy growth. We have identified two main groups of perspectives on this issue: the “renewed conflict” camp and the “reduced conflict” camp. The first believes that the energy transition is not likely to reduce energy-related conflict, whereas the second believes that greater self-sufficiency will reduce the amount of energy-related conflict between states.

The first camp argues that a world that derives most of its energy from renewable sources will be no less conflictual than one running on fossil fuels (Rothkopf [77], Buijs and Sievers [78], Raman [79], Laird [80], Hache [81], Capellan-Perez et al. [82], Umbach [83]). This camp envisages renewables as leading to the same types of conflicts as those caused by fossil fuels, or to new but just as severe types of conflicts. One perspective we place in the renewed conflict camp is that renewables do not change all that much. Capellan-Perez et al. [82], for example, argue that if the transition to renewables occurs under conditions of continuing high-energy consumption, this would lead to new energy security vulnerabilities similar to the old ones such as interrupted energy supplies or geopolitical instability in energy-producing countries.

According to Raman [79], renewable energy may take over the role that has been played by fossil fuels and become a driver of new geopolitical tensions: “[T]echnologies are already being fossilized in the sense of becoming akin to the political economy of fossil fuels” (p. 176). Escribano [84] lends further support to this view by exploring the cases of Desertec (the shelved renewable super-grid plan for the EU, the Middle East and North Africa [MENA] region) and the Mediterranean Solar Plan, noting that these two projects “adopted counter-productive geopolitical narratives, presenting themselves as the mere substitution of hydrocarbons and pipelines by renewables and electricity lines” (p. 4). Freeman [85] also offers an interesting point of view, where renewable energy is seen as putting an end to the petroleum wars, but also potentially giving rise to international economic conflicts in the form of trade wars.

Another branch of the renewed conflict camp envisages renewables

Table 2
Comparison of fossil fuels and renewables according to the literature.

Main issues	Fossil fuels	Renewable energy
Resource scarcity	Very significant	Not significant, except for critical materials
Importance of location	High	Moderate
Control over resources	Centralised	Decentralised
Geopolitical power	Asymmetric	Less asymmetric
International competition	High	Low
International interdependence	High	Low if renewables domestic/high if imported
Security of supply	Highly important	Moderately important
Geopolitical tensions	Frequent	Opinions vary greatly ^a
Conflict type	Large-scale and violent	Small-scale and non-violent
Critical materials	Unimportant	Important
Cybersecurity	Unimportant	Important
Key market aspects	Demand and supply, exports and imports	Storage, intermittency, infrastructure management

^a See the discussion on the two different camps in Section 3.1 regarding the security implications.

as leading to new types of conflict that are somehow different from those associated with fossil fuels. According to Rothkopf [77], in a new international energy system “there will be new types of conflicts, controversies, and unwelcome surprises in our future” (p. 1). A major issue in this regard is critical materials, which we discuss in detail in Section 3.4. Many authors have pointed out how access to critical materials required for renewable energy generation, distribution, or storage technology could pose a new but similar (to that of fossil fuels) dependence on countries that possess them (Habib et al. [86], Exner et al. [87], De Ridder [69], Hurd et al. [88], Buijs and Sievers [78], Rothkopf [77]). Moreover, Pitron [89] holds a radical view and claims that the geopolitical costs of a new dependence on rare earth materials could be even more dramatic than those in the previously observed dependence on oil. Another issue is that of the availability of electricity at the right time due to the intermittent nature of renewables. Scholten and Bosman [54] and Heinrich et al. [90] point to disputes between Germany and its neighbours over unwarranted cross-border electricity flows triggered by excessive wind-power production. Lastly, the increasing risk of cyber-attacks is frequently discussed as a challenge to renewable energy systems (see Section 3.5 for more details).

By contrast, the reduced conflict camp sees geopolitical tensions as less likely in a world that has renewables as its main source of energy (Peters [91], Verrastro et al. [92], Lacher and Kumetat [93], Kostyuk et al. [94], Escribano et al. [95], Johansson [96], Hoggett [97], Sweijts et al. [70], Månsson [72], Paltsev [98], Scholten and Bosman [54], Smith Stegen [99], Escribano [84], Freeman [85]). This camp emphasises that it is more difficult to control, cut the supply or manipulate the price of renewable energy than of fossil fuels and the expansion of renewables will therefore lead to greater energy self-sufficiency and less conflict. It shifts the focus from the external to the internal supply of energy, reducing the scope for conflict among states.

An argument frequently used by this camp is that renewables are more difficult than fossil fuels to manipulate as they are less dense and more evenly distributed geographically. Månsson [72] holds the view that due to its geographic and technical characteristics, renewable energy creates few geopolitical motivations for states to start conflicts in order to control it. Peters [91], Tsao et al. [100] and Kostyuk et al. [94] similarly note that developing renewable energy would lead to a more equitable energy distribution and energy-based economic power, in turn leading to reduced geopolitical tensions. Also Overland et al. [101] found that geopolitical power will be more evenly distributed after a complete transition to renewable energy. In a related vein, Krewitt et al. [61] argue that the creation of international solar energy partnerships would have geopolitical advantages because they could “reduce economic imbalances between the North and the South and create global markets for future-oriented energy technologies without having to fear conflicts over scarce resources” (p. 23).

The application of a resource scarcity perspective to the geopolitics of oil triggers energy-insecurity anxiety among states and implicitly or explicitly justifies aggressive behaviour in resource conflicts (Jaffe and Soligo [102], Stern [103]). This perspective is not simple to transpose onto renewables, as they are both non-exhaustible and abundant, except for the critical materials used in the production of renewable energy technologies (see Section 3.4 for more on this). Fischhendler et al. [104, 105] exemplify how geopolitical arguments have been used to convince Israeli decision-makers to adopt renewable energy to reduce the country’s energy dependence and improve its security. These arguments have led others to draw further conclusions. Compared to an energy system based on fossil fuels, in a system dominated by renewables, access to resources is less important than distribution and infrastructure management (Scholten and Bosman [54]). Escribano [84] implies the same when he writes that “[e]nergy dependence and security of supply lose geopolitical relevance, whereas technical and regulatory aspects gain weight” (p. 7).

Many publications share an understanding that the location of renewable energy resources is as important as that of fossil fuels (Skeet

[106], Crieckemans [67], Crieckemans [107]). However, location as a *geopolitical* concern is mainly relevant for the large-scale and not for the small-scale domestically-oriented production and transmission of electricity from renewable energy. O’Sullivan et al. [75] argue that if renewable energy is deployed on a large scale and cross-border trade in electricity grows, then the principle of territorial control will be similar to that for oil and gas pipelines: “[c]ountries like Algeria, Mexico or Morocco, or transit countries, or actors such as the Islamic State, could still try to leverage their geographical position and in case of conflict they could threaten to interrupt electricity supplies” (p. 41). Several authors also ask whether an external supply of electricity can be used as an “energy weapon” (e.g. Escribano et al. [95]). Renewable energy infrastructure, such as the ambitious but failed Desertec project, can also be an easy target for terrorists (Smith Stegen et al. [108]). The same logic can be applied to the location of biofuels.

On the other hand, if countries produce electricity from domestic renewable energy sources, geopolitical tensions and risks might recede due to falling energy imports and reduced interdependence between countries (Strunz and Gawel [66]). Escribano et al. [95] and Scholten and Bosman [54] argue that the geopolitical risks associated with domestically produced renewable energy are close to zero if we apply the energy-security standards of IEA. Hoggett [97] similarly notes that small-scale photovoltaics (and nuclear power) technologies are likely to promote a secure low-carbon transition with reduced geopolitical risks. Some believe that it is likely that the consumption of renewable energy at the location of production will prevail over large-scale regional production and distribution as it is seen as much more efficient and cost-effective when compared to the long-distance distribution of electricity (Proedrou [109], Sovacool [110]). These authors therefore see geographical location as less important for renewable energy resources than for fossil fuels from a geopolitical perspective. Nevertheless, there is a risk of local conflicts involving non-state actors that could potentially be caused by increased global competition for the land required for renewable energy installations (Capellan-Perez et al. [82], Månsson [72], Johansson [96], Walker [111]).

One issue seems to be stuck between the two camps: new interdependencies among states as a result of electricity interconnectors. Hache [81] discusses the possible emergence of new and unfamiliar inter-state interdependencies. Similarly, Westphal and Droege [64] argue that more electricity interconnectors between countries will lead to greater interdependence, which may translate into reduced international security. Pierri et al. [112] examine this question in the context of the European Union. Konstantelos et al. [113] discuss the division of costs and benefits among members of an integrated North Sea grid, making it similar to the difficulties caused by major pipeline projects. By contrast, Smith Stegen [99] argues that international affairs should benefit from renewables in many ways because their distribution will not be exposed “to the political and strategic dilemmas wrought by dependence on hydrocarbons” (p. 92). In a similar vein, IRENA [76] notes that electricity cut-offs and the use of hegemonic power to cut off transport bottlenecks will be greatly reduced due to increased rerouting possibilities, decentralised power generation and the absence of global electricity connections. But Smith Stegen [99] acknowledges that some tensions are possible due to increased interdependencies in such areas as high-voltage direct current (HVDC) transmission lines, biofuels and rare earth elements. Similarly, Verrastro et al. [92] and Lacher and Kumetat [93] see that renewable energy may strengthen energy security while facilitating the emergence of new interdependencies among states.

It is difficult to reconcile the renewed conflict and reduced conflict camps, as they base themselves on different underlying assumptions about the evolution of renewable energy and geopolitics. The most straightforward compromise is offered by an agnostic group of scholars who argue that the implications of the energy transition remain uncertain and that it is therefore premature to draw conclusions about future geopolitical tensions (Grubb [114], Bradshaw [115]). One version of this undecided stance is the creation of multiple, contrasting scenarios of

the future renewables–geopolitics nexus (Scholten and Bosman [54], Tynkkynen et al. [73]). Scholten and Bosman [54] present two scenarios – a “continental” scenario and a “national” scenario – and conclude that the future energy system will most likely be a mix of both, although that would still imply less conflict than in the current situation.

What we nevertheless can see from the literature is that the geopolitics of renewables will probably be different from the geopolitics of fossil fuels, regardless of whether it is more peaceful or not. Looking at the tensions renewables are expected to alleviate and at the new challenges they are likely to create, the literature suggests that energy-security concerns will generally shift from a strategic emphasis on energy resources to a focus on energy distribution, while power generation will see new challenges replacing the old ones, for example critical materials. It is also notable that both the renewed conflict and reduced conflict camps share a limited analysis of the transition itself. While energy security can be strengthened as a result of large-scale renewable energy use in the long run (Valentine [116], Scholten [117]), renewables are likely to carry security-related features similar to those of fossil fuels during the transitional phase (Johansson [96]). Unfortunately, only a few scholars give concrete and detailed examples of the potential risks and conflicts associated with the transitional phase (e.g. Sweijts et al. [70], Reusswig et al. [118]), beyond pointing to the decline of petrostates in general.

3.2. Geopolitical winners and losers

There is a growing body of experts and scholars who argue that a global transition to renewable energy will lead to a geopolitical and strategic reshuffle, with the emergence of new winners and losers (see Mecklin [119], De Ridder [69], Sweijts et al. [70], Overland and Kjaermet [120]).

Fossil fuel exporters risk that their fossil fuels become stranded assets (Organisation for Economic Co-operation and Development [121]). This may weaken their economies and nullify their geopolitical power. Several authors discuss how fossil fuel assets may become stranded, how this might affect petrostates, including their economic and geopolitical power, and the way in which these countries may react to the transition to renewable energy (Rothkopf [77], Ansar et al. [122], Sweijts et al. [70], Pascual [123], Hache [81], Jaffe [124], Scholten [125], Van de Graaf [126], Van de Graaf and Verbruggen [127] and Proedrou [128]). The entrenched interests of the fossil fuel industry in a country’s domestic political, economic and social institutions create a carbon lock-in situation that can result in resistance to institutional change by fossil fuel players (Unruh [129,130]). This poses the risk that traditional hydrocarbon exporters will either not be aware of, or be reluctant to consider, ongoing changes that will ultimately affect demand for their exports. O’Sullivan et al. [75] distinguish between the impact of the global energy transition on oil and gas exporters on the one hand, and importers on the other.

By contrast with the former petrostates, countries that achieve industrial leadership in clean technologies (and related patents) have a chance to emerge as winners. According to Eisen [131], Scholten [125], Scholten and Bosman [132], Freeman [85] and Crikemans [107], technologies and intellectual property are core components of renewable energy. Producing and exporting large amounts of renewable energy-generation equipment or support services such as storage are obvious growth markets. IRENA [76] lists employment, revenues and international prestige as potential gains. As a result, one can expect a rise in cyberwars and trade conflicts when renewables become the main source of energy. While renewable energy may reduce open conflicts over oil and gas, it may lead to trade wars over technology exports (Freeman [85]).

Some scholars have tried to systematically work out which countries or regions are the main potential losers and winners (Smith Stegen [99], Overland et al. [101], Stang [133], Sweijts et al. [70], Pascual [123]). Most of these analyses conclude that big oil exporters are likely to be hit

Table 3
Typologies of winners and losers.

Least and most exposed to EU energy transition [70]	Geopolitical winners vs laggards [99]		GeGaLo Index of 156 countries [101]
<ul style="list-style-type: none"> • Saudi Arabia (least exposed) • Qatar • Kazakhstan • Egypt • Libya • Russia • Algeria (most exposed) 	<ul style="list-style-type: none"> • Main winners: <ul style="list-style-type: none"> • Uruguay • Namibia • Kenya • Mali • Sweden • Finland • France • Nicaragua • Honduras • India • Jordan • Mongolia • Sri-Lanka • China • USA • Algeria 	<ul style="list-style-type: none"> • Main losers: <ul style="list-style-type: none"> • Brunei • Qatar • Bahrain • Kuwait • Timor-Leste • Trinidad & Tobago • Bhutan • Slovakia • Belize • Georgia • Bangladesh • Gabon • Samoa • Puerto Rico 	<ul style="list-style-type: none"> • Main winners: <ul style="list-style-type: none"> • Iceland (no. 1 in the index) • Mauritania (2) • Guyana (3) • Bhutan (4) • New Zealand (5) • Uruguay (6) • C. African Rep. (7) • Mauritius (8) • Main losers: <ul style="list-style-type: none"> • Nigeria (149) • Sudan (150) • Venezuela (151) • Qatar (152) • North Korea (153) • DRG (154) • Iraq (155) • Yemen (156)

particularly hard by the energy transition (see Table 3). Thus, the oil reserves of Brazil, Nigeria, Russia, Saudi Arabia and Venezuela will likely become “stranded geopolitical assets”, to use the term coined by Overland et al. [101].

However, not all scholars see Brazil as a prospective loser. For instance, Bastos Lima [134] argues that biofuels have made Brazil a renewable energy power and have strengthened its position in international affairs. Also, MENA has a significant advantage in its high levels of solar radiation and available space for renewable energy infrastructure (Akhonbay [135], El-Ashry [136], Günel [137], Luomi [138], Murooshid [139], Reiche [140,141], Schmitt [142], Koch [143], Verdeil [144]). Used right, this could improve the stability in the region (Pascual [123], Marktanner and Salman [145]). Similar points can be made about Russia (Koch and Tynkkynen [146], Poberezhskaya and Ashe [147]). Van de Graaf [126] views the United States as a winner in the transition, along with China, the EU member states and Japan, not least because these states will no longer need to import oil and thus will be alleviated of a significant burden. Similar statements are also made by Stratfor [148]. Contrary to this, Overland et al. [101] in their quantitative study found that China and the USA will lose more geopolitically due to their excessive dependence on fossil fuels, coal in particular. This is often overlooked by other analyses.

Smith Stegen [99] offers a typology of winners and losers in the transition to renewable energy based on country scores on three indicators – renewable energy potential, political receptiveness and hydrocarbon lobby. Overland et al. [101] composed an index of geopolitical gains and losses (GeGaLo) for 156 countries after a full-scale transition to renewable energy. The index includes the following indicators: fossil fuel production (representing geopolitical losses), fossil fuel reserves (geopolitical losses), renewable energy resources (geopolitical gains), governance and conflict (representing the capacity to handle changes in geopolitical strength). Proedrou [128] notes that Australia, Canada and Norway represent particularly complicated cases as they are likely to lose substantial revenues from fossil fuel exports, but at the same time, they have more economic resources to adapt to the energy transition than other hydrocarbon-rich countries do.

However, the existing literature, except for Smith Stegen [99] and Overland et al. [101], provides scant methodological explanation of how countries will become geopolitical winners and losers and why some countries might be more vulnerable than others. Moreover, most publications do not discuss the potential response strategies of the so-called losers (Van de Graaf [126]). Many scholars instead gravitate towards a

simplistic dichotomy: advanced renewable energy leaders will win the day; traditional fossil fuel exporters will lose out. This could be seen as implying that the prospective winners will promote the full-scale adoption of renewables while the prospective losers will drag their feet on energy transition and stick to fossil fuels.

In light of this, Ladislav et al. [149] note that “between 2007 and 2009 the geopolitical dynamics of energy took on a discernibly new tone. Traditional fossil-based energy producers became concerned about the apparent growth in global willingness to seriously consider alternative sources of energy” (p. 5). Some of the main traditional fossil fuel exporters rushed to monetise their oil assets (Jaffe [124]). Saudi Arabia and the United Arab Emirates became increasingly aware of the risks that the energy transition posed to them and started to introduce measures such as increasing the renewable energy share in their energy supply for domestic consumers, diversifying their financial holdings and partially privatising national oil companies (Van de Graaf [126]). Even though the efforts to date are unlikely to be sufficient to make them winners in the energy transition, they may lessen the negative consequences for these petrostates and render black-and-white images of winners and losers less relevant.

There is also an ongoing debate about whether Russia may join the global race for renewables, although when and how it might do so remains unclear (Smeets [150]). Tynkkynen et al. [73] argue that developing renewables on a large scale is in Russia’s best interests, as otherwise the country would lose its geopolitical weight which is currently based on fossil fuel exports.

Meanwhile, some scholars disagree with the view that the transition to renewable energy will put an end to petrostates. Goldthau and Westphal [151] hold the view that the energy transition may

... facilitate new oligopolies, and a higher market concentration among fewer crude oil suppliers. As energy-intensive sectors relocate from fast-decarbonizing OECD countries, this presents oil-producer countries with new export opportunities in refined oil products and in the fast-growing petrochemicals sector ... [f]or traditional oil exporters this opens in roads into the new demand centres in Southeast Asia (and Latin America) (p. 4).

Yet, they agree that this applies to the transition phase and not to the end state of the transition where oil will cease to exist as a key global commodity. Several scholars have created scenarios of how hydrocarbon-rich industries might fight back against the renewable energy industry (see Table 4). Heinonen et al. [152] present four dramatic – some might say exaggerated – scenarios where they apply the volatility, uncertainty, complexity, ambiguity (VUCA) concept, and discuss a potential weakening of the role of the West, with the rise of China and other emerging economies. In each of the four scenarios, they include some form of backlash from the fossil fuel industry as a wild card or black swan event. However, they do not believe that a backlash is unlikely. Rather the question is what form it might take and whether it will succeed.

There is also another group of losers and winners that has received little attention from scholars thus far. De Ridder [69] points out that the resource-poor developing countries are likely to be the losers because they have limited financial means for purchasing new technologies (e.g. solar panels and wind turbines). Gupta and Chu [153] view the situation differently and argue that developing countries can benefit from

large-scale renewable energy adoption – because of their natural endowments of solar radiation and falling costs of solar power installations – and will no longer need to invest in fossil fuels and their production.

The sum of the findings of the existing research is that it is difficult to identify clear-cut losers and winners in the global shift to renewable energy as the picture will be mixed. This is because several different factors are at play and may partially cancel each other out: the extent of the adoption of risk-management and renewable energy policies by countries rich in fossil fuels, access to renewable energy technologies, access to electricity grids, storage capacity, and access to critical materials (Paltsev [98], Scholten [71]). Nevertheless, some conclusions are clear. Traditional fossil fuel exporters are likely to lose more than others in the energy transition and will need to make a greater effort than former fossil fuel importers to adapt to a new reality. Conversely, those that currently import large quantities of oil and gas would see their import dependence diminish. What is more uncertain is which countries will emerge as industrial leaders, exporting renewable energy generation technologies and services.

3.3. Impact on relations between states

Besides the implications for the nature and stability of energy relations and discussions of potential winners and losers, the literature on the geopolitics of renewable energy also highlights several issues that are relevant for the broader field of international relations. Some authors note that the decline of petrostates will have complex consequences for the international state system (Rothkopf [77], Van de Graaf [126]). Overland et al. [101] argue that the decline of fossil fuels will have greater geopolitical consequences than the growth of renewables for international relations.

One of the main implications discussed in the literature is the democratisation of many countries (Laird [154], Sweijs et al. [70], Burke and Stephens [155]). As Sweijs et al. [70] suggest, a decline in foreign earnings for rentier states could lead to their rulers being toppled and the emergence of more democratic governments, provided that the population is prepared for such a development. In addition, decentralised generation reduces centralised control by political and economic elites and thus helps achieve a balance of power between “elites” and “ordinary people” – a key feature distinguishing democratic from authoritarian political systems (Powell et al. [156]). If we apply the Democratic Peace Theory, which postulates that democracies do not engage in wars with other democracies, the emergence of a higher number of democratic regimes should also lead to more peaceful international relations (Doyle [157], Russett [158]).

Many scholars see an energy system based on renewable energy as more symmetrical than one dominated by fossil fuels, where demand-and-supply relations among states are key elements, because they are more evenly distributed around the globe (Omo-Fadaka [59], Laird [154], Haug [159], Scholten and Bosman [54], Paltsev [98], O’Sullivan et al. [75], Crikemans [107]). In addition, renewable energy is thought to be conducive to “energy democracy” because renewables involve more democratic processes than fossil fuels in their management, distribution and use (Burke and Stephens [155]). A world with a “democratised” energy system should also enjoy increased geopolitical stability. Casertano [63] draws a parallel to new digital technologies and argues that renewable energy democratises the energy supply and creates new network structures that can be called the “internet of energy”.

Table 4
Four transformative scenarios with possible fossil fuel industry backlashes.

Scenario	Radical start-ups	Value-driven techemoths	Green do-it-yourself (DIY) engineers	New consciousness
Fossil fuel industry black swan backlash	Commercial and cyber warfare against renewable energy start-ups	Large oil companies’ aggression against renewable energy techemoths	DIY engineers criminalised, sanctioned	Missionaries of the old world, revenge mostly fails

Source: Heinonen et al. [152].

Rifkin [160] discusses how expanding the deployment of renewable energy can lead to a “Third Industrial Revolution” and make the international energy system more egalitarian due to the more even distribution of renewable energy resources compared to fossil fuels.

Gruenig and Lombardi [161] argue that large renewable energy projects will inevitably modify existing geopolitical alliances. According to Crieckemans [67], investment in renewables and new technologies is likely to form new centres of geopolitical power that would either lead to a world order with a few great powers – most likely including China and/or the USA – or to a world where geopolitical power would be more equally distributed among many countries. In his later work, Crieckemans [107] introduces the concept of a duo-multipolar system where China and the USA would play key roles due to their research and development investments in renewable energy and their possession of rare earth materials.

De Ridder [69] believes that an energy transition will push the international system towards greater multipolarity. Reusswig et al. [118] argue that the types of actors and their power to influence decision-making in a renewable energy system are different from those in a fossil fuel-based system in several ways. Environmental NGOs and individual energy consumers are seen as more powerful in the context of renewable energy compared to the roles they play in the fossil fuel-based system. This is because all these players are expected to be more numerous in a renewable energy system, there is a higher degree of decentralisation and a more equal distribution of power among them. Similar comments can be made about the current role of international organisations such as the IEA and IRENA, which are expected to proliferate and gain in importance in a renewables-based system (IRENA [76], Scholten et al. [162]). This, in turn, is expected to transform the security context and dynamics.

There is also another strand of literature that argues that those countries that deploy renewable energy on a large scale may benefit significantly from cooperation with each other (Gullberg [163], Gullberg et al. [164]). Huebner [65] explains that renewable energy should lead to the emergence of new types and levels of regional collaboration. Endeo [165] assumes that in a world with more renewable energy, cooperation between the Mediterranean states is likely to grow. And yet, Dreyer [166] argues that the politics of renewable energy has remained largely confined within national boundaries and has not provided a basis, for example, for EU diplomatic policy. But she also acknowledges that the EU, rather than the Middle East, can potentially become a gravitational force in terms of energy exports for many countries in the wider region. And yet, high gains from cooperation are likely to be achieved in the end phase of the energy transition, while the transition itself will likely be “path dependent rather than revolutionary, cumulative rather than fully substitutive” (Sovacool [110], p. 212) because of its complexity and the likely resistance from incumbents in the existing international energy system.

Furthermore, the global transition to renewable energy may strengthen regionalisation processes in the international energy system. Guler et al. [167] present a conceptual framework called “Regional Energy Hubs” where they discuss the advantages of establishing regional alliances (states or provinces) that would invest in and improve the transmission capacity for inter-regional electricity trade. This would enhance interdependence among states and have positive spillover effects for geopolitical stability. Similarly, Scholten and Bosman [54] introduce the concept of “grid communities” that can ensure energy security and lay the ground for regional peace and stability, although differences in political and economic power among members will have to be managed.

3.4. Critical materials

Many scholars and institutions have highlighted the geopolitical implications of critical materials: metals and industrial minerals required for renewable energy technologies (Habib et al. [86], Exner

et al. [87], De Ridder [69], Hurd et al. [88], Buijs and Sievers [78], Rothkopf [77], Gulley et al. [168], World Bank [169], OECD [170], Månberger and Johansson [171]). Exner et al. [87], Hurd et al. [88] and Rothkopf [77] all point out that while renewable energy reduces dependence on petroleum resources, it also increases dependence on critical materials and intensifies international competition over them. Several scholars argue that the growing demand for various minerals and metals in the production of renewable energy is likely to have serious security implications that could in turn result in geopolitical instability (Bazilian [172], Baldi et al. [173], Pavel et al. [174]).

Furthermore, Pitron [89] holds that the world is going to face a new and even more severe dependence on rare earth elements with rising geopolitical costs. Umbach [83] notes that “the expansion of renewables also creates new geopolitical dependencies, risks and vulnerabilities as these resources and technologies (i.e. batteries, robotics, artificial intelligence systems, etc.)” (p. 39) depend on an uninterrupted supply of critical materials. Gulley et al. [175] in their study of conflict-prone nonfuel minerals conclude that it is likely that there will be competition between China and the USA over 11 minerals and especially over those that cannot be substituted in new technologies, including renewable energy equipment.

There is no consensus as to exactly which materials are critical for the production of renewable energy (Overland [3]). An analysis produced by the International Council on Mining and Metals (ICMM) [176] concludes that different types of metals are needed as renewable energy inputs, but which of these will be needed will depend on the types of renewable energy technology involved. In addition, Kim et al. [177] note that different actors (research, government, industry) assign different degrees of criticality to materials according to their different viewpoints and goals. Månberger and Stenqvist [178] created scenarios for selected critical metals and found that reserves will be sufficient to provide for renewable energy production. They identified only one serious challenge, related to rising lithium demand. However, a report from the Resnick Institute [179] sees problems with more materials and lists dysprosium, neodymium, terbium, europium and yttrium as key elements for renewable energy hardware.

The International Institute for Sustainable Development (IISD) [180] provides a summary of critical-material use in renewable energy technologies (see Table 5). Some scholars warn that the availability of silver, indium, tellurium or ruthenium might hold back solar-panel

Table 5
Critical materials for clean-energy technologies.

	Solar power	Wind power	Electric vehicles, storage
Bauxite & aluminium	x	x	x
Cadmium	x		
Chromium		x	
Cobalt		x	
Copper	x	x	x
Gallium	x		
Germanium	x		
Graphite			x
Indium	x		
Iron	x	x	x
Lead	x	x	x
Lithium			x
Manganese		x	x
Molybdenum		x	
Nickel	x		x
Rare earths		x	x
Selenium	x		
Silicon	x		x
Silver	x		
Tellurium	x		
Tin	x		
Titanium			x
Zinc	x	x	

Source of data: IISD [180], IRENA [76].

manufacturing (Grandell et al. [181]). However, Bazilian [172] reasons that there has been insufficient analysis thus far on the role, availability and technologies of critical metals, and that it is premature to assess the types of geopolitical risks that can arise from the global supply of critical materials in a low-carbon future.

Much of the literature on critical materials focuses on rare earth elements (Grandell et al. [181], Pavel et al. [174,182]). According to Lovins [183], Scholten [125] and Overland [3], the whole issue is exaggerated, and the alleged scarcity of rare earth elements is not supported by the evidence. Lovins [183] exemplifies this with rare earth elements used for super-magnets in gearless wind turbines and notes that there are alternative turbine types that use software and cheap electronics to substitute for super-magnets. The attention to rare earth elements can also potentially distract from more common, structural materials that may end up being more critical for energy transition. Recent studies by Hache et al. [184] and Bonnet et al. [185], for example, analyse the criticality of lithium, copper, cobalt and nickel in the face of surging demand.

According to O'Sullivan et al. [75] and Overland [3], rare earth elements are in fact not rare as they can be found in numerous countries, including Australia, Brazil, China, Greenland, India, Kazakhstan, Malaysia, Russia, Thailand and the USA. But at the same time, 57% of the known global reserves are concentrated in China and Russia, with most of the current global production taking place in China. However, it is not availability as such but the high cost of mining, separation, processing and capital intensity of rare earth elements that complicate their production (Kalantzakos [186]). Some scholars nonetheless believe that China may further monopolise its role in this sector and may thus pose a geopolitical threat to other countries (Smith Stegen [187], Rabe et al. [188]). In 2019, a *Foreign Policy* [189] special report analysed China's dominating role in critical materials and warned that an increase in Beijing's dominance in critical minerals and new technologies would have "serious implications" for US national security.

Finally, the existing literature on critical materials rarely discusses the potential significance of new disruptive energy technologies that may reduce the demand for critical materials. Overland [3] and Renner and Wellmer [190] argue that the criticality of materials and the demand for them will depend on the evolution of the numerous technologies that are involved in the clean-energy transition and that it is impossible to predict how those technologies will evolve. The implications of developments in other sectors, for example the electrification of transportation, also need to be considered (Hache et al. [184]). O'Sullivan et al. [75] hold that "[d]emand for minerals is a function of the prevalent technologies at any moment. Advances in engineering often make it possible to replace one material with another within a technology. In addition, entire technologies are sometimes replaced once scarcity develops or innovation creates viable alternatives" (p. 13, see also Overland [3]).

3.5. Cybersecurity

Many scholars have raised cybersecurity issues related to renewable energy infrastructure (Barichella [191], Crikemans [107], Dignum [192], Handke [193], Umbach [83], O'Sullivan et al. [75], Johnson [194], Madnick et al. [195], Qi et al. [196], Månsson [72], Hawk and Kaushiva [197], Onyeji et al. [198], Overland [3], Pearson [199]). This is one of the newest parts of the literature on the geopolitics of renewables and one of those that is receiving most attention in seminar and conference discussions. Only a few of these publications are based on empirical evidence or detailed technical explanations. Månsson [72] and Liu et al. [200] argue that the high dependence on complex electricity control systems can facilitate cyberattacks; however, decentralised, small-scale electricity generation can also reduce cybersecurity risks.

We should note that the cybersecurity risks involved in electricity transmission are not specific to renewable energy. These risks affect all

infrastructure that is connected to the internet and have digital platforms (Overland [3]). The control of oil and gas platforms and pipelines, sub-sea technology, oil and liquefied natural gas (LNG) tanker navigation, refineries and nuclear power plants are also digitalised. Thus, it is questionable whether renewable energy has any cybersecurity implications beyond those of other sectors and some of this literature comes across as sensationalist and/or seeking to denigrate renewable energy (Overland [3]).

4. Discussion

The geopolitical implications of renewable energy have attracted increasing attention from international relations and political science scholars since 2010. Before that, almost all of these scholars focused on oil and gas when studying energy security or geopolitics, while renewable energy experts targeted the development, system integration and market diffusion of new technologies, largely ignoring the implications of renewables for international politics. Consequently, the two strands of literature rarely came into contact with each other.

After 2010, the literature on the geopolitics of energy increasingly came to have two branches. One continued focusing on oil and gas, shale gas, unconventional oil and the globally expanding LNG market. The other is the literature that we have presented in this article, which focuses on the geopolitics of growing renewable energy use. As the length of this article's bibliography indicates, the literature has grown substantially in a short period of time. The publication of the multi-institution reports by O'Sullivan et al. [75] and the IRENA Global Commission on the Geopolitics of Energy Transformation [76] attracted further attention to the topic.

The novelty of the field, however, is still evident. Not only is there still a great deal of uncertainty about the geopolitical implications of renewable energy, but there are also some recurrent shortcomings among these publications. Among other things, several potentially important topics are neglected. First, only a few authors distinguish between different types of renewable energy and their geopolitical consequences (e.g. Ren and Sovacool [201], Crikemans [107]). In their qualitative and quantitative analyses, Ren and Sovacool [201] found that hydroelectricity and wind power have the greatest potential to strengthen China's energy security, while solar power has the least potential. However, the majority of scholars refer to "renewable energy" or "clean energy" at a general level without explaining which types they have in mind. This leaves important questions unanswered. Are the international security risks related to biofuels, wind power, solar power and hydropower similar? Are the geopolitical consequences of expanding wind power the same as those for solar power? Moreover, what about energy carriers such as hydrogen or lithium-ion batteries?

Second, much of the literature reflects old patterns of thinking and analysis from the fossil fuel era. As oil was considered to be the object of significant geopolitical conflict, the path of least mental resistance is to replace oil with new sources of energy in geopolitical thinking. Critical materials are a case in point. Their geographical distribution is often considered to have the same effect as the concentrated nature of oil reserves. The question is whether (or not) we need to update the energy-security lexicon to fit a renewable world.

Third, only a few authors clearly distinguish between the geopolitics of the transitional phase and the geopolitics of a world where renewables are already established as the dominant energy sources. But the transition and end phases could be seen as two separate analytical categories (Scholten and Bosman [54]). The transition phase is likely to have a destabilising effect on global security, not least due to a potential backlash from traditional fossil fuel exporters, the emergence of new types of interdependence among states, as well as threats from armed non-state actors (Rothkopf [77], Westphal [62], Westphal and Droege [64], Overland et al. [101]). It is also unclear how a renewable energy leader that is also authoritarian, such as China, will act if it manages to free itself from dependency on energy imports. All these aspects deserve

further in-depth research and analysis.

The literature also has more fundamental problems. One of them is that no specific theory on energy geopolitics has been formulated to back up the claims regarding the geopolitical implications of renewable energy. On the one hand, also the broader energy geopolitics literature is full of rich historical descriptive accounts that lack an analytical framework for theorisation (Yergin [202], O'Sullivan et al. [75]); on the other hand, the theoretical work that has been carried out on geopolitics does not necessarily focus on energy (and even less so on renewable energy) and rarely creates predictive value (Dodds [203], Crikemans [204]). As a result, it remains unclear *how* exactly the specific geographic and technical characteristics of energy systems shape the stability of inter-state energy relations.

Analysing the geopolitical consequences of increased use of renewable energy is a complex undertaking as it is a new situation. Unlike the geopolitics of oil and gas, where the supply–demand balance is the key parameter, no analytical framework has been elaborated that would fully address the complexity of renewable energy geopolitics. One possible exception is Scholten [125], who has attempted a new analytical framework, relying on works on socio-technical systems and energy security. But this framework only incorporates those implications that specifically follow from renewables' geotechnical features and not those that will result from the transition to renewables.

A more fundamental problem is that only a few authors define what they mean by “geopolitics” (e.g. Scholten [125], Crikemans [107], Proedrou [128], Overland et al. [101]). As a result, the terms “geopolitics”, “great power rivalry” and “international relations” are often used interchangeably. It would also be appropriate to clarify the difference between energy geopolitics and energy security. And only a few authors define the concepts of geography or space in relation to renewable energy (e.g. Stoeglehner et al. [44], Bridge et al. [45], Scholten [125]).

Yet another weakness is that most of the analysis is based on hypothetical and unstated assumptions about the future, and few authors use established forecasting, scenario-building or foresight methodologies.

Finally, systematic empirical data is scarce, with most publications relying on anecdotal evidence. There is also a need for more concrete case studies of the geopolitical implications of specific renewable energy types – especially solar and wind – before general statements can be made. This is, of course, difficult at this point. There simply is not a century of renewable energy politics to look back on, as there is for oil. Moreover, renewable energy cases are located in a world that is still very much fossil fuel-based; they alone do not shape energy geopolitics yet. However, with time, the empirical opportunities will expand.

5. Conclusions

This article has reviewed, systematised and aggregated the existing research on the geopolitical consequences of the transition to renewable energy. It briefly addressed the history of the topic in the academic literature before discussing five overarching themes: the peace potential of renewable energy, possible geopolitical winners and losers, the impact of renewable energy on international relations, the contentiousness of critical materials, and cybersecurity.

We found that the relationship between renewable energy and geopolitics was discussed as early as the 1970s and 1980s, meaning that it is less novel than some of the recent contributions make it out to be. Still, it was only after 2010 that it really gained traction and the vast majority of publications we identified were from after this date. Since then, a large number of analyses have been published and any publication claiming that this is an entirely new topic is misleading its readers. There are many such publications.

The literature is divided over the peace potential of renewables. Renewable energy has many advantages over fossil fuels for international security and peace, mostly because its sources are abundant and continuously replenished. However, in terms of critical materials and cybersecurity, renewable energy is thought to bring greater security

risks and geopolitical tensions than fossil fuels have done, although this view is not very strongly backed up. There is also an expectation that increased renewable energy use will lead to a variety of small-scale conflicts but will reduce the risk of large inter-state conflicts.

As for potential geopolitical winners and losers, former fossil fuel exporters are clearly seen as the greatest losers, whereas the winners are harder to agree upon. Many countries will benefit from reduced import dependence and some will benefit from their own rich renewable energy resources, but only a few will be able to establish themselves as industrial leaders in clean tech.

The implications for international relations more broadly may be a levelling of energy relations from asymmetric dependencies to mutual, horizontal dependencies, a shift away from existing energy alliances towards regional grid communities and a greater diversity of actors involved in energy policy. Overall, renewables are expected to democratise domestic politics and international relations, stabilising them in the process.

The literature on renewable energy and geopolitics fills an important academic gap, but it also has significant weaknesses and lacunae, some of which may be due to teething problems. There is an almost systematic failure to define what “geopolitics” means, a lack of theorisation and the analytical frameworks to handle the complexity of the topic remain underdeveloped. Methodologically, there is limited use of established forecasting, scenario-building or foresight methodologies, and empirical evidence remains scarce. Most authors also fail to distinguish between the geopolitical risks associated with different types of renewable energy, and only a few distinguish properly between the geopolitics of the transitional phase and the geopolitics of a post-transition world. Finally, a disproportionately large part of the literature is dedicated to critical materials and cybersecurity, while only a small part concerns the decline of former fossil fuel powers. Among those publications that do discuss the decline of fossil fuels, there is also an over-focus on oil producers and a lack of attention to the countries that rely heavily on coal, for example Australia, China, Germany, Indonesia, Poland and the United States.

On the upside, there is still time to address these weaknesses, considering that the transition to renewable energy is still in its early stages and its full force will not be felt until decades from now. Our recommendations for further research follow from the above-mentioned weaknesses. It is important to recognize that the exploratory phase has been completed and first observations have been made. Initial overviews of the topic, which include this article, have also been published.

Future research in this field can now move in three general directions. First, it can firm up and systematise the empirical basis for analysis. Second, it can utilise established forecasting and scenario methods to inform policy makers about energy strategies for a steadily more renewable age. This would be a relatively short-term effort aimed at informing policy makers and industry. Third, in the longer term, suitable analytical frameworks could be established to systematically analyse cases in an effort to raise our understanding and develop a theory on energy geopolitics that could be used to predict the geopolitical implications of renewables. This would require a long-term academic effort.

Acknowledgements

This article is a product of the Kodak Moment project, which is funded by the NORRUSS program of the Research Council of Norway (project number 287937).

References

- [1] Jacobson M, Delucchi M, Bauer Z, Goodman S, Chapman W, Cameron M, et al. 100% Clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world. *Joule* 2017;1(1):108–21.
- [2] International Energy Agency (IEA). *World energy outlook 2004*. Paris: OECD; 2004.

- [3] Overland I. The geopolitics of renewable energy: debunking four emerging myths. *Energy Res Soc Sci* 2019;49:36–40. <https://www.sciencedirect.com/science/article/pii/S2214629618308636>.
- [4] Ó Tuathail G. Imperialist geopolitics. Introduction. In: Ó Tuathail G, Dalby S, Routledge P, editors. *The Geopolitics reader*. London: Routledge; 1998. p. 15–26.
- [5] Mahan A. *The influence of sea power upon history, 1660–1783*. Boston, MA: Little, Brown; 1890.
- [6] Ratzel F. *Politische geographie*. München: Oldenbourg; 1897.
- [7] Mackinder H. The geographical pivot of history. *Geogr J* 1904;23:421–42.
- [8] Haushofer K. *Weltpolitik von heute*. Zeitgeschichte-Verlag Wilhelm Undermann; 1934.
- [9] Spykman N. *The geography of the peace*. Harcourt: Brace and Company; 1944.
- [10] Kissinger H. *Diplomacy*. New York: Simon & Schuster; 1994.
- [11] Brzezinski Z. *The grand chessboard: American primacy and its geostrategic imperatives*. New York: Basic Books; 1997.
- [12] Agnew J. *Geopolitics: Re-visioning world politics*. New York: Routledge; 1998.
- [13] Ó Tuathail G, Dalby S. *Rethinking geopolitics*. London: Routledge; 1998.
- [14] Amineh M. *Globalisation, geopolitics and energy security in Central Eurasia and the Caspian Region*. The Hague: CIEP Clingendael International Energy Programme; 2003.
- [15] Dodds K. *Geopolitics: a very short introduction*. New York: Oxford University Press; 2017.
- [16] Flint C. *Introduction to geopolitics*. New York: Routledge; 2017.
- [17] Moiso S. *Geopolitics/critical geopolitics*. In: Agnew JA, Mamadouh V, Secor AJ, Sharp JP, editors. *The Wiley Blackwell companion to political geography*. Hoboken: Wiley-Blackwell; 2015. p. 220–34.
- [18] Painter J, Jeffrey A. *Political geography: An introduction to space and power*. Los Angeles: SAGE; 2009.
- [19] Overland I. Future petroleum geopolitics: consequences of climate policy and unconventional oil and gas. In: Yan J, editor. *Handbook of Clean Energy Systems*. Chichester: Wiley; 2015. p. 3517–44.
- [20] Bromley S. *American hegemony and world oil: the industry, the state system and the world economy*. University Park: The Pennsylvania State University Press; 1991.
- [21] Clingendael International Energy Programme (CIEP). *Study on energy supply and geopolitics. Final Report for DG TREN*. Den Haag 2004.
- [22] O'Sullivan M. *Windfall*. New York: Simon & Schuster; 2017.
- [23] Högselius P. *Energy and geopolitics*. Taylor & Francis Ltd; 2019.
- [24] Dalby S. *Environmental security*. Minneapolis: University of Minnesota Press; 2002.
- [25] Dalby S. *Environmental geopolitics - nature, culture, urbanity*. In: Anderson K, Domosh M, Pile S, Thrift N, editors. *Handbook of cultural geography*. Thousand Oaks: Sage; 2003. p. 498–510.
- [26] Dalby S. *Ecology, security, and change in the Anthropocene*. *Brown J World Aff* 2007;13(2):155–64.
- [27] Dalby S. *Security and Environmental Change*. Malden: Polity; 2009.
- [28] Dalby S. The geopolitics of climate change. *Political Geogr* 2013;37:38–47.
- [29] Dalby S. *Anthropocene formations: environmental security, geopolitics and disaster*. *Theory Cult Soc* 2017;34(2–3):233–52.
- [30] Dalby S. *Climate change and geopolitics*. In: van Storch H, editor. *Oxford research encyclopedia of climate science*. Oxford: Interactive Factory; 2017.
- [31] Dalby S. *Canadian geopolitical culture: climate change and sustainability*. *Can Geogr/Le Géographe canadien* 2019;63(1):100–11.
- [32] Dalby S, O'Leary S. *Towards ecological geopolitics: climate change reframed*. In: Dalby S, O'Leary S, editors. *Reframing climate change: Constructing ecological geopolitics*. New York: Routledge; 2015. p. 203–16.
- [33] O'Leary S. *Environmental geopolitics*. Lanham: Rowman & Littlefield; 2018.
- [34] Chaturvedi S, Doyle T. *Climate terror: A critical geopolitics of climate change*. New York: Palgrave Macmillan; 2015.
- [35] Harner N. *Crude geopolitics: Territory and governance in post-peak oil imaginaries*. *Territory, Politics, Governance* 2018;6(4):405–28.
- [36] Aklin M, Urpelainen J. *Renewables: The politics of a global energy transition*. Cambridge: The MIT Press; 2018.
- [37] Gallagher KS. *Why & how governments support renewable energy*. *Daedalus* 2013;142(1):59–77.
- [38] Haas R, Eichhammer W, Huber C, Langniss O, Lorenzoni A, Madlener R, Menanteau P, Morthorst P, Martins A, Oniszk A, Schleich J, Smith A, Vass Z, Verbrüggen A. *How to promote renewable energy systems successfully and effectively*. *Energy Policy* 2004;32(6):833–9.
- [39] Scoones I, Leach M, Newell P. *The politics of green transformations*. New York: Routledge; 2015.
- [40] Tellam I. *Fuel for change: World bank energy policy - rhetoric and reality*. New York: Zed Books; 2000.
- [41] Verbong G, Geels F. *The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004)*. *Energy Policy* 2007;35:1025–37.
- [42] Sovacool B, Mukherjee I. *Conceptualizing and measuring energy security: a synthesized approach*. *Energy* 2011;36:5343–55.
- [43] Winzer C. *Conceptualizing energy security*. *Energy Policy* 2012;46:36–48.
- [44] Stoeglehner G, Niemetz N, Kettl K. *Spatial dimensions of sustainable energy systems: new visions for integrated spatial and energy planning*. *Energy Sustain Soc* 2011;1(2):1–9.
- [45] Bridge G, Bouzarovski S, Bradshaw M, Eyre N. *Geographies of energy transition: space, place and the low-carbon economy*. *Energy Policy* 2013;53:331–40.
- [46] Ireland A. *Geopolitics and oil development in the Middle East*. *Tulsa Geol Soc Dig* 1958;26:74–8.
- [47] Conant M, Gold F. *The geopolitics of energy*. Boulder: Westview Press; 1978.
- [48] Klare M. *Resource wars: the new landscape of global conflict*. New York: Henry Holt; 2001.
- [49] Klare M. *Blood and oil: the dangers and consequences of America's growing dependency on imported petroleum*. New York: Metropolitan Books; 2004.
- [50] Barnes J, Myers Jaffe A. *The Persian Gulf and the geopolitics of oil*. *Survival* 2006;48(1):143–62.
- [51] Harris K. *Geopolitics of oil*. New York: Nova Science Publishers; 2009.
- [52] Yergin D. *The quest: energy, security, and the remaking of the modern world*. London: Penguin Press; 2011.
- [53] Krane J, Medlock K. *Geopolitical dimensions of US oil security*. *Energy Policy* 2018;114:558–65.
- [54] Scholten D, Bosman R. *The geopolitics of renewables; exploring the political implications of renewable energy systems*. *Technol Forecast Soc* 2016;103:273–83.
- [55] Goldthau A, Westphal K, Bazilian M, Bradshaw M. *Model and manage the changing geopolitics of energy*. *Nature* 2019;569:29–31.
- [56] NSF/NASA. *An assessment of solar energy as a national energy resource*. National Science Foundation/NASA Solar Energy Panel. Grant from the Research Applications Directorate of the National Science Foundation to the Department of Mechanical Engineering, University of Maryland; 1972. Available from: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19730018091.pdf>. [Accessed 12 August 2018].
- [57] Williams J. *Solar energy: technology and applications*. Ann Arbor, Michigan: Science Publishers; 1974.
- [58] California Academy of Sciences. *Dispersed, decentralized and renewable energy sources: alternatives to national vulnerability and war*. In: Final report prepared for the Federal Emergency Management Agency (FEMA); 1980. Contract No.: DCPA 01-79-C-0320.
- [59] Omo-Fadaka J. *Alternative sources of energy: indigenous renewable resources*. *Alternatives* 1980;6(3):409–17.
- [60] Shea C. *Renewable energy: today's contribution, tomorrow's promise*. Washington, DC: Worldwatch Institute; 1988. *Worldwatch Paper No. 81*.
- [61] Krewitt W, Nitsch J, Nienhaus K. *Bedeutung der erneuerbaren Energien und der Energieeffizienz in verschiedenen globalen Energieszenarien (The importance of renewable energy and energy efficiency in various global energy scenarios)*. Annual Meeting of the Forschungsverbund Erneuerbare Energien (FVEE) in Cooperation with the Agency for Renewable Energy (AEE); 2009 Nov 24–25. *Umweltforum Berlin, Germany*.
- [62] Westphal K. *Energy in an era of unprecedented uncertainty: international energy governance in the face of macroeconomic, geopolitical, and systemic challenges*. In: Koranyi D, editor. *Transatlantic energy futures: strategic perspectives on energy security, climate change and new technologies in Europe and the United States*. Center for Transatlantic Relations; 2011. p. 1–26.
- [63] Casertano S. *Risiken neuer Energie – Konflikte durch erneuerbare Energien und Klimaschutz (Risks of new energy – risks posed by renewable energy and climate protection)*, vol. 9. Brandenburg Institute for Society and Security (BIGS); 2012.
- [64] Westphal K, Droegge S. *Global energy markets in transition: implications for geopolitics, economy and environment*. *Global Trends* 2015. *Prospects for World Society*; 2015.
- [65] Huebner C. *Politische Agenda. Globale Energiewende–Geopolitik (Political agenda. Global energy transition and geopolitics)*. Konrad Adenauer Stiftung, Regional Program for Energy Security and Climate Change in Latin America (EKLA); 2016.
- [66] Strunz S, Gaweel E. *Importabhängigkeit und Energiewende – ein neues Risikofeld der Versorgungssicherheit? (Import dependency and energiewende – a new risk for security of supply?)*. Helmholtz-Zentrum für Umweltforschung (UFZ), Department of Economics; 2016. *Discussion Papers* 5/2016.
- [67] Crikemans D. *The geopolitics of renewable energy: different or similar to the geopolitics of conventional energy? ISA Annual Convention 2011 Mar 19 [Montréal, Canada]*.
- [68] Scholten D, Bosman R. *The geopolitics of renewables; a mere shift or landslide in energy dependencies? PoliticologenEtnaal 2013*. May 30–31; Ghent, Belgium.
- [69] De Ridder M. *The Geopolitics of Mineral Resources For Renewable Energy Technologies*. The Hague: The Hague Centre for Strategic Studies; 2013.
- [70] Sweijts T, de Ridder M, de Jong S, Oosterveld W, Frinking E, Auping W, et al. *Time to Wake Up: The Geopolitics of Eu 2030 Climate and Energy Policies*. The Hague: The Hague Centre for Strategic Studies (HCSS); 2014.
- [71] Scholten D, editor. *The geopolitics of renewables*. Cham: Springer Nature; 2018.
- [72] Månsson A. *A resource curse for renewables? Conflict and cooperation in the renewable energy sector*. *Energy Res Soc Sci* 2015;10:1–9.
- [73] Tynkynen V-P, Pynnöniemi K, Höysniemi S. *Global energy transitions and Russia's energy influence in Finland. Prime minister's Office of Finland, government's analysis, assessment and research activities*. 2017. *Policy Brief No. 19*.
- [74] Ministerio de la Defensa. *Energía y geoestrategia 2016 (Energy and geostrategy 2016)*. Ministerio de la Defensa; 2015. Available from: http://www.ieee.es/Galerias/fichero/cuadernos/Energia_y_Geoestrategia_2016.pdf. [Accessed 7 January 2019].
- [75] O'Sullivan M, Overland I, Sandalow D, Begg H, Behrens A, Bhatiya N, Clark A, Cremer T, Elkind J, Fessler M, Lemphers N, Nakagawa M, Seol M, Soylyu C, Vakulchuk R. *The geopolitics of renewable energy*. Harvard University. Columbia University and the Norwegian Institute of International Affairs; 2017. <https://www.researchgate.net/publication/317954274>.

- [76] International Renewable Energy Agency (IRENA). The Global Commission on the Geopolitics of Energy Transformation. A new world. The geopolitics of the energy transformation. Abu Dhabi: IRENA; 2019.
- [77] Rothkopf D. Is a green world a safe world? not necessarily. A guide to the coming green geopolitical crises. *Foreign Pol* 2009 [September/October].
- [78] Buijs B, Sievers H. Critical thinking about critical minerals: assessing risks related to resource security. The Hague: Clingendael International Energy Programme; 2011.
- [79] Raman S. Fossilizing renewable energies. *Sci Cult* 2013;22(2):172–80.
- [80] Laird F. Against transitions? Uncovering conflicts in changing energy systems. *Sci Cult* 2013;22(2):149–56.
- [81] Hache E. La géopolitique des énergies renouvelables: amélioration de la sécurité énergétique et/ou nouvelles dépendances? (The geopolitics of renewables: does more energy security come with more energy dependencies?). *Revue Internationale et Stratégique* 2016;1(101):36–46.
- [82] Capellan-Perez I, de Castro C, Inaki A. Assessing vulnerabilities and limits in the transition to renewable energies: land requirements under 100% solar energy scenarios. *Renew Sustain Energy Rev* 2017;77:760–82.
- [83] Umbach F. Energy security in a digitalized world and its geostrategic implications. Konrad Adenauer Stiftung; 2018.
- [84] Escribano G. The geopolitics of renewable and electricity cooperation between Morocco and Spain. *Mediterr Politics* 2018;1–8. <https://doi.org/10.1080/13629395.2018.1443772>.
- [85] Freeman D. China and renewables: the priority of economics over geopolitics. In: Scholten D, editor. *The geopolitics of renewables*. Cham: Springer Nature; 2018. p. 187–201.
- [86] Habib K, Hamelin L, Wenzel H. A dynamic perspective of the geopolitical supply risk of metals. *J Clean Prod* 2016;133:850–8.
- [87] Exner A, Lauk C, Zittel W. Sold futures? The global availability of metals and economic growth at the peripheries: distribution and regulation in a degrowth perspective. *Antipode* 2015;47(2):342–59.
- [88] Hurd A, Kelley R, Eggert R, Lee M. Energy-critical elements for sustainable development. *MRS Bull* 2012;37(4):405–10.
- [89] Pitron G. La guerre des métaux rares: la face cachée de la transition énergétique et numérique. Paris: Éditions Les Liens qui Libèrent; 2018.
- [90] Heinrich A, Kuszniir J, Lis A, Pleines H, Smith Stegen K, Szulecki K. Towards a common EU energy policy? Debates on energy security in Poland and Germany. *ESPRi Policy Paper*; 2016.
- [91] Peters S. Courting future resource conflict: the shortcomings of western response strategies to new energy vulnerabilities. *Energy Explor Exploit* 2002;20–1(6–1): 29–60.
- [92] Verrastro F, Ladislav S, Hyland M. The geopolitics of energy. Emerging trends, changing landscapes, uncertain times. CSIS energy and national security program; 2010.
- [93] Lacher W, Kumetat D. The security of energy infrastructure and supply in North Africa: hydrocarbons and renewable energies in comparative perspective. *Energy Policy* 2011;39(8):4466–78.
- [94] Kostyuk V, Makarov A, Mitrova T. Энергетика и геополитика [Energy and geopolitics]. *Energocademy* 2012;1(44):46–59.
- [95] Escribano G, Marin-Quemada JM, San Martin Gonzalez E. RES and risk: renewable energy's contribution to energy security. A portfolio-based approach. *Renew Sustain Energy Rev* 2013;26:549–59.
- [96] Johansson B. Security aspects of future renewable energy systems. A short overview. *Energy* 2013;61:598–605.
- [97] Hoggett R. Technology scale and supply chains in a secure, affordable and low carbon energy transition. *Appl Energy* 2014;123:296–306.
- [98] Paltsev S. The complicated geopolitics of renewable energy. *B Atom Sci* 2016;72(6):390–5.
- [99] Smith Stegen K. Redrawing the geopolitical map: international relations and renewable energies. In: Scholten D, editor. *The geopolitics of renewables*. Cham: Springer Nature; 2018. p. 75–95.
- [100] Tsao J, Schubert E, Fouquet R, Lave M. The electrification of energy: long-term trends and opportunities. *MRS Energy Sustain* 2018;1–14. <https://doi.org/10.1557/mre.2018.6>.
- [101] Overland I, Bazilian M, Uulu TI, Vakulchuk R, Westphal K. The GeGaLo index: geopolitical gains and losses after energy transition. *Energy Strategy Reviews* 2019;26. <https://www.sciencedirect.com/science/article/pii/S2211467X19300999>.
- [102] Jaffe A, Soligo R. Energy security: the Russian connection. In: Moran D, Russell J, editors. *Energy security and global politics*. Abingdon: Routledge; 2009. p. 112–34.
- [103] Stern R. Oil scarcity ideology in US foreign policy, 1908–1997. *Secur Stud* 2016; 25(2):214–57.
- [104] Fischhendler I, Nathan D, Boymel D. Marketing renewable energy through geopolitics: solar farms in Israel. *Glob Environ Politics* 2015;15(2):98–120.
- [105] Fischhendler I, Herman L, Anderman J. The geopolitics of cross-border electricity grids: the Israeli-Arab case. *Energy Policy* 2016;98:533–43.
- [106] Skeet I. Geopolitics of energy. *Energy Explor Exploit* 1996;14(3/4):265–72.
- [107] Crikemans D. Geopolitics of the renewable energy game and its potential impact upon global power relations. In: Scholten D, editor. *The geopolitics of renewables*. Cham: Springer Nature; 2018. p. 37–73.
- [108] Smith Stegen K, Gilmartin P, Carlucci J. Terrorists versus the sun: desertec in North Africa as a case study for assessing risks to energy infrastructure. *Risk Manag* 2012;14(1):3–26.
- [109] Proedrou F. Are smart grids the key to EU energy security? In: Leal-Arcas R, Wouters J, editors. *Research handbook on EU energy law and policy*. Cheltenham: Edward Elgar; 2017. p. 450–9.
- [110] Sovacool BK. How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res Soc Sci* 2014;13:202–15. <https://doi.org/10.1016/j.erss.2015.12.020>.
- [111] Walker G. Energy, land use and renewables: a changing agenda. *Land Use Policy* 1995;12(1):3–6.
- [112] Pierri E, Binder O, Hemdan N, Kurrat M. Challenges and opportunities for a European HVDC grid. *Renew Sustain Energy Rev* 2017;70:427–56.
- [113] Konstantelos I, Pudjianto D, Strbac G, De Decker J, Joseph P, Flament A, et al. Integrated North Sea grids: the costs, the benefits and their distribution between countries. *Energy Policy* 2017;101:28–41.
- [114] Grubb M. The Cinderella options a study of modernized renewable energy technologies part 1-A technical assessment. *Energy Policy* 1990;18(6):525–42.
- [115] Bradshaw M. In search of a new energy paradigm: energy supply, security of supply and demand and climate change mitigation. *Mittl Osterreichischen Geogr Ges* 2010;152:11–28.
- [116] Valentine S. Emerging symbiosis: renewable energy and energy security. *Renew Sustain Energy Rev* 2011;15(9):4572–8.
- [117] Scholten D. Renewable energy security. In: *EUCERS newsletter [internet]*; 2017. Available from: <https://www.kcl.ac.uk/sspp/departments/warstudies/research/groups/eucers/newsletter/newsletter64.pdf>. [Accessed 5 October 2019].
- [118] Reusswig F, Komendantova N, Battaglini A. New governance challenges and conflicts of the energy transition: renewable electricity generation and transmission as contested socio-technical options. In: Scholten D, editor. *The geopolitics of renewables*. Cham: Springer Nature; 2018. p. 231–56.
- [119] Mecklin J. Introduction: international security in the age of renewables. *B Atom Sci* 2016;72(6):377.
- [120] Overland I, Kjaermet H. Russian renewable energy: the potential for international cooperation. Surrey: Ashgate; 2009.
- [121] Organization for Economic Co-operation and Development. Divestment and stranded assets in the low-carbon transition. In: Background paper for the 32nd Round Table on Sustainable Development. Paris: OECD; 2015 Oct 28.
- [122] Ansar A, Caldecott B, Tilbury J. Stranded assets and the fossil fuel divestment campaign. Stranded Assets Program. Smith School of Enterprise and Environment (SSEE), University of Oxford; 2013.
- [123] Pascual C. The new geopolitics of energy. In: The Center on Global Energy Policy. Columbia University in the City of New York School of International and Public Affairs (SIPA); 2015.
- [124] Jaffe A. The role of the US in the geopolitics of climate policy and stranded oil reserves. *Nat Energy* 2016;16158:1–4.
- [125] Scholten D. The geopolitics of renewables – an introduction and expectations. In: Scholten D, editor. *The geopolitics of renewables*. Cham: Springer Nature; 2018. p. 1–33.
- [126] Van de Graaf T. Battling for a shrinking market: oil producers, the renewables revolution, and the risk of stranded assets. In: Scholten D, editor. *The geopolitics of renewables*. Cham: Springer Nature; 2018. p. 97–121.
- [127] Van de Graaf T, Verbruggen A. The oil endgame: strategies of oil exporters in a carbon-constrained world. *Environ Sci Policy* 2015;54:456–62.
- [128] Proedrou F. Geopolitics and development in a steady-state world. In: Proedrou F, editor. *Energy policy and security under climate change*. Cham: Palgrave Macmillan; 2018. p. 145–75.
- [129] Unruh G. Understanding carbon lock-in. *Energy Policy* 2000;28(12):817–30.
- [130] Unruh G. Escaping carbon lock-in. *Energy Policy* 2002;30(4):317–25.
- [131] Eisen J. New energy geopolitics? China, renewable energy, and the greentech race. *Chic Kent Law Rev* 2011;9(86):9–58.
- [132] Scholten D, Bosman R. The strategic realities of the emerging energy game – conclusion and reflection. In: Scholten D, editor. *The geopolitics of renewables*. Cham: Springer Nature; 2018. p. 307–28.
- [133] Stang G. Shaping the future of energy. European Union Institute for Security Studies (EUISS); 2016. Brief Issue 24.
- [134] Bastos Lima M. The Brazilian biofuel industry: achievements and geopolitical challenges. In: Amineh MP, Guang Y, editors. *Secure oil and alternative energy*. Leiden: Brill; 2012. p. 343–69.
- [135] Akhonbay H. The economics of renewable energy in the Gulf. New York: Routledge; 2019.
- [136] El-Ashry M. National policies to promote renewable energy. *Daedalus* 2012;141(2):105–10.
- [137] Günel G. Spaceship in the desert: Energy, climate change, and urban design in Abu Dhabi. Durham: Duke University Press; 2019.
- [138] Luomi M. The Gulf monarchies and climate change: Abu Dhabi and Qatar in an era of natural unsustainability. London: C Hurst & Co; 2012.
- [139] Murooohid H. The adoption of renewable energy policies in a rentier state: a case study of the United Arab Emirates. *The Arab World Geographer* 2018;21(1): 43–57.
- [140] Reiche D. Energy policies of Gulf Cooperation Council (GCC) countries—possibilities and limitations of ecological modernization in rentier states. *Energy Policy* 2010;38(5):2395–403.
- [141] Reiche D. Renewable energy policies in the Gulf countries: a case study of the carbon-neutral "Masdar City" in Abu Dhabi. *Energy Policy* 2010;38(1):378–82.
- [142] Schmitt T. Why did Desertec fail? An interim analysis of a large-scale renewable energy infrastructure project from a social studies of technology perspective. *Local Environ* 2018;23(7):747–76.
- [143] Koch N. Green laboratories: university campuses as sustainability "Exemplars" in the arabian peninsula. *Soc Nat Resour* 2018;31(5):525–40.

- [144] Verdeil É. The contested energy future of Amman, Jordan: between promises of alternative energies and a nuclear venture. *Urban Stud* 2014;51(7):1520–36.
- [145] Marktanner M, Salman L. Economic and geopolitical dimensions of renewable vs. nuclear energy in North Africa. *Energy Policy* 2011;39:4479–89.
- [146] Koch N, Tynkkynen V. The geopolitics of renewables in Kazakhstan and Russia. *Geopolitics* 2019:1–20.
- [147] Poberezhskaya M, Ashe T. Climate change discourse in Russia: Past and present. New York: Routledge; 2018.
- [148] Stratfor. How renewable energy will change geopolitics. 2018. Available from: <https://worldview.stratfor.com/article/how-renewable-energy-will-change-geopolitics>. [Accessed 5 October 2019].
- [149] Ladislav S, Leed M, Walton M. New energy, new geopolitics: background report 1: energy impacts. Lanham, MD: Rowman & Littlefield Publishers; 2014.
- [150] Smeets N. The green menace: unraveling Russia's elite discourse on enabling and constraining factors of renewable energy policies. *Energy Res Soc Sci* 2018;40: 244–56.
- [151] Goldthau A, Westphal K. Why the global energy transition does not mean the end of the petrostate. *Glob Policy* 2019:1–4. <https://doi.org/10.1111/1758-5899.12649>.
- [152] Heinonen S, Karjalainen J, Ruotsalainen J, Steinmüller K. Surprise as the new normal – implications for energy security. *Eur J Futures Res* 2017;5:12.
- [153] Gupta J, Chu E. Inclusive development and climate change: the geopolitics of fossil fuel risks in developing countries. *Afr Asian Stud* 2018;17:90–114.
- [154] Laird F. Constructing the future: advocating energy technologies in the cold war. *Technol Cult* 2003;44(1):27–49.
- [155] Burke M, Stephens J. Political power and renewable energy futures: a critical review. *Energy Res Soc Sci* 2018;35:78–93.
- [156] Powell G, Dalton R, Ström K. Comparative politics today: a world view. eleventh ed. London: Pearson Education Limited; 2015 [Chapter 6].
- [157] Doyle M. Kant, liberal legacies, and foreign affairs. *Roy I Ph S* 1983;12(3):205–35.
- [158] Russett B. Grasping the democratic peace principles for a post-cold war world. Princeton: Princeton University Press; 1994.
- [159] Haug M. Shale gas and renewables: divergence or win-win for transatlantic energy cooperation? *J Transatl Stud* 2012;10(4):358–73.
- [160] Rifkin J. The third Industrial Revolution. how lateral power is transforming energy, the economy, and the world. New York: Palgrave Macmillan; 2011.
- [161] Gruenig M, Lombardi P. Low-carbon energy security from a European perspective. San Diego: Elsevier Science Publishing Co Inc; 2016.
- [162] Scholten D, Bazilian M, Overland I, Westphal K. Nieuwe energie, nieuwe politiek – hoe de energietransitie de relatie tussen landen verandert. *De Helling* 2018;4: 54–8.
- [163] Gullberg A. The political feasibility of Norway as the 'green battery' of Europe. *Energy Policy* 2013;57:615–23.
- [164] Gullberg A, Ohlhorst D, Schreurs M. Towards a low carbon energy future: renewable energy cooperation between Germany and Norway. *Renew Energy* 2014;68:216–22.
- [165] Endeo F. La Geopolítica de la región mediterránea (geopolitics of the mediterranean region). 2014. Available from: <http://www.ieee.es/Galerias/fichero/docs/trabajo/2014/DIEEET03-2014.GeopoliticaEnergia.RegionMediterranea.pdf>. [Accessed 5 October 2019].
- [166] Dreyer I. Renewables: do they matter for foreign policy? vol. 23. Brief Issue: European Union Institute for Security Studies (EUISS); 2013.
- [167] Guler B, Çelebi E, Jatin N. A 'regional energy hub' for achieving a low-carbon energy transition. *Energy Policy* 2018;113:376–85.
- [168] Gulley A, McCullough E, Shedd K. China's domestic and foreign influence in the global cobalt supply chain. *Resour Policy* 2019;62:317–23.
- [169] World Bank. The Growing Role of Minerals and Metals for a Low Carbon Future. 2017. Washington DC.
- [170] OECD. Global Material Resources Outlook to 2060. Economic drivers and environmental consequences. 2018. Paris.
- [171] Månberger A, Johansson B. The geopolitics of metals and metalloids used for the renewable energy transition. *Energy Strategy Reviews* 2019;26.
- [172] Bazilian M. The mineral foundation of the energy transition. *Extr Ind Soc* 2018;5: 93–7.
- [173] Baldi L, Massimo P, Vandone D. Clean energy industries and rare earth materials: economic and financial issues. *Energy Policy* 2014;66:53–61.
- [174] Pavel C, Thiel C, Degreif S, Blagoeva D, Buchert M, Schüler D, et al. Role of substitution in mitigating the supply pressure of rare earths in electric road transport applications. *Sustain Mat Tech* 2017;12:62–72.
- [175] Gulley A, Nassar N, Xun S. China, the United States, and competition for resources that enable emerging technologies. *Proc. Natl. Acad. Sci. U.S.A* 2018;115(16): 4111–5.
- [176] International Council on Mining & Metals. The role of minerals and metals in a low carbon economy. London: ICMM; 2012.
- [177] Kim J, Lee J, Kim BC, Kim J. Raw material criticality assessment with weighted indicators: an application of fuzzy analytic hierarchy process. *Resour Policy* 2019; 60:225–33.
- [178] Månberger A, Stenqvist B. Global metal flows in the renewable energy transition: exploring the effects of substitutes, technological mix and development. *Energy Policy* 2018;119:226–41.
- [179] Resnick Institute. Critical materials for sustainable energy applications. Resnick Institute Report; 2011.
- [180] International Institute for Sustainable Development (IISD). Green conflict minerals: the fuels of conflict in the transition to a low-carbon economy. International Institute for Sustainable Development; 2018.
- [181] Grandell L, Lehtilä A, Kivinen M, Koljonen T, Kihlman S, Laura S. Role of Critical metals in the future markets of clean energy technologies. *Renew Energy* 2016; 95:53–62.
- [182] Pavel C, Lacal-Arántegui R, Marmier A, Schüler D, Evangelos T, Buchert M, et al. Substitution strategies for reducing the use of rare earths in wind turbines. *Resour Policy* 2017;52:349–57.
- [183] Lovins A. Clean energy and rare earths: why not to worry. *B Atom Sci*; 2017. May 23. Available from: <https://thebulletin.org/2017/05/clean-energy-and-rare-earth-s-why-not-to-worry/>.
- [184] Hache E, Seck G, Simoen M, Bonnet C, Carcanague S. Critical raw materials and transportation sector electrification: a detailed bottom-up analysis in world transport. *Appl Energy* 2019;40:6–25.
- [185] Bonnet C, Seck G, Hache E, Simoen M, Carcanague S. Copper at the crossroads: assessing the interactions of the low carbon energy transition with a non-ferrous and structural metal. Working Paper; 2019.
- [186] Kalantzakos S. China and the geopolitics of rare earths. Oxford: Oxford University Press; 2017.
- [187] Smith Stegen K. Heavy rare earths, permanent magnets, and renewable energies: an imminent crisis. *Energy Policy* 2015;79:1–8.
- [188] Rabe W, Kostka G, Smith Stegen K. China's supply of critical raw materials: risks for Europe's solar and wind industries? *Energy Policy* 2017;101:692–9.
- [189] Policy Foreign. Mining the future. How China is set to dominate the next Industrial Revolution. Foreign Policy (FP). FP Analytics – Special Report. 1 May 2019.
- [190] Renner S, Wellmer F. Volatility drivers on the metal market and exposure of producing countries. *Mineral Economics* 2019. <https://doi.org/10.1007/s13563-019-00200-8>.
- [191] Barichella A. Cybersecurity in the energy sector. A comparative analysis between Europe and the United States. Ifri: Études de l'Ifri; 2018.
- [192] Dignun M. Connecting visions of a future renewable energy grid. In: Scholten D, editor. The geopolitics of renewables. Cham: Springer Nature; 2018. p. 257–76.
- [193] Handke S. Renewables and the core of the energy union: how the pentilateral forum facilitates the energy transition in western Europe. In: Scholten D, editor. The geopolitics of renewables. Cham: Springer Nature; 2018. p. 277–303.
- [194] Johnson J. Roadmap for photovoltaic cyber security. Sandia National Laboratories; 2017. Report No.: SAND2017-13262.
- [195] Madnick S, Jalali M, Siegel M, Lee Y, Strong D, Wang R, et al. Measuring stakeholders' perceptions of cybersecurity for renewable energy systems. In: Woon W, Aung Z, Kramer O, Madnick S, editors. Data analytics for renewable energy integration, Lecture notes in artificial intelligence 10097. Cham: Springer; 2017. p. 67–77.
- [196] Qi J, Hahn A, Lu X, Wang J, Liu C-C. Cybersecurity for distributed energy resources and smart inverters. *IET Cyber-Phys Syst, Theory Appl* 2016;1(1): 28–39.
- [197] Hawk C, Kaushiva A. Cybersecurity and the smarter grid. *Electr J* 2014;27(8): 84–95.
- [198] Onyeji I, Bazilian M, Bronk C. Cyber security and critical energy infrastructure. *Electr J* 2014;27(2):52–60.
- [199] Pearson I. Smart grid cyber security for Europe. *Energy Policy* 2011;39(9): 5211–8.
- [200] Liu J, Xiao Y, Li S, Liang W, Chen C. Cyber security and privacy issues in smart grids. *IEEE Commun Surv Tut* 2012;14(4):981–97.
- [201] Ren J, Sovacool B. Prioritizing low-carbon energy sources to enhance China's energy security. *Energy Convers Manag* 2015;92:129–36.
- [202] Yergin D. The prize: the epic quest for oil, money, and power. New York: Simon & Schuster; 1991.
- [203] Dodds K. Global geopolitics. A critical introduction. New York: Routledge; 2005.
- [204] Crikemans D. Geopolitics: 'Geographical consciousness' of foreign policy? [dissertation]. Garant; 2007.