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# The Geopolitics of Renewables;

## Exploring the Political Implications of Renewable Energy Systems

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**Abstract**

This paper explores the potential political implications of the geographic and technical characteristics of renewable energy systems. This is done through a thought experiment which imagines a purely renewable based energy system, keeping all else equal. We find two major implications for renewable energy based markets: a) countries face a make or buy decision, i.e. they have a choice to produce or import energy; b) electricity is the dominant energy carrier, implying a more physically integrated infrastructure with stringent managerial requirements. Two scenarios illustrate the strategic concerns arising from these implications: Continental, following a buy decision and more centralized network, and National, following a make decision and more decentralized network. Three observations stand out compared to the geopolitics of fossil fuels. First, a shift in considerations from getting access to resources to strategic positioning in infrastructure management. Second, a shift in strategic leverage from producers to consumers *and* those countries being able to render balancing and storage services. Finally, the possibility for most countries to become a 'prosumer country' may greatly reduce any form of geopolitical concern.

Keywords: geopolitics; renewable energy systems; thought experiment.

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## 1. Introduction

Rising fossil fuel tensions, increasing fossil fuel price volatility, deteriorating environmental conditions and looming climate change call for a transition towards a more sustainable energy system (Amineh 2010; Nutall and Manz 2008; Dorian et al. 2006; Rifkin 2002; Grübler and Nakićenović 1996; Bosman & Loorbach 2015; Loorbach and Verbong 2012). Renewable energy sources and supporting technologies are to be the cornerstone of such a future (cf. IEA 2014; WWF and Ecofys 2011). At the moment renewable energy is only a marginal contributor to global primary energy and electricity supply but is growing rapidly in installed capacity and investment (REN21 2012; NREL 2008, 43-45; Cowan and Daim 2009; Schleicher-Tappeser 2012; BNEF 2013a; BNEF 2013b). What is more, the potential of renewable energy sources is huge and waiting to be exploited: "current technologies in renewable energy only capture a fraction of the available solar energy, wind energy, biomass, geothermal energy, ocean thermal energy, wave energy and hydropower" (Criekemans 2011, 23).

The current academic debate on renewable energy systems is dominated by studies on economic modeling of their diffusion (cf. Cagnin et al. 2013; Duan et al. 2014; Kajikawa et al. 2008; Meade and Islam 2015), scenarios on their role in possible future energy systems (cf. Fortes et al. 2015; IEA 2014; Schaeffer et al. 2015; WWF and Ecofys 2011) and the policy implications they entail (Eom et al. 2015; Gouvea et al. 2013; Johnson et al. 2015; Riahi et al. 2013; Schwanitz et al. 2015). Although these studies are insightful for guiding the short and medium term transition process (Grin et al., 2010), we feel that study of the (geo)political implications of widespread diffusion of renewable energy systems is lacking. We currently have hardly any academic research on how the geographic abundance of renewable sources will affect energy system topology and cross-border energy flows, or how intermittency, the possibility for decentralized generation and the generally electric nature of renewable energy transportation and storage will pose new challenges to energy trade and security. What strategic considerations and political tensions may be expected?

This matter is made worse by the fact that the other side of the medallion, the literature on energy geopolitics (mostly from the field of International Relations – Amineh 2007, 2010, 2012; Dannreuther 2010; Correlje and van der Linde 2006; Umbach 2010, Klare 2008; Akiner 2004; Friedman 2006; Andrews-Speed 2008; Ölz et al. 2007; Eisen 2011), has thus far focused on oil and gas security, barely scratching "the surface with regard to exploring the potential geopolitical effects of the transition towards more renewable energy sources" (Criekemans 2011, 4). Only a few works in this area exist, predominantly focussing on the conflict potential of rare earth materials in international energy dependencies (de Ridder 2012, 2013; Buijs and Sievers 2011). Consequently, whereas the strategic implications of the increasingly scarce and geographically concentrated nature of oil and natural gas are well-documented, there still exists a great deal of uncertainty regarding the economic and political implications of renewable energy systems.

Considering the still marginal role such systems play in the current energy system this is not surprising. However, the mounting societal and political pressure to increase their contribution, makes studying those implications a pressing topic.

These considerations lead to an intriguing question: what are the potential political implications of the geographic and technical characteristics of renewable energy systems? Put differently, what might renewable energy sources and supporting technologies imply for energy-related patterns of cooperation and conflict between states? Moreover, will a transition to renewables provide solutions to the geopolitical challenges associated with the use of fossil fuels or merely replace old challenges by new ones?

This paper aims to provide food for thought through a structured thought experiment in which we explore what political concerns may be expected to arise between energy producer, consumer, and transit countries from the geographical characteristics of renewable energy sources and the technological specificities of the accompanying infrastructure systems. Our intention is specifically to deduce general principles that shape the nature of interstate renewable energy relations. In follow up research more detailed case studies on specific regions and countries could further refine and specify these principles. We utilize a thought experiment because the technique is suitable for discussing hypothetical cases and their possible consequences in order to provoke the imagination of the reader (Hacking 1992). In this paper, the hypothetical case comprises that we exchange the existing fossil fuel based energy systems with renewable sources based counterparts, keeping all else equal.[2] Put differently, we imagine an energy system that is purely based on renewable sources. We then ask what this implies for the energy market structure and subsequently where sources for geopolitical tensions would lie. On several occasions a comparison with fossil fuels is made in order to contrast important differences.[3]

Carrying out this thought experiment is relevant for both science and policy. First, it spurs us to further develop our understanding of the relationship between the geographic and technical characteristics of energy sources, production, and transport on the one hand, and market formation and countries' strategic realities and policy responses on the other. Second, such an understanding may be able to assist decision makers to oversee the geopolitical implications of large-scale use of renewables, allowing them to make informed decisions on securing an affordable renewable energy supply in the future.

We proceed with a literature review on the geopolitics of renewables in section 2, then detailing the structure of our thought experiment (section 3). Afterwards, section 4 explores the geopolitics of

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[2] This implies assuming today's technology, political-economic environment, and socio-cultural values. We hence rather explore an alternate reality and not necessarily a possible future.

[3] For a more detailed comparison between the geopolitics of fossil fuels and renewables we refer to an earlier version of this article, the conference paper for the 'Politicologenetmaal' 2013 in Ghent, where the geopolitics of fossil fuels served as an explicit reference point for the geopolitics of renewables and the application of the thought-experiment.

renewables. We round up with a discussion (section 5) and brief conclusion (section 6).

## 2. Theories on Geopolitics *and* Renewables

The geopolitics of renewables is a rather novel topic, despite the abundant literature on energy geopolitics, renewable energy technologies and energy transitions.

Most works on energy geopolitics stem from the field of International Relations. Considering the physical-geographic nature of energy sources and the economic and strategic importance of energy for the wealth and power of states, international relations scholars have always had a great interest in energy security questions. A multitude of studies reveal ample examples of how the topology of oil and gas reserves affect political decision making in both consumer and producer countries and the nature of interstate energy relations (Amineh 2007, 2010, 2012; Dannreuther 2010; Correlje and van der Linde 2006; Umbach 2010, Klare 2008; Akiner 2004; Friedman 2006; Andrews-Speed 2008; Ölz et al. 2007; Eisen 2011). A famous example is the EU's efforts to secure energy supply[4] in the wake of the Ukrainian crises in 2005-2006 and the pipeline politics that followed it or the more recent energy union. The concept of geopolitics implied in these studies tends to be of the most basic nature; it usually equates to "politics, especially international relations, as influenced by geographical factors", usually through politicians that act upon geographic considerations (Oxford online dictionary 2012). Foregoing a lengthy discussion on what geopolitics is[5], we also follow this simple definition in this paper. Considering this attention, it is remarkable that present-day geopolitical and international relations literature has "only barely scratched the surface with regard to exploring the potential geopolitical effects of the transition towards more

[4] According to the European Commission "[e]nergy supply security must be geared to ensuring […] the proper functioning of the economy, the uninterrupted physical availability […] at a price which is affordable […] while respecting environmental concerns" (EC 2001, 2). The policy framework, with which security of supply should be assured, however, is controversial. While some decision makers trust in market instruments for optimising the energy supply mix, others urge for more government intervention arguing that markets fail to ensure adequate and sustained levels of energy supply security (Percebois 2003; Constantini et al. 2007; Egenhofer and Legge 2001).

[5] The notion of geopolitics, belonging to both Political Geography and International Relations harbours a great many different interpretations. To Criekemans (2011, 4), for example, geopolitics "investigates the interaction between [political actors] and their surrounding territoriality in its three dimensions: physical-geographical, human-geographical and spatial." Energy would mostly/only fall in the first category. A different classification can be made between the more classical or orthodox geopolitics and that of neo-geopolitics (Mahan 1890; Ratzel 1897; Mackinder 1904; Amineh 2003; Agnew 1998; Tuathail and Dalby 1998). The former relates mostly to the 'rivalry between great powers in its geographic dimension' (akin to the realist school of international relations). In this struggle for power land and resources are imperative for the survival of the nation. Famous examples in this light are the 'scramble for Africa', Mackinder's heartland notion, or Soviet containment policy during the Cold War. The latter perceives "Geographic arrangements [as] social constructions that are changeable over time depending on political, economic and technological changes" (Amineh 2003, 24) (akin to liberal and critical theories in IR). Next to the traditional focus on hierarchies of power and the access to natural resources, explanatory factors are also found in the global economy (control of trade, production and finance), political discourse, and the legitimacy of power.

renewable energy sources" (Criekemans 2011, 4). Another issue is that these studies tend to focus on the conflictuous nature of energy, ignoring often their presence as an everyday commodity that can stimulate growth. Nevertheless, the literature harbours a rich set of operationalized notions with which to discuss the strategic realities of producer, transit, and consumer countries: energy scarcity, dependence and vulnerability[6], stability of energy prices in global markets, and possibilities for diversification (country, source or route). These notions seem just as relevant for renewables as they are for fossil fuels when it comes to estimating the possible political implications of renewables' topology.

There is also no lack of technical and economic studies of renewable energy technologies and the energy transition. Much literature details the economic modeling of renewable energy diffusion (cf. Cagnin et al. 2013; Duan et al. 2014; Kajikawa et al. 2008; Meade and Islam 2015), scenarios on their role in possible future energy systems (cf. Fortes et al. 2015; IEA 2014; Schaeffer et al. 2015; WWF and Ecofys 2011) and the policy implications they entail (Eom et al. 2015; Gouvea et al. 2013; Johnson et al. 2015; Riahi et al. 2013; Schwanitz et al. 2015). Yet these studies focus more on promoting renewables through policy instruments, their potential and efficiency, or the challenges associated with their market and system integration, largely ignoring any international or geopolitical aspects. Only occasionally is renewables' spatial dimension discussed (Bridge et al. 2013; Stoeglehner et al. 2011) or is global energy governance addressed (van de Graaf 2013; Lesage et al. 2010). Nevertheless, if there is one important lesson to be had for this paper, it is that renewables should not only refer to the actual sources[7], such as wind, solar etc., in our effort, but also the infrastructure technologies (physical network assets, control facilities) necessary to bring them to market.[8] Moreover, the impact of introducing renewables in the energy mix extends much further than merely the factual generation component, including infrastructure operations, energy markets, consumer behaviour and sector regulation. We hence perceive energy infrastructures[9] as complex adaptive

6 Fossil fuel energy security is tightly linked to the concepts of dependence and vulnerability, especially for net-importing or consumer countries. Dependency refers to "the share of national energy consumption which is produced domestically vis-à-vis energy imports" (Gnansounou 2008, 3735). It is closely related to the concept of risk. "The vulnerability of a system is the degree to which that system is unable to cope with selected adverse events." Vulnerability expresses the consequences of energy supply interruptions (Gnansounou 2008, 3735).

7 According to the International Energy Agency (IEA) "[r]enewable energy is energy that is derived from natural processes that are replenished constantly [in a natural way and includes such sources as] solar, wind, biomass, geothermal [and heat], hydropower, ocean resources [tidal and wave], and biofuels, and electricity and hydrogen derived from those renewable resources" (IEA 2004, 12). Renewable energy sources hence stand in direct contrast to exhaustive fossil fuel sources such as coal, oil, and natural gas, whose deposits are essentially finite. The concept 'renewable' should not be confused with sustainable (Brundtland Commission 1987).

8 Deudner (1989) already referred to the close relationship between accessibility of energy sources and technological possibilities of extracting and capturing energy as the 'geotechnical ensemble'. We only add here the notion of infrastructure, more in line with contemporary works that conceptualize energy systems as socio-technical systems.

9 We define infrastructures as "the framework of interdependent networks and systems comprising identifiable industries, institutions (including people and procedures), and distribution capabilities that provide a reliable flow of products and services […]" (Rinaldi et al. 2001, 13, citing the US Critical Infrastructure Assurance Office (CIAO)).

socio-technical systems.[10] A shift to renewables is hence much more than a shift in sources, it entails all accompanying and consequent changes in the infrastructure and its management as well.

First attempts to bring the worlds of geopolitics and renewables together are slowly emerging. Criekemans (2011), for example, noting the different locations for efficient generation of renewable energy vis-à-vis the location of fossil fuel reserves today, speculates about the effects on the position of major powers to utilize the transition to renewables to move up in the global hierarchy. Others, have studied specific cases of renewable energy related security risks/threats (Smith-Stegen 2014), the effect of the energy transition in one country on its neighbouring countries, e.g. Germany's Energiewende (Bosman 2012; Bruninx et al. 2013), or possibilities for mutually beneficial energy cooperation among countries (Gullberg et al. 2014). Again others note more broadly the impact of the clean energy transition on international oil (Haug 2011) or the political implications for the EU of a shifting generation and infrastructure topology as a result of renewables (Scholten et al. 2014). While these provide useful initial analyses, to which we gladly refer for a first reading to understand the potential political implications of the geographical and technical characteristics of renewable energy systems, they fail to address specifically how renewables' characteristics affect cross-border energy *relations*. While potential new trade patterns are highlighted, for example between the US and Mexico or the EU and Algeria, the nature of interaction, i.e. the play of the game as framed by the broader geographic and technical characteristics of renewable energy systems, remains largely unexplored. How will the geographic abundance of renewable sources affect energy system topology and cross-border energy flows? What new challenges to energy trade and security will renewables' intermittency, the possibility for decentralized generation and the generally electric nature of renewable energy transportation and storage pose? What strategic considerations and political tensions may be expected?

As such, this paper is not about how the transition to renewables may affect the relative position of major powers or what the specific political implications for individual countries are, but focuses on how renewables may reshape the play of the game between producer, transit and consumer countries and the strategic realities and/or political concerns these countries face. We are hence after general principles that shape the nature of interstate renewable energy relations. Thus, this paper sets out to explore, not to prove, potential geopolitical implications of renewables.

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[10] The obvious peculiarity of this perspective is that it does not follow an exclusively technical topology of infrastructures (like Barabasi 2003; Newman 2003) but also considers (besides the transport and distribution network) the production/conversion and storage facilities, the management and control systems, and the relevant markets and governance frameworks as crucial elements in determining system performance (Ewertsson and Ingelstam 2004; Hughes 1983; Kroes et al. 2006; Kaijser 2005; Nelson 1994; Geels 2004; Weijnen and Bouwmans 2006; Scholten 2013).

## 3. Methodology: a structured thought experiment

A framework with which to systematically approach and investigate the geopolitics of renewables adequately is currently lacking. Two core challenges stand out. First, we need to link renewable energy system characteristics to the security notions utilized in energy geopolitics literature. Second, we need to find a suitable way to investigate a phenomenon that is only emerging as we speak and does not provide for many cases to investigate.

Regarding the first, we propose to utilize insights from the field of micro-economics to relate geographical and techno-infrastructural features of renewables to their effect on energy markets and subsequently to political implications.

Concerning the second, we choose to do a thought experiment. In order to highlight the unique features of the geopolitics of renewables as opposed to fossil fuels, a situation of 100% renewables in the energy mix is the best way to create a clear contrast. However, real world experiences with renewable energy systems on a scale that would influence geopolitical dependencies between countries are still largely absent. Moreover, the dominance of fossil fuels in the energy mix also affects the geopolitics of renewables. Next to that, findings are likely to be context specific, not the general principles that shape the nature of interstate renewable energy relations that we are after. Current case studies hence cannot provide for the desired setting; thought experiments can. In addition, describing possible futures for modelling or scenario purposes is problematic, as the description heavily depends on the assumptions authors make on the complex and non-linear cultural, economic, technological, behavioural, ecological, and institutional developments that together shape societal change (Grin et al. 2010). A thought experiment enables us to set clear research boundaries, unhindered by questions of likelihood, allowing us to focus solely on the link between geographic and technical features of renewables and their political implications, leaving other (political-economic) considerations out.

Thought experiments comprise a technique that is often employed in science, especially in philosophy to discuss a hypothetical case and its possible consequences in order to provoke the imagination of the reader (Haggqvist 1996; Hacking 1992; Horowitz & Massey 1991). Their use by renown scientist such as Newton and Einstein provides a point in case for their academic value. Building on physicist Ernst Mach and Erwin Hiebert's classical Knowledge and Error (1976), Aligica (2005, 820) explains the value of thought experiments. The function of thought experiments is

> "to provide pictures of the new field under investigation. Those pictures are composed of representations of already known phenomena: pieces of information based on known phenomena are put together in new configurations. […] The mental models or pictures represent the world. The manipulations of the mental pictures were defined by a selective variation of one parameter that is similar to that used in ordinary experimentation. The difference is that in

thought experiments the method of variation is applied to his mental pictures of the world not directly to a specific aspect of the world."

Using a thought experiment has advantages and disadvantages. This is no different for the topic of the geopolitics of renewable. According to Mach and Hiebert experimenting in the mind is less dangerous and more cost-effective than real world experiments. They are especially an appropriate method if one aims to have a "heuristic device … for attempting to break away from conventional thinking" (Walton 2008, 149). As such, they seem well suited for our purposes. The great pitfall of a thought experiment is that the discussion can go in all directions, lacking cohesion and internal consistency. What considerations to take into account; what is the guiding reasoning behind any conclusions. In order to explore the potential geopolitical implications of a large-scale utilization of renewable energy, we propose to structure our discussion in the following way:

Please insert Figure 1 here.

To start, our thought experiment builds on three premises. First, we imagine a purely[11] renewable based energy system to replace the current largely fossil fuel based system. In this case, we do not assess this as a possible future; rather we imagine it as an alternate reality. Second, we assume today's technology and that renewables would be sufficient to meet all demand. Finally, we assume today's political-economic context and socio-cultural values, though we treat them as the exogenous environment that does not affect our reasoning.

As for our reasoning, this is structured in three steps. We start by detailing the geographic characteristics of renewable energy supplies (location and potential), the available generation and infrastructure technologies, and the location of demand for that energy. The location and accessibility of major oil, gas, and coal fields with respect to major demand centers and infrastructure technologies have played an important role in shaping the current fossil fuel based energy systems and markets.[12] We may hence reasonably assume that the geographical characteristics of renewable sources and technical possibilities to bring them to markets will play a major role in shaping a renewable energy system. The

[11] Of course, it matters tremendously whether one imagines a penetration of 20%, 50%, 80%, or 100% renewables in any energy system. A penetration of, say, 60% would always allow sufficient strategic reserves or back-up capacity for more strategic applications, for example. The choice for a purely renewables based energy system has one significant drawback: it does not allow us to explore shifts in the merit order if renewable sources, with notably zero or very low marginal costs, would compete with coal and gas based power plants, as would be the case in an actual transition.

[12] Ever since the Industrial Revolution the particular constellation of the geographic location of coal, oil, and natural gas reserves, the nature of energy demand, and infrastructure technologies has formed the specific trade patterns of regional and global energy markets and shaped a complex web of relations between and among energy producing, consuming, and transit states and a host of non-state actors. In the meantime, the energy trade created a variety of possibilities and impediments for energy related cooperation and conflict among states (Amineh 2007).

prime locations of renewable energy production (think of the location and intensity of solar radiation, wind speeds, waves, geothermal hotspots etc.) are weather and geology dependent and highly unlikely to change over the course of decades.

This overview of the technical and geographical characteristics of renewables then serves as a point of departure for interpreting what renewable based energy markets may look like (step 2). This intermediate step is the crucial link between the geo-infrastructural and political dimension. Borrowing from the field of micro-economics (Mankiw 2008; Perez-Arriaga 2012; Van Gendt et al. 2004), we may interpret how the technical characteristics of renewable energy systems affect the relevant market, market structure, and system boundaries. The first refers to product characteristics, time constraints (storage possibilities), and market scope. For example, renewable sources vary in terms of intermittency and market size and trade partners may be local/national, regional/continental, or global. The second refers to the amount of producers and consumers (many, few, single), barriers to entry/exit, and the nature of the good (homogenous or heterogeneous, substitutability); the matter being whether it is a seller's or buyer's market. The key logic here is a rather familiar one: like with any market, the presence of many producers, consumers, and transit possibilities, results in a competitive market, and the energy source or carrier may be considered a commodity; the more monopolistic features on the consumer or producer end or bottlenecks in transport, the more the energy source or carrier becomes politicized, is considered a strategic good, and may be expected to lead to geopolitical tensions. The third refers to how technical system boundaries may enable and constrain market functioning. For example, the ramp-up and down time of nuclear power plants as compared to combined cycle natural gas turbines or wind turbines greatly impacts their position in the merit order, and therefore functioning of the energy market.[13]

The final step zooms in on the strategic realities of producer, transit, and consumer countries within the market characteristics identified in step 2. We assume here that consumer countries are concerned about security of supply and desire stable and affordable energy prices, that producers want to maximize energy revenues to fuel their economy and desire security of demand, and that transit countries are essentially interested in retaining their position in the infrastructure in order to extract a fair rate for their services and to create some political leverage for themselves (sitting at the table). We then investigate which strategic considerations these countries face in light of their interests and market characteristics. What dependencies and vulnerabilities or other considerations will inform countries' policy response? What policy options do these countries have at their disposal to pursue their interests given market characteristics? Are they likely to lead to more or less cooperative interstate energy relations, i.e.

[13] Different energy production technologies imply various capex and opex trade-offs. There is hence no uniform cost-curve to describe the economics of power plants. Network capacity is another factor that seriously impacts how much energy may be 'traded' between producers and consumers at a given point in time. Combined with demand patterns, these operational considerations have already given rise to a variety of energy markets: day ahead spot markets; long-term bilateral contracts; balancing markets; and a number of derivative markets.

geopolitical tensions?

While it is easy to criticize such a thought experiment for all its premises and assumptions (see discussion section), we believe its value lies therein that it enables us to analyze the main geopolitical implications of a different energy system in a focused and structured manner. Rather than prescribing a blueprint for a future energy system, with this thought experiment we aim to open a discussion on what such a future could look like and what its main geopolitical implications would be. The logical next step would then be regional case studies in which the implications of our thought experiment for specific countries are detailed.

## 4. The Geopolitics of Renewable Energy

Having laid out how we frame and intend to investigate the geopolitics of renewables, let us now explore what the geographic and technical characteristics of renewable energy systems might imply for energy relations among countries by moving along the three steps of the though experiment.

### 4.1 The Geo-infrastructural Ensemble of Renewables

A convenient way of detailing the geographic and technical characteristics of renewable energy systems is to move down the supply chain, starting with renewable energy sources and generation and then moving to transport and storage, and finally consumption. Five characteristics stand out.

First, renewable energy sources are not scarce or as geographically constrained as fossil fuels. Every country has access to at least some form of renewable energy, be it wind, solar, biomass, hydro, or geothermal. Even an extremely densely populated country such as the Netherlands has the theoretical potential to source a third of its current energy demand from domestic renewable energy sources (PBL and ECN 2011). However, the potential for renewable energy is not spread equally across the globe. Just like the reserves of fossil fuels, some countries and regions are better endowed than others (see Figure 2). As a consequence, some countries can more efficiently generate energy from solar, wind, hydro etc. sources. In addition, the potential for energy generation is not the same for all renewables. Solar and wind potential is far larger than that of biomass, hydro, or geothermal energy (for a detailed look, please see IEA 2011; Perez et al. 2009; Criekemans 2011; Ecofys 2008; Hoogwijk 2004). Let us briefly sum up the forms and geographical characteristics of renewable energy sources (Boyle 2004):

- Solar radiation can be captured as heat by solar thermal collectors and as electricity with the help of photovoltaic (PV) cells. Highest insolation can be found in semi-arid regions.

- Wind energy is usually captured with wind turbines, turning the kinetic energy of the wind into electricity. Primary wind locations are further away from the equator and closer to coastal areas.
- Hydropower utilizes turbines to turn kinetic energy extracted from falling water into electricity. Generation requires ample water supply and height differences, therefore mountainous locations and areas with generally high levels of precipitation are best. Oceanic energy, be it tidal, wave, or thermal, is another option. There, the best locations are specific coastal areas.
- Biomass is organic material mostly from plants but also (municipal) waste. Biomass can be converted into energy either through thermal or (bio)chemical conversion, producing biofuels, heat, or electricity. The most productive areas are generally those with high precipitation and insolation, such as the tropics.
- Geothermal energy is derived from heat sources in the earth's crust, resulting mostly from radioactive decay of minerals. While essentially a global resource when drilled deep enough, hotspots can be found near tectonic plate boundaries. It can be used directly for heating purposes, or, when hot enough, it can be fed through a turbine to generate electricity.

Please insert Figure 2 here.

Second, many sources, including the most potent (solar and wind), are intermittent, meaning that they are not available on demand, but rather are weather dependent. Moreover, while some fluctuations are predictable (solar), others are far less so (wind). The intermittency adds supply fluctuations to a system that is currently focused on matching variable demand patterns (daily and seasonal) via a mix of stable base-load generation plants and flexible standing reserve capacity. This turns the energy market from demand driven to more supply driven and makes balancing the grid more challenging. Concepts of smart meters and smart grids are there to mediate, but can only do so within the variable production and consumption constraints.

Third, the nature of renewable energy generation technology, whose units are often much smaller than that of conventional energy technology hint at a more distributed energy system; every land- or even roof owner is a potential energy producer. This furthers the energy self-sufficiency of countries, local communities, or even households.

Fourth, renewable energy generation technology sometimes requires rare earth materials. These resources may need to be imported.

Fifth, electricity can be expected to become the dominant energy carrier in a world powered by renewable energy, since those renewables with most potential (solar and wind as we saw in Figure 2) are most easily converted into electricity. This is not to say, however, that this will be an all-electric system. Biogas or biofuels, for example, can still play an important role. This has important consequences. The nature of a renewable electricity grid implies a physically integrated infrastructure that connects producers and consumer countries through a single interconnected grid (unlike, for example, oil tankers that traverse open seas). The size of the grid is somewhat limited due to the loss of load that occurs when transporting electricity over large distances. In addition, the management requirements of electricity grids are high. Electricity moves close to the speed of light through the grid and requires on the spot management of loads and voltage levels. Accidents may cascade throughout the entire grid and affect all parties in a matter of seconds. This in turn requires immediate response measures and redundant assets to manage. Sufficient generation and transport capacity is crucial to maintain reliable operations. While storage methods exist (pumped hydro storage, flywheels, batteries, super capacitors, CAES, power-to-gas), their efficiency leaves much to be desired and those means with the greatest capacity have geographical limitations. It is not possible to store electricity as a strategic reserve like fossil fuels.[14]

### 4.2 Energy Market Structure of Renewables

From the five geographical and technical characteristics of renewable energy systems we derive five major implications for our hypothetical renewable energy based markets.

First and foremost, the abundance of renewable sources and possibility of producing energy domestically fundamentally changes power relations between producer and consumer countries as compared to the current fossil fuel situation characterized by resource scarcity and geographical concentration (though less so when considering unconventional oil and gas). When every country has the ability to source energy domestically (at least a strategic part), but some countries are able to harvest energy more efficiently, one may assume that a) there are many (potential) producers in the market; b) production shifts to those countries that can do so most efficiently; and that c) most, if not all, countries face a 'make or buy' decision, i.e. have a choice between cheaper electricity imports from regions with more favourable conditions on the one hand and the security of supply of domestic production on the other. Regarding the former two, the presence of many producers allows consumer countries to more readily switch producers and limits the possibilities of producers to set prices. As a consequence, energy

[14] There are some important operational differences between fossil fuels and renewables. The production and refinement of fossil fuels typically occurs in central, high capacity facilities near oil and gas fields or coal mines or in harbors closer to demand centers after oversea shipping and generates a constant output of energy. Another important characteristic of solid, liquid, and gaseous fossil energy sources is that they can be efficiently stored using a variety of means (tanks, cylinders, depots) and transported over long distances without loss of energy content. Moreover, storage depots may hold strategic buffers in case of accidents or cut-offs and with the exception of pipelines the transportation of fossil fuels does not occur with a physically interconnected infrastructure; the delivery via trucks, rail, or barge is far more compartmentalized than that of pipelines. Hence the effect of an accident or sabotage action may be isolated to the part where it occurred and the entire network and its users need not be all, nor immediately, affected. In turn, elaborate long-distance infrastructures over sea and land (tankers, pipelines, rail, road) connect user centers with coal, oil, and natural gas producing countries and regions via hubs and transfer facilities across the globe.

trade patterns between producers, consumers, and transit countries are rather flexible. The only limitation to customer switching seems to be that all would like to switch to the most cost-efficient producer, given the necessary infrastructure is in place. Concerning the latter, the mere ability to switch to domestic production gives consumer countries leverage on the bargaining table when push comes to shove (even if capacity still needs to be built). Those who possess sufficient cheap domestic renewable energy potential may even forego imports altogether. This empowerment of consumer countries results in a market setting that is akin to that of perfect competition and a view of electricity as a commodity instead of strategic good. Put differently, renewable energy markets are likely to be buyer's markets. Nevertheless, consumer countries will have to deal with two issues: a) while resource scarcity might not be a concern, the availability of solar and wind energy at the right moment is not guaranteed, likely leading to higher electricity prices at times with little sun or wind; and b) sufficient production, transport, and storage capacity is a cause for concern in a setting where one area may produce electricity more efficiently and all consumers vie for the cheapest electricity possible.

Next, energy markets are constrained by the size of the grid. The nature of electricity transport implies a tightly integrated infrastructure that physically connects producers and consumer countries (unlike, for example, oil tankers that traverse open seas). Without the grid, there is no energy trade. In this light a few considerations matter with regard to the size of the grid: a) electricity transport is hindered by the loss of load over large distances; b) the larger the grid, the more sources / productive capacity may be included; c) the larger the grid, the more geographical fluctuations in availability of renewable resources can be exploited; and d) the larger the grid, the more likely that it is vulnerable to disruptions and the larger the consequences of a disruption. As a consequence electricity grids tend to span countries and continents, but not the globe. Renewable energy markets are thus expected to exist nationally or regionally even though global markets might exist for the material input and technology necessary to produce electricity from renewable sources.

Third, renewable electricity harbours the possibility of distributed generation and with it new business models that differ from centrally operated systems. Domestically, countries have to decide whether they prefer centrally or decentrally produced electricity and whether to rely on incumbent energy companies and grid operators or empower households and local communities with their own production and distribution networks (connected to the grid or not). If the distributed option is chosen, energy markets become locally oriented, likely to involve a mix of private and communal companies. This choice in generation capacity adds a strategic consideration within the make or buy context. The question is in how far flexibility is retained to revert a previously made make or buy decision. Once a country makes a 'make' decision, it seems easier to revert that decision if it chooses to supply domestic demand in a centralized manner than when it focuses on distributed generation. Connecting large-scale generation and transmission systems to international connections is common practice; doing the same with local energy communities is unlikely.

Fourth, the switch to renewables also affects mobility. While oil is dominant today, electric vehicles, hydrogen fuel cell technologies and biofuels will make up renewable based transport. The market is likely to be split between EV for lighter transport on the one hand and biofuel based heavy duty vehicles on the other. The inefficiency to generate hydrogen from renewable sources via electrolysis practically rules out its use as reforming from fossil sources (the cost-competitive option) has to be ignored considering the thought experiments' boundaries (even though fuel cells are efficient compared to internal combustion engines). The added infrastructure costs are another point of concern in this regard. Besides the food vs. fuel debate that surrounds biofuels, the geographic limitations to the amount of biofuels that can be produced in a given area are very real. Densely populated urban areas or countries will need to get their fill elsewhere or abroad. Similar dynamics as in today's oil markets are likely, the more so because transportation is also similar (non-electric). Getting access to biomass will be the order of the day. As for electric vehicles, fuelling takes place using the same electricity infrastructure as for other appliances. This implies another major component the electricity grid should accommodate. Electric vehicles do have the added benefit of being 'batteries on wheels' that may help dealing with intermittency (see point below). In terms of geopolitical implications of EVs, because the electricity is distributed to retail outlets via the grid, they do not present specific challenges of their own.

Finally, the variability of renewable energy generation is likely to result in more volatile electricity prices as compared to fossil fuels and in a need for storage to create stable energy markets. Solar panels and wind turbines operate at near zero marginal costs. In times of plenty sun or wind the market is hence flooded with extremely cheap electricity. Because of this effect, Germany experiences negative electricity prices several times a year (Nicolosi 2010). Of course, the opposite also holds: in times of little sun or wind, electricity is likely to have a higher price than current coal power plants provide. Moreover, daily demand also knows its ups and downs. When it increases drastically in the evening, at the time the sun sets, prices may be truly high, while during the night they may be rather low. Such fluctuations send strong price signals to consumers to balance their energy use over the day, given on the spot pricing, and to producers to invest into generating capacity of those renewables that can be harvested at peak-demand. They also bring a great deal of uncertainty, however: what are the effects on energy markets and the renewable mix; how certain are returns on investment; should day-ahead markets become hour-ahead markets to accommodate forecasting issues? These questions signal the need for balancing capacity, not just for operational reliability, but also for market stability's sake. Options to balance energy prices are large-scale storage facilities, investment in renewable sources that are able to deliver at times of peak demand, and great interconnector capacity to link various sources to the same cross-border grid to manage intermittency effects.

### 4.3 Strategic Considerations of Renewables

To discuss the geopolitical implications of renewables, we need to do justice to how the make or buy decision and central or decentral generation and transport options could play out if we are to understand the specific strategic realities of different countries. To this end we propose two (extreme) scenarios in which a renewable energy system could materialize. In the first scenario the buy decision and central production and transportation prevail (signalling a setting where countries prefer cost-efficiency over security considerations). We call this the 'Continental' scenario. In the second scenario the make decision and a predominantly decentralized energy system where countries or even local communities will largely provide in their own energy needs prevail (signalling a setting where countries prefer security over cost-efficiency considerations). We call this the 'National' scenario.

#### *4.3.1 Strategic realities in the Continental scenario*

In the Continental scenario production will take place in those countries that have most favourable circumstances for renewable energy. Considering that countries prefer efficiency over security, i.e. cheap imports over domestic production, centralized production and transport infrastructures dominate. Examples of visions that resemble such an energy system are the European Roadmap 2030 and plans to source renewable energy from favourable locations - solar energy from the Mediterranean (Spain, Italy, North Africa (e.g. Desertec Foundation, d.u.) and wind from the North Sea (e.g. North Sea Offshore Grid by the UK, Netherlands, Denmark and Germany) - and then transport it to end-users using long distance high voltage direct current (HVDC) lines that together form a 'copperplate' grid that spans the continent (Verbong and Geels 2010).

What may be expected in the Continental scenario is that the abundance of renewable energy sources and the interconnected and electric nature of renewable energy grids imply a strategic focus on the infrastructure (and accompanying markets). In a buyer's market, getting access to resources is not an issue while energy prices and market shares (control) take center stage. Consequently, producer, consumer, and transit countries will have an interest in physical grid assets as it allows to exert influence over electricity flows, and in turn markets. The grid focus has several strategic consequences.

First, geopolitical interdependencies are limited to the size of the grid that connects different producing, transit, and consuming countries, leading to the emergence 'grid communities'. Dependency on far away overseas territories, and accompanying security of shipping lanes etc., becomes less when the continental grid can foresee in energy needs. Of course, for the supply of materials to build the physical infrastructure, global markets still apply. Nevertheless, there is no need for global energy import, transport, or demand diversification policies, only within the limits of the physical connection.

Second, power struggles will focus on acquiring ownership and decision rights with regard to the grid and its management. The key issue here is the allocation of costs and benefits of developing and utilizing a centralized renewable energy system. Who builds, owns, manages, and protects the grid? Who finances projects, where are production and storage facilities to be located, what about employment and transportation tariffs? In such a setting, geopolitics becomes business politics. We already see how building an interconnector across borders (France and Spain) raises strategic considerations as to who wins and who loses in terms of economic activity (Scholten et al. 2014). Countries are wary of a single grid, let alone a single market; they understand only too well that interconnection means foreign competition that they might not win. There are also other technical and legal issues. Who is going to be the main responsible for operations and disturbance response? How to manage the intermittency of power generation in cross-border networks; how will damages in one area incurred by fluctuating power in another area be resolved; what new modes of operating these systems may be required? Clear agreements or supranational regulatory framework to cover the energy and monetary flows seem a prerequisite to avoid opportunistic behaviour and conflicts.

Third, as all countries within a grid community are physically interconnected, actions in one part will immediately affect another, especially when considering that electricity moves at the speed of light. In this setting, producer, transit, and consumer countries within a grid community have an equal stake in the well-functioning of the electricity grid. Such a characteristic of the electricity grid leaves little room for direct geopolitical pressure. If one country in the interconnected energy system would like to cut off the energy supplies to another, it would be practically impossible to do so because of rerouting possibilities and without also affecting other members of the grid community and even itself (at least in terms of reputation). Therefore, trust and mutual benefits are an important driver for the development of grid communities. If the network topology of the grid, however, would allow for such action towards a single nation, a potential cut-off is much more hazardous than for fossil fuels, considering the difficulty in storing electricity would remove the option of holding strategic reserves, leaving only installing extra capacity as an option. Here also the vulnerability to cyber-attacks comes in (Smith Stegen et al. 2012; Onyeji et al. 2013). Moreover, any cross-border issues regarding the energy supply will be more acute, because an interruption of supplies in electricity will directly lead to black-outs, while for example the delay of an oil tanker will not directly lead to failure of the energy system. In this sense, the electricity grid is more vulnerable to disruptions than the current fossil energy supply.

Fourth, within the context of the continental grid, strategic positions are occupied by those countries endowed with favourable conditions to produce renewable energy, large consumer countries or areas, and increasingly also those countries being able to render balancing and storage services. While the former two are rather obvious, the latter still deserves closer attention. Looking at today's state-of-the-art in matching supply and demand, there are several ways: storing excess supply and delivering power on demand in times of undersupply (both upward and downward); having sufficient standing reserve capacity (upward only); continental interconnection to level intermittent production; and demand management. Countries with large-scale storage potential, that can deliver at times of peak demand (possessing standing reserves), and with large interconnector capacity may hence provide key services to reliable grid operations and stable energy markets. Such countries would be able to strategically position themselves as key players in the grid community and could exert leverage or at least make sure that they receive ample payment for their services. In this regard, storage takes a special position as it has a strong geographical component: the largest potential lies in hydropower (impoundment and pumped storage) or compressed air energy storage capacity. This makes countries with mountainous areas or underground caverns especially interesting. Norway's rapidly expanding grid capacity to neighbouring countries and even overseas to the UK, for example, has already led it to be (reluctantly) coined 'the battery of Europe' (Seidler 2012; Gullberg 2013). While other countries could develop their own storage and balancing capacities, they are likely to do so less efficiently.

*4.3.2 Strategic realities in the National scenario*

In the National scenario, countries or even communities have the opportunity to internalize all functions (production, transit, consumption) and become self-sufficient regarding their energy needs, at least to a certain extent. In this so-called 'prosumer country' model energy consumer countries source all or a significant share of their energy domestically (Loock et al. 2010) and production and consumption of energy takes place much closer to each other, thereby exercising control over their energy supply. Such an energy system seems to be materializing already in Germany, for example, where over 50% of new renewable capacity is represented by decentralized energy systems owned by private people, farmers, and energy cooperatives (Trend Research 2011). Obviously, the big premise underpinning this scenario is that the geographic capacity for domestic generation is present; something that is highly unlikely except for a few countries. Nevertheless, the National scenario takes this position to contrast the political implications with those of the Continental scenario.

A first shift entails that geopolitical implications of energy supply are almost non-existent. As each country now generates its own electricity from renewables without the need to import sources, geopolitical concerns change from energy input to material input of clean energy production technology. Once a wind park or solar panels have been built, they generally provide energy for 20 to 30 years. As the production of clean energy technology closely resembles other manufacturing industries, such as making cars or televisions (and there is little attention for such industries from a geopolitical perspective), it is expected that the geopolitical implications of this scenario are much smaller than in the current fossil energy system, in which dependencies are present throughout the supply chain. Of course, clean tech companies such as wind turbines and solar panel producers operating globally will play a key role. However, after selling the device, their influence is limited. It hence makes little sense to discuss cross-border geopolitical implications in terms of producer, transit, and consumer country jargon. Still it could be of strategic interest for countries to make sure their country is able to produce critical technologies.

Another major shift in this scenario relates to the way in which renewable electricity may be generated. Countries may choose to generate electricity either in centralized, large-scale wind parks or solar farms or with the use of decentralized, small-scale individual turbines and solar panels on rooftops. In the former, geopolitical issues may play out locally around various regions and local communities within a country that either wish to have renewable electricity generated in their area (for employment and revenue reasons) or that do not (for NIMBY reasons). It is likely that incumbent energy companies are in a good position to provide the finance and expertise to construct large-scale wind parks or solar farms. In the latter option, 'prosumers' take center stage and energy moves out of the international geopolitical realm. Of course, some domestic political issues remain: how to integrate these new decentral renewable production technologies into existing, more centralized, electricity grids; how will incumbent energy companies respond; how to organize feed-in or local spot markets; what are accompanying regulatory frameworks? Such questions, however, fall outside the scope of this paper.

## 5. Discussion

Separating the Continental and National scenarios gives the impression that a choice has to be made, i.e. that the renewable energy system resembles either one or the other. The most likely outcome, of course, is a mix of both scenarios. In a National scenario there would be opportunities for efficiency gains through cross-border trade: energy surpluses in one country, undersupply in another country, and available transport and storage capacity of yet another country could complement each other. Moreover, in a Continental scenario countries would have opportunities to limit their dependence by investing in domestic generation and storage capacity. The most probable outcome is that a balance will be struck between security of supply and self-sufficiency on the one hand and efficiency gains through energy trade on the other. Vital functions of society could be powered by local energy sources, probably including local storage capacity. Less vital functions could rely on intermittent domestic energy production and foreign trade. The question remains, of course, where that balance should lie and in how far a country is able to create the space for such a choice.

In this light, one concern relates to both scenarios. Geopolitical tensions could arise in the production of the technology that is used to capture renewable energy sources. One of the dimensions that gained increased attention in the energy transition debate is that of rare earth materials (see e.g.

Weterings et al. 2010). Rare earth materials are a crucial input for certain clean-tech applications such as wind turbines, solar panels, batteries for electric vehicles, and other storage media. Lately, focus has been on China as being home to a significant share of the world's rare earth resources and its activities in acquiring control over overseas rare materials. However, critical scholars show that also rare earth materials respond to market forces. In recent years mines for different rare earth resources have been closed in the US and South-Africa, because China was able to provide these materials cheaper. These scholars expect that when China will use rare earths to exert geopolitical pressure, mines around the world can be expected to reopen and markets will diversify again (Buijs and Sievers 2011) or shift to new technologies.

These statements, of course, need to be seen within the boundaries and assumptions of the thought experiment. There are some important limitations to note. First, it is rather geographically and technologically deterministic in nature. Other factors that drive the behaviour of states, such as most notably the international political distribution of wealth and power (of which the geopolitics of energy are only a part), broader financial markets, or specific socio-cultural contexts of countries are not taken into account when it comes to interpreting the nature of renewable energy markets and countries' strategic realities. The choice was made here to keep the discussion focused on the political implications of the geographical and technical characteristics of renewables. In a second step, we might then, for example, place the renewable energy system and accompanying markets within scenarios that represent different global power constellations and degrees of market liberalization (CIEP 2002; Correljé and van der Linde 2006) and see how this might affect the political considerations of countries engaged in renewable energy markets. How will their preference for security of supply versus cost-efficiency change? Another choice was to assume that renewables would be sufficient to meet all demand. If not, we could assume a share of 60% or 80% renewables and the rest for fossil fuels. This way a hybrid system would be analyzed that is more likely to resemble a transition towards increasingly renewable energy systems. Finally, we could allow for more future technologies to be included; a large role for smart grids might be the first contender in this regard.

## 6. Conclusion

This paper started by asking what the potential political implications of the geographic and technical characteristics of renewable energy systems are, noting the differences in our understanding between the geopolitics of fossil fuels and renewable energy. Focus was on finding general principles that shape the nature of interstate renewable energy relations, leaving the impact for specific countries for follow-up research. To investigate, we proposed a thought experiment in which we imagined a purely renewable based energy system, keeping all else equal.

The geographical and technical characteristics of renewable energy systems highlight five key points. First, every area has access to at least some form of renewable energy, while some areas are better endowed with renewable sources than others, allowing them to generate energy more efficiently. Second, many renewable energy sources are intermittent in nature. Third, electricity generation from renewable sources may be distributed in character. Fourth, renewable energy production requires new rare materials. Fifth, electricity is the energy carrier for most renewables - especially those renewables with the most potential (solar and wind), implying stringent managerial conditions and increasing importance of efficient storage means.

These observations in turn have five major implications for our hypothetical renewable energy based markets. First, the widespread presence of renewable energy sources harbours the possibility of many producers, empowering consumer countries, and enables countries a make or buy decision. Second, the technical characteristics of electricity and accompanying grid management determine the market scope. Third, the possibility of investing in central and decentral renewable energy production and transportation capacity implies an additional strategic consideration within the make or buy context. Fourth, the fuelling of electric vehicles implies another major component the electricity grid should accommodate while biofuels will be transported as liquids. Finally, the variability of renewable energy sources stresses the importance of storage and balancing capacity for reliable operations and market stability.

Finally, the thought experiment shows that the potential geopolitical implications of a renewable energy based system depend greatly on which scenario materializes in a possible future, i.e. whether countries will prefer to import cheap renewable energy from abroad or utilize secure domestic sources. When the buy decision prevails, a centralized Continental scenario emerges resulting in a strategic focus on control over grid management, and in this way energy markets, in what we have dubbed 'grid communities'. The abundance of resources and electric nature of renewable energy markets suggest strategic leverage for large consumers, efficient producers and countries with the capacity to render cheap balancing and storage services to stabilize energy markets and handle intermittent renewables. Moreover, they suggest a regional or continental scope of the grid and that targeting single countries within the grid community becomes more difficult, though the effect of a deliberate action is acute and severe due to the nature of electricity as energy carrier. The Continental scenario essentially retains the same game between producer, transit, and consumer countries when compared to fossil fuels, though the abundance of resources and the electric nature of the grid reshape the play of the game. If the make decision prevails, a decentralized National scenario emerges where the presence of 'prosumer countries' lessens cross-border energy trade and in turn reduces geopolitical tensions to those related to clean generation technology imports. The National scenario hence implies a fundamental shift in the way the energy system is organized as compared to the fossil fuel situation. The most likely outcome, however, will be a mixed picture, in which countries will source a strategic share of their energy locally and exploit the efficiency gains international trade offers.

**References**


3Tier. 2010. All renewables. Retrieved online on 20 October 2013 at: http://www.3tier.com/static/ttcms/us/images/support/maps/3tier_all_renewables_poster.jpg

Agnew, J. 1998. *Geopolitics: Re-visioning World Politics*. London: Routledge.

Akiner, S. (ed.). 2004. *The Caspian: Politics, Energy and Security*. London: RoutledgeCurzon.

Aligica, P. D. (2005). Scenarios and the growth of knowledge: notes on the epistemic element in scenario building. *Technological Forecasting and Social Change*, *72*(7), 815-824.

Amineh, M.P. 2003. Globalisation, Geopolitics and Energy Security in Central Eurasia and the Caspian Region, CIEP Clingendael International Energy Programme.

Amineh, M.P. 2007. The Greater Middle East in Global Politics; Social Science Perspectives on the Changing Geography of the World Politics. Leiden/Boston: Brill.

Amineh, M.P. and Y. Guang (eds.) 2010. *The Globalization of Energy; China and the European Union*. Leiden/Boston: Brill.

Amineh, M.P. and Guang, Y. (eds.) 2012. S*ecure Oil and Alternative Energy; The Geopolitics of Energy Paths of China and the European Union*. Leiden/Boston: Brill.

Andrews-Speed, P. (ed.) 2008. *International Competition for Resources: The role of law, the state and markets*. Dundee: Dundee University Press.

Bloomberg New Energy Finance (BNEF). 2013a. BNEF Summit 2013 Keynote by BNEF CEO Michael Liebreich. Available online at: http://about.bnef.com/presentations/bnef-summit-2013-keynote-presentation-michael-liebreich-bnef-chief-executive/

Bloomberg New Energy Finance (BNEF). 2013b. Strong growth for renewables expected through to 2030. Available online at: http://about.bnef.com/press-releases/strong-growth-for-renewables-expected-through-to-2030/

Bosman, R. (2012) Germany's Energiewende: Redefining the rules of the energy game. Clingendael International Energy Programme Briefing Paper. The Hague, Netherlands.

Bosman, R. and Loorbach, D. 2015. What is the ideal oil price for the energy transition? Energy Post, 5th of January 2015.

Boyle, G. 2004. *Renewable Energy: Power for a sustainable future*. 2nd Edition. Oxford: Oxford University Press

Bridge, G., Bouzarovski, S., Bradshaw, M., and Eyre, N. 2013. Geographies of energy transition: Space, place and the low-carbon economy. Energy Policy, 53, 331-340.

Bruninx, K., Madzharov, D., Delarue, E., & D'haeseleer, W. 2013. Impact of the German nuclear phase-out on Europe's electricity generation—A comprehensive study. *Energy Policy*, 60, 251-261.

Buijs, B. and Sievers, H. 2011. *Critical Thinking about Critical Minerals: Assessing risks related to resource security*. Briefing Paper. Den Haag: Clingendael International Energy Programme.

Cagnin, C., Havas, A., & Saritas, O. (2013). Future-oriented technology analysis: Its potential to address disruptive transformations. *Technological Forecasting and Social Change*, *80*(3), 379-385.

Clingendael International Energy Programme (CIEP) 2002. *Study on Energy Supply Security and Geopolitics*. Report (TREN/C1-06-2002).

Constantini, V., Gracceva, F., Markandya, A. and Vicini, G. 2007. "Security of energy supply: Comparing scenarios from a European perspective", *Energy Policy*, Vol. 35, 210–226.

Correlje, A. and van der Linde, C. 2006. "Energy supply security and geopolitics: A European perspective", *Energy Policy*, Vol. 34, 532-543.

Cowan, K. and Daim T. 2009. "Comparative technological road-mapping for renewable energy", *Technology in Society*, Vol. 31, 333-341.

Criekemans, D. 2011. "The geopolitics of renewable energy: different or similar to the geopolitics of conventional energy?", paper presented at the ISA Annual Convention 2011, 16-19 March 2011, Montréal, Canada.

Dannreuther, R. 2010. International Relations Theories: Energy, Minerals and Conflict. POLINARES working paper n8.

De Ridder, M., S. Overheul and A. Poorterman. 2012. *Security Organizations and Access to Natural Resources*. The Hague Centre for Strategic Studies; POLINARES working paper n. 58.

De Ridder, M. 2013. *The Geopolitics of Mineral Resources for Renewable Energy Technologies*. The Hague Centre for Strategic Studies.

Desertec Foundation (d.u.). Desertec-EUMENA. Retrieved online on 20 October 2013 at: http://www.desertec.org/fileadmin/downloads/media/pictures/DESERTEC_EU-MENA_map.jpg

Deudney, D.H. 1989. *Global Geopolitics: A Reconstruction, Interpretation, and Evaluation of Materialist World Order Theories of the Late Nineteenth and Twentieth Centuries*. Princeton University Press (PhD thesis).

Dorian, J.P., Franssen, H.T. and Simbeck, D.R. 2006. "Global challenges in energy", *Energy Policy*, Vol. 34, No. 15 1984-1991.

Duan, H. B., Zhu, L., & Fan, Y. (2014). A cross-country study on the relationship between diffusion of wind and photovoltaic solar technology.*Technological Forecasting and Social Change*, *83*, 156-169.

Ecofys. 2008. *Global Potential of Renewable Energy Sources: a Literature Assessment*. Utrecht; Ecofys.

Economist. 2013. *The future of oil: Yesterday's fuel.* Retrieved online on 20 October 2013 at: http://www.economist.com/news/leaders/21582516-worlds-thirst-oil-could-be-nearing-peak-bad-news-producers-excellent

Egenhofer, C. and Legge, T. 2001. *Security of Supply: a question for policy or markets?* Brussels: CEPS.

Eisen, J.B. 2011. "New Energy Geopolitics?: China, Renewable Energy, and the Greentech Race", 86 Chi.-Kent L. Rev.9.

Electrical Power Research Institute (EPRI) (d.u.). Global distribution of tidal range. Retrieved online on 20 October 2013 at: http://www.wbdg.org/resources/oceanenergy.php

Energy Information Administration 2008. *International Energy Outlook 2008*. Washington.

Eom, J., Edmonds, J., Krey, V., Johnson, N., Longden, T., Luderer, G., ... & Van Vuuren, D. P. (2015). The impact of near-term climate policy choices on technology and emission transition pathways. *Technological Forecasting and Social Change*, *90*, 73-88.

European Commission (EC). 2001. *Green paper; Towards a European Strategy for the Security of Energy Supply*. Brussels: European Commission.

European Wind Energy Association (EWEA). 2015. *Offshore wind*. Retrieved online on 3 April 2015 at: http://www.ewea.org/policy-issues/offshore/

Fortes, P., Alvarenga, A., Seixas, J., & Rodrigues, S. (2015). Long-term energy scenarios: Bridging the gap between socio-economic storylines and energy modeling. *Technological Forecasting and Social Change*, *91*, 161-178.

Friedman, T.L. 2006. "The First Law of PetroPolitics", *Foreign Policy*, May/June 2006.

Geothermal Education Office (GEO). 2000. *Hottest known geothermal regions*. Retrieved online on 20 October 2013 at: http://geothermal.marin.org/GEOpresentation/sld015.htm

Gnansounou, E. 2008. "Assessing the energy vulnerability: Case of industrialised countries*"*. *Energy Policy*, Vol. 36, 3734–3744.

Gouvea, R., Kassicieh, S., & Montoya, M. J. R. (2013). Using the quadruple helix to design strategies for the green economy. *Technological Forecasting and Social Change*, *80*(2), 221-230.

Grin, J., Rotmans, J., Schot, J., Geels, F. and Loorbach, D. 2010. *Transitions to Sustainable Development – Part 1. New Directions in the Study of Long Term Transformative Change*. New York: Routledge.

Grübler, A., & Nakićenović, N. (1996). Decarbonizing the global energy system.*Technological Forecasting and Social Change*, *53*(1), 97-110.

Gullberg, A. T. (2013). The political feasibility of Norway as the 'green battery'of Europe. *Energy Policy* 57, 615-623.

Gullberg, A.T., Ohlhorst, D., and Schreurs, M. 2014. Towards a low carbon energy future–Renewable energy cooperation between Germany and Norway. *Renewable Energy* 68, 216-222.

Haberl, H., Erb, K., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W. and Fischer-Kowalski, M. 2007. "Quantifying and mapping the global human appropriation of net primary production in Earth's terrestrial ecosystem", Proceedings of the National Academy of Sciences of the USA. 104: 12942-12947.

Hacking, I. 1992. "Do Thought Experiments Have a Life of Their Own?", In A. Fine, M. Forbes, and K. Okruhlik, (eds.), *PSA 1992*, Vol. 2. East Lansing, MI: The Philosophy of Science Association, 302–310.

Hagerman, G. 2004. Wave power. Retrieved online on 20 October 2013 at: http://www.geni.org/globalenergy/library/renewable-energy-resources/ocean.shtml

Haggqvist, S. (1996) Thought experiments in philosophy. Almqvist & Wiksell International, Stockholm (1996)
Horowitz, T. & Massey, G. (1991) (Eds.), Thought experiments in science and philosophy, Rowman & Littlefield Publishers, Bollman Place, Savage, MD

Haug, M. 2011. "Clean energy and international oil", Oxford Review of Economic Policy 27(1).

Hoogwijk, M.M. 2004. *On the Global and Regional Potential of Renewable Energy Sources*. PhD Thesis. Utrecht, 12 March 2004.

International Energy Agency (IEA) 2004. *World Energy Outlook 2004*. Paris: OECD.

International Energy Agency (IEA) 2010. *World Energy Outlook 2010*. Paris: OECD.

International Energy Agency (IEA) 2014. *World Energy Outlook 2014*. Paris: OECD

International Energy Agency (IEA) 2011. *Renewable Energy; Markets and Prospects by Region*. Paris; OECD.

Johnson, N., Krey, V., McCollum, D. L., Rao, S., Riahi, K., & Rogelj, J. (2015). Stranded on a low-carbon planet: Implications of climate policy for the phase-out of coal-based power plants. *Technological Forecasting and Social Change*,*90*, 89-102.

Kajikawa, Y., Yoshikawa, J., Takeda, Y., & Matsushima, K. (2008). Tracking emerging technologies in energy research: Toward a roadmap for sustainable energy. *Technological Forecasting and Social Change*, *75*(6), 771-782.

Klare, Michael. 2008. *Rising Powers, Shrinking Planet: The New Geopolitics of Energy*. New York: Henry Holt and Company.

Lesage, D., T. van de Graaf and K. Westphal. 2010. *Global Energy Governance in a Multipolar World.* Ashgate.

Loock, M., Kuenzel, K. and Wüstenhagen, R. 2010. IMPROSUME - *The Impact of Prosumers in a Smart Grid based Energy Market.* Retrieved online on 20 October 2013 at: http://www.alexandria.unisg.ch/Projets/70172

Loorbach, D. and Verbong, G. 2013. "Conclusion: Is Governance of the Energy Transition a Reality, an Illusion or Necessity?", In G. Verbong, and D. Loorbach (eds.), *Governing the energy transition: Reality, illusion or necessity?* London: Routledge.

Mackinder, H.J. 1904. "The Geographical Pivot of History", Geographical Journal, no. 23: 421-42.

Mahan, A.T. 1890. *The Influence of Sea Power upon History, 1660-1783*. Boston, MA: Little, Brown.

Mankiw, N.G. 2004. Principles of Economics. Thomson-South-Western.

Meade, N., & Islam, T. (2015). Modelling European usage of renewable energy technologies for electricity generation. *Technological Forecasting and Social Change*, *90*, 497-509.

National Renewable Energy Laboratory (NREL). 2008. *Global Renewable Energy Development*. Washington.

Nicolosi, M. (2010). Wind power integration and power system flexibility–An empirical analysis of extreme events in Germany under the new negative price regime. *Energy Policy*, *38*(11), 7257-7268.

Nuttall, W. J., & Manz, D. L. (2008). A new energy security paradigm for the twenty-first century. *Technological forecasting and social change*, *75*(8), 1247-1259.

Ölz, S., R. Sims and N. Kirchner. 2007. *Contribution of renewables to energy security*. IEA Information Paper, www.iea.org.

Oxford dictionary. 2012. Definition of geopolitics retrieved on 31-01-2012 at http://oxforddictionaries.com/definition/geopolitics.

Planbureau voor de Leefomgeving (PBL) en Energieonderzoekscentrum Nederland (ECN). 2011. *Naar een schone economie in 2050: routes verkend.* Den Haag.

Percebois, J. 2003. *Vulnerability and its management*. OECD report 2003, 51-62.

Perez et al. 2009. *A Fundamental Look at Reserves for the Planet*. Draft for publication in the IEA/SHC Solar update.

Pérez-Arriaga, I.J. (2013). *Regulation of the Power Sector*. Springer London.

Ratzel, F. 1897. *Politische Geographie*. München: Oldenbourg.

Riahi, K., Kriegler, E., Johnson, N., Bertram, C., Den Elzen, M., Eom, J. and Edenhofer, O. 2013. "Locked into Copenhagen pledges—Implications of short-term emission targets for the cost and feasibility of long-term climate goals", *Technological Forecasting and Social Change*, article in press.

Renewable Energy Policy Network for the 21st Century (REN21). 2012. *Renewables 2012 Global Status Report*. Paris. Available online: www.ren21.net

Rifkin, J. 2002. *The Hydrogen Economy: The Creation of the Worldwide Energy Web and the Redistribution of Power on Earth*. New York: Penguin Putnam.

Schaeffer, M., Gohar, L., Kriegler, E., Lowe, J., Riahi, K., & van Vuuren, D. (2015). Mid-and long-term climate projections for fragmented and delayed-action scenarios. *Technological Forecasting and Social Change*, *90*, 257-268.

Scholten, D.J. 2013. "The Reliability of Energy Infrastructures; the Organizational Requirements of Technical Operations", Competition and Regulation in Network Industries, special issue, Vol. 14, No. 2, 173-205.

Scholten, D.J., Sattich, T. and I.M. Ydersbond. 2014. "Power Struggles: the Geopolitical Implications of EU Energy Policy", Energi og Klima, 27 November 2014, at: http://energiogklima.no/kommentar-analyse/power-struggles-the-geopolitical-implications-of-eu-energy-policy/

Schwanitz, V. J., Longden, T., Knopf, B., & Capros, P. (2015). The implications of initiating immediate climate change mitigation—A potential for co-benefits?. *Technological Forecasting and Social Change*, *90*, 166-177.

Schleicher-Tappeser, R. 2012. How renewables will change electricity markets in the next five years. *Energy policy*, *48*, 64-75.

Seidler, C. 2012. *Renewable Energy Ambitions: Norway Wants to Become Europe's Battery*. Retrieved online on 20 October 2013 at: http://www.spiegel.de/international/europe/norway-wants-to-offer-hydroelectric-resources-to-europe-a-835037.html

Sharman, 2009. *Wind Energy: The case of Denmark*. Copenhagen: Center for Politiske Studier (CEPOS).

Smith Stegen, K. 2014. "The Risks and Rewards of Renewable Energies" in *New Realities: Energy Security in the 2010s and Implications for the US Military*, Strategic Studies Institute.

Smith Stegen, K., Gilmartin, P., and Carlucci, J. 2012. Terrorists versus the Sun: Desertec in North Africa as a case study for assessing risks to energy infrastructure. *Risk management*, 14(1), 3-26.

Stoeglehner, G., N. Niemetz and K-H. Kettl. 2011. "Spatial dimensions of sustainable energy systems: new visions for integrated spatial and energy planning", *Energy, Sustainability and Society* 1(2).

Trend research. 2011. *Anteile einzelner Marktakteure an Erneuerbare Energien-anlagen in Deutschland*. Bremen: Trend Research

Tuathail, G. and S. Dalby 1998. *Rethinking Geopolitics*. London, Routledge.

Umbach, F. 2010. "Global energy security and the implications for the EU", Energy Policy 38(3), 1229-1240.

Van de Graaf, T. 2013. "Fragmentation in Global Energy Governance: Explaining the Creation of IRENA", Global Environmental Politics, Vol. 13, No. 3, 14-33.

Van Gendt, C., P.A.G. van Bergeijk and H.J. Heuten. 2004. Groningen: Wolters-Noordhoff.

Verbong, G. and F. Geels. 2007. "The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004)", Energy Policy 35, 1025–1037.

Verbong, G. and Geels, F. 2010. "Exploring sustainability transitions in the electricity sector with socio-technical pathways", Technological Forecasting and Social Change, 77(8), 1214-1221.

Walton, J.S. (2008) *Scanning beyond the horizon: exploring the ontological and epistemological basis for scenario planning.* Adv. Dev. Hum. Resour. 10, 147–165

Weterings, R., Korteweg, R. and de Ridder, M. 2010 *Rare earth elements and strategic mineral policy*. TNO and HCSS. Retrieved online on 20 October 2013 at: http://www.hcss.nl/reports/rare-earth-elements-and-strategic-mineral-policy/5/

World Energy Council 2008. *Europe's vulnerability to Energy Crisis, executive summary*. Retrieved online on 20 October 2013 at: http://www.worldenergy.org/publications/2008/europes-vulnerability-to-energy-crisis.

World Wildlife Fund (WWF) and Ecofys (2011). *The Energy Report*. Available online: http://wwf.panda.org/what_we_do/footprint/climate_carbon_energy/energy_solutions/renewable_energy/sustainable_energy_report/

Figure 1. Reasoning towards the geopolitics of renewables

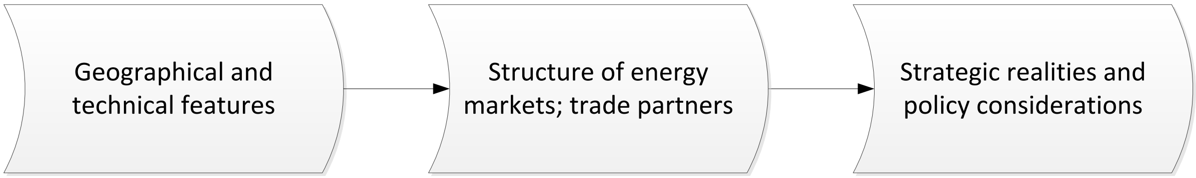
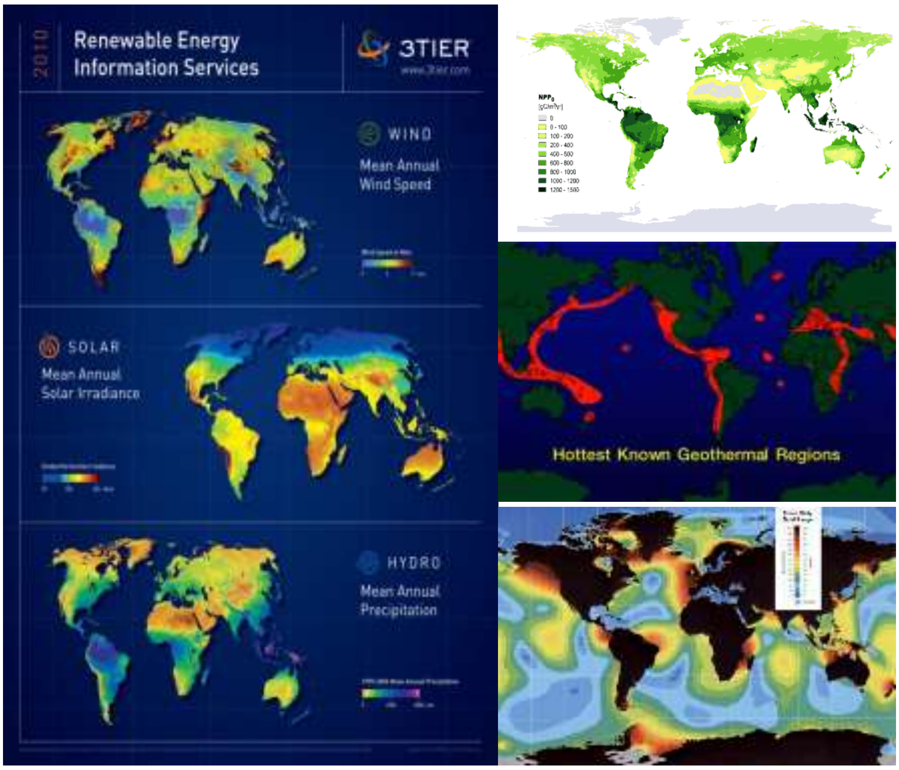


Figure 2. Renewable energy potential of countries and regions




From left to right and up to down: global wind, biomass, solar, geothermal, hydro, and tidal energy potential. Source: solar, wind, and hydro: 3Tier 2010; biomass: Haberl et al. 2007; geothermal: GEO 2000; tidal: EPRI d.u.