# The Geopolitics of Renewable Energy;
# a Mere Shift or Landslide in Energy Dependencies?

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**Abstract**

Renewable energy sources are often hailed as the panacea for a plethora of challenges associated with the use of fossil fuels. Partly for good reasons; while the utilization of renewables diminishes energy scarcity and lowers various kinds of pollution, their potential to address energy related geopolitical tensions among producer, consumer, and transit countries remains to be seen. This paper aims to provide some food for thought by exploring the potential political implications of the geographical and technical characteristics of renewable energy systems. To this end we conduct a thought experiment in which we exchange the existing fossil fuel based energy systems for a purely renewable based energy system where electricity is the energy carrier, keeping all else equal. We find that two major implications for renewable energy based markets stand out: countries face a make or buy decision, i.e. they have a choice to produce or import (side-stepping the scarcity issues of fossil fuels) and the nature of renewable electricity transport implies a much more physically integrated infrastructure whose load requires on the spot management, whose cut-offs or blackouts may affect all parties in the network immediately, and which knows difficulties in storing energy (fossil fuels tend to know less stringent operational conditions). Two scenarios are explored to illustrate which strategic concerns for producer, consumer, and transit countries these implications lead to: Continental (following a buy decision and more centralized network) and National (following a make decision and a more decentralized network). In the end, three observations stand out compared to 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* transit countries. Finally, for most countries the possibility exists to become a 'prosumer' country, thereby greatly reducing any form of geopolitical concern.

Keywords: geopolitics, renewable energy systems, thought experiment.

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## 1. Introduction

Renewable energy sources are often hailed as the panacea for a plethora of challenges associated with the use of fossil fuels. Partly for good reasons; while a large-scale utilization of renewables diminishes energy scarcity and lowers various kinds of pollution, their potential to address energy related geopolitical tensions among producer, consumer, and transit countries remains to be seen. Whereas the political implications of the geographic and technological specificities of fossil fuels are well known, there exists a great deal of uncertainty regarding the economic and political implications of renewable energy systems.

First, renewable energy sources are not 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. This allows for the emergence of new energy producers and has the potential to fundamentally rearrange interstate energy trade patterns. Statesmen have to ask themselves who tomorrow's import, export, and transit partners are. What relations will continue and where might new dependencies arise?

Second, because renewable energy can be more efficiently generated at certain locations than others, some countries are better endowed to become cheap solar, wind, hydro etc. energy producers. This leaves less fortunate countries with a difficult choice: should they produce renewable energy themselves (good for supply security) or should they buy it elsewhere (good for affordability)? Hence strategic make or buy decisions replace the old dilemma of getting access to foreign fossil fuel deposits.

Third, electricity is the energy carrier for most renewables - and especially those renewables with the most potential (solar and wind). Electricity has distinct characteristics compared to coal, oil, and gas that represent new challenges. Electricity transport requires a physically interconnected grid and the instantaneous balancing of demand and supply. Moreover, electricity grids miss efficient and sufficient storage capacity besides pumped hydro storage and require on the spot emergency response, as accidents may cascade from one section of the grid to another in a matter of seconds. What are the geopolitical consequences of electricity as the dominant energy carrier compared to oil and gas? Will countries with unique storage means such as alpine lakes be the new hubs of future continental electricity markets?

Fourth, part of renewable energy production is of an intermittent nature (with predictability also varying) and is suited for more distributed or decentralized electricity generation. Issues of integrating new (decentral) renewable production technologies into existing grids and managing the intermittency of power generation in cross-border networks may require new modes of operating these systems. How will incumbent energy companies respond and what role may 'smart' technologies imply for control? How will damages in one area incurred by fluctuating power in another area be resolved? Finally, some generation materials are scarce resources as well. Dependencies by renewable producers upon countries possessing such materials also need to be considered when assessing energy markets.

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 by providing a 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. Thought experiments (Hacking, 1992) comprise a technique that is often used in philosophy to discuss a hypothetical case and its possible consequences in order to provoke the imagination of the reader.[3] 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.[4] Put differently, we imagine an energy system that is purely based on renewable sources and where electricity is the dominant energy carrier. We then ask where sources for geopolitical tensions would lie (as opposed to those due to fossil fuels).

Carrying out this thought experiment is relevant for both science and policy. On the one hand it spurs us to further develop our understanding of the relationship between the geographic and technical characteristics of energy sources, production, and transport, market formation, and countries' strategic realities and policy responses. On the other hand, 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 by detailing a structure for our thought experiment in the next section. Afterwards, section 3 utilizes this framework to analyze the contemporary geopolitics of fossil fuels in order to provide some reference material for the thought experiment on the geopolitics of renewables, which will be the focus of section 4. We conclude with a brief comparison between the geopolitical challenges of fossil fuels and renewables.

## 2. A Structured Thought Experiment on Energy Geopolitics

[3] The approach of a thought experiment is preferred over that of working with possible future scenarios of renewable energy in, for example, 2050. Describing possible futures is always 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). Of course, a thought experiment also should set clear boundaries to avoid going in all directions, but we may focus solely on the link between geographic and technical features of renewables, not being hindered by political-economic and other considerations.

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

Geopolitics refers to "politics, especially international relations, as influenced by geographical factors", usually through politicians that act upon geographic considerations (Oxford online dictionary 2012). The field of geopolitics, belonging to both Political Geography and International Relations, "investigates the interaction between [political actors] and their surrounding territoriality (in its three dimensions: physical-geographical, human-geographical and spatial" (Criekemans 2011, 4). Considering the physical-geographic nature of energy sources and the economic and strategic importance of energy for the wealth and power of states, scholars of geopolitics have always had a great interest in energy security questions. All the more 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 renewable energy sources" (Criekemans 2011, 4).

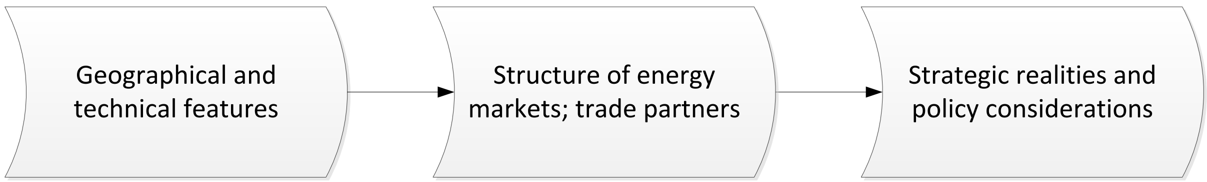
The great pitfall of a thought experiment on the geopolitics of renewables is that the discussion can go in all directions, especially the ones as exploratory in nature as the one of this article. What considerations to take into account; which steps to undertake to move from the geographical factors of renewable energy sources to their geopolitical implications in a structured and reproducible fashion; 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 (see also Figure 1 below).

We start of 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. We focus on the geographical and technical characteristics of renewable energy systems as these are currently the clearest features of renewables and can be considered key factors in shaping the formation of energy systems and markets. The 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. In addition, as we will see in section 3, the location and accessibility of major oil, gas, and coal fields with respect to major demand centers and infrastructure technologies has played an important role in shaping the current fossil fuel based energy system. 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. Some time ago, the close relationship between accessibility of energy sources and the technological possibilities of extracting and capturing energy has led Deudney (1989) to refer to this relationship as the 'geotechnical ensemble'. We only add here the notion of infrastructure to bring the energy to markets.

This overview then serves as a point of departure for interpreting how future renewable energy markets may look like in terms of locality of trade partners and market structure. The former refers to the local/national, regional/continental, or global size of markets. The latter refers to markets structure in terms of the amount of producers and consumers (competitive, oligopolistic, or monopolistic etc.) and the nature of the good (homogenous, heterogenous); 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, when there are many producers, consumers, and transit possibilities, the energy market represents that of 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 final step then zooms into the strategic realities of producer, transit, and consumer countries or regions within the market structure identified in step 2. We assume here that consumer countries are concerned about security of supply and desire stable and low 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 (such as providing land for the transport lines) and to create some political leverage for themselves (sitting at the table). We then ask what policy options these countries or regions have at their disposal to pursue these interests within the market structure identified in the second step. What are the dependencies and vulnerabilities of the strategic realities these countries face? What considerations will inform countries' policy response? Do they lead to more or less cooperative or conflictuous interstate energy relations?

Figure 1. Reasoning towards the geopolitics of renewables




There are some important limitations to note to this approach. 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 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 is made here to keep the discussion focused on the political implications of the geographical and technical nature of renewables as compared to those of fossil fuels, keeping all other things equal. 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 free trade attitudes (like in the Shell or EU scenarios (CIEP 2002)) and see how this might affect the political considerations of countries engaged in renewable energy markets.

## 3. The Geopolitics of Fossil Fuels; a Point of Reference

The economic and strategic importance of energy sources such as coal, oil, and natural gas for the wealth and power of states can hardly be overstated. Ever since the Industrial Revolution the particular constellation of the geographic location of 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. Currently, energy security[5] challenges and environmental concerns are putting pressure on the energy relations between countries.

Let us now elaborate the contemporary geographical characteristics of fossil fuel resources and accompanying infrastructure technologies and their implications for the geopolitical situation of fossil fuels (despite their diversity) at the hand of the analytical steps provided in the previous section. The resulting overview not only illustrates our approach but also should provide us with a convenient point of reference for a comparison with the thought experiment on the geopolitics of a renewable energy system.

### 3.1 The Geo-technical Ensemble of Fossil Fuels

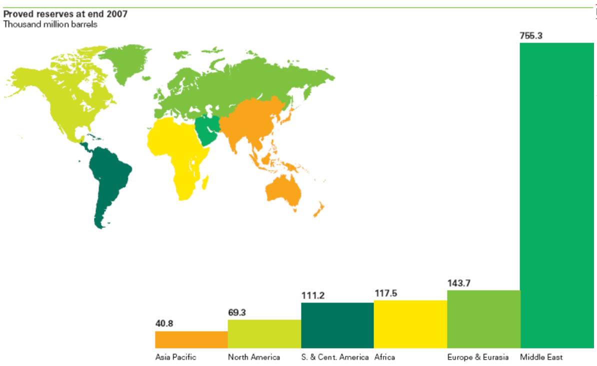
Fossil fuel resources are strongly geographically bound and the degree of concentration varies according to fuel type and source. Oil is highly concentrated in the Middle East. On the first of January 2008, the total global stock of oil reserves was estimated at 1,332 billion barrels (bbl) (EIA 2008). Of these, around 70% is located in OPEC countries and just five countries (Saudi Arabia, Iraq, the UAE, Kuwait, and Iran) hold about 55% of global proven oil reserves (Amineh and Guang 2010, 4). Only the countries comprising the former Soviet Union can come anywhere near these numbers. Natural gas, in contrast, is slightly less concentrated. "Russia (including the Caspian Sea region) and the Middle East each represent about 1/3 and 2/5 of proven global reserves respectively. Moreover, Russia and Iran hold about 42.5% of the global gas reserves as of 2008 (January 1, 2008)" (Amineh and Guang 2010, 5; EIA 2008). The Middle Eastern gas potential is significant, but remain largely untapped, mainly due to the costs of bringing them to market. Coal, finally, is far less concentrated and more abundant. North America, Europe and the

[5] Energy security may be defined as "an uninterruptible supply of energy, in terms of quantities required to meet demand at affordable prices" (World Energy Council 2008, 1).

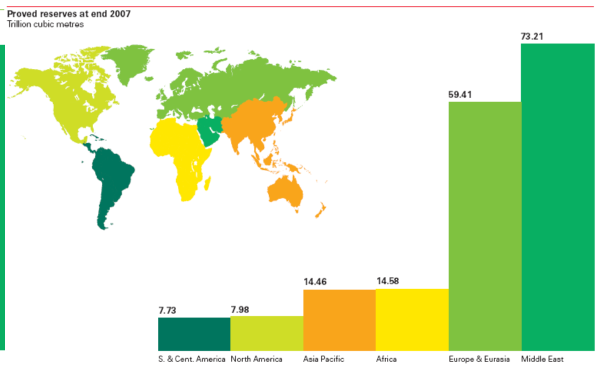
former Soviet Union, and Asia and Australia each hold about 30% of global reserves. While coal has fallen from grace for its polluting nature in the West over the last decades, its abundance and low costs still make it an interesting alternative, see also Figure 2.

Future outlooks for fossil fuels are dominated by their finite nature: predictions of peak oil (c.f. Economist 2013) and increasing fossil fuel scarcity sketch an image that somewhere in the latter half of this century the world will run out of oil and gas reserves, not counting newer findings such as shale gas, tar sands, or deep sea oil. Coal might last longer, but is in the end also finite. Apart from dwindling reserves because of consumption, stocks are considered to diminish also because of a lack of market-efficient access to them, inadequate productive capacity and pipeline infrastructure, and their inefficient use in appliances (Amineh and Guang 2010, 6). One consequence of this is that fossil fuels in the long term are expected to originate in fewer countries than today, as some sources will run out. Currently, however, this inevitable concentration is hardly found due to the development of new oil and gas in Canada, Brazil, and US.

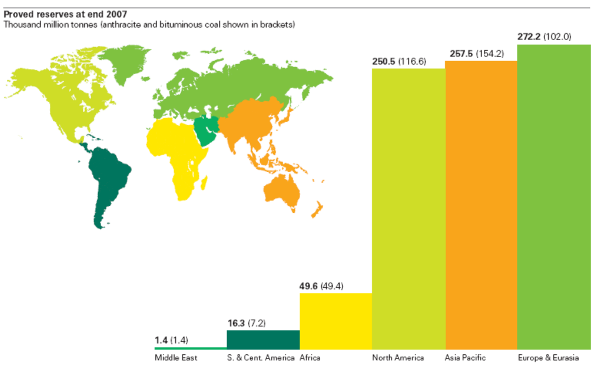
Figure 2. Global Fossil Fuel Reserves and Demand



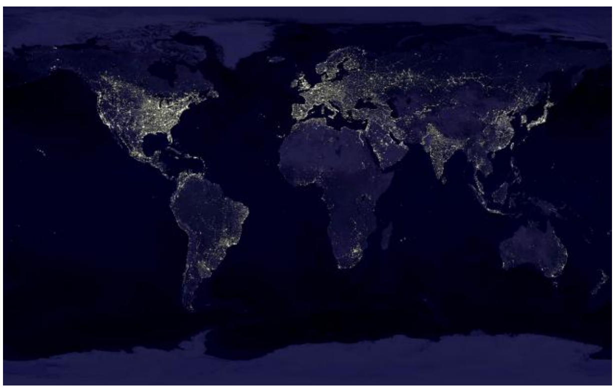

Oil reserves




Gas reserves




Coal reserves



Energy demand

Sources: BP Statistical Review of World Energy 2008 and http://www.masterresource.org.

From a demand perspective, a combination of "population growth, a rising per capita income resulting in higher levels of consumption, and technological change that renders fossil fuels more essential for the production of wealth and power", is currently increasing the already high global demand for fossil fuels (Amineh and Guang 2010, 6). The world's major consumer regions are traditionally the OECD countries located in North America, Europe, Japan, and Australia (British Petroleum 2013a). See Figure 2 above for a somewhat alternative indicator. However, the rapidly developing BRIC countries (Brazil, Russia, India, and China) are expected to lead to a strong increase in global energy demand (Dorian et al. 2006, British Petroleum 2013b). The IEA (WEO 2010) estimates that global primary energy demand is expected to increase by 36% by 2035 from the 2008 level, while the already high levels of per capita energy use in OECD countries are expected to remain largely the same. An important aspect in this regard is the also rather inelastic nature of energy demand. Modern economies run on fossil fuels and there is currently no alternative. Moreover, this situation is expected to remain largely the same: by 2030 fossil fuels are still expected to represent around 80% of world primary demand (IEA 2010, 80). To meet rising consumption levels, increasing renewable energy production capacity and expanding fossil fuel production are both needed. Needless to say; this puts pressure on the dwindling reserves and the productive capacity of producer countries.

Elaborate infrastructures over sea and land (tankers, pipelines, rail, road) connect these user centers with coal, oil, and natural gas producing countries and regions via hubs and transfer facilities across the globe. An important characteristic of these solid, liquid, and gaseous 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. The production and refinement of fossil fuels occurs typically in central, high capacity facilities near oil and gas fields or coal mines or in harbors closer to demand centers after oversea shipping.

### 3.2 Energy Market Structure of Fossil Fuels

The geographical and technical characteristics of fossil fuel based energy systems show five things. First, fossil fuel resources are finite (and dwindling fast). Second, oil, coal, and gas reserves are geographically bound and concentrated in certain areas, mostly the Gulf, Russia, and the Caspian Sea region. Third, consumption levels are rising and the main user centers are not those countries that possess most of the resources (perhaps with the exception of coal and shale gas). Fourth, a broad variety of means exist to transport coal, oil, and gas as solids, liquids, and gases across local, regional, and global distances; the ease with which they can be stored is also instrumental in this regard. Fifth, production and refinement takes place in large, centralized facilities and generate a constant output of energy.

These observations have two major implications for fossil fuel based markets. First, there is a clear separation between countries that possess and that do not possess fossil fuel deposits and between those that are net-importers or net-exporters. Against the background of rising consumption, diminishing reserves, and geographic concentration of fossil fuel deposits, the world's consumer areas are increasingly dependent on a few producer countries for their supply. This holds especially for oil and gas but much less so for coal. In this setting, producers hold considerable market power, the more so because fossil fuels are crucial to the well-functioning of modern economies and because there is no alternative for those fossil fuel producers in the long run (except renewables). Put differently, fossil fuel markets are increasingly becoming seller's markets of an oligopolistic nature. Combined with generally rising and increasingly volatile energy prices due to peak oil expectations, unstable financial markets, and political tensions and religious fundamentalism in oil and gas producing countries and regions, energy supply security is not a given. In turn, consumer countries will perceive fossil fuels as strategic goods rather than a 'mere' commodity (Amineh and Guang 2010, 2012) and assign great significance to getting access to scarce foreign fossil fuel deposits, a challenge that is hardly lessened by the possibility to hold strategic buffers for several months. Global energy relations may hence be expected to increasingly politicize.[6]

Second, the absence of a significant loss of energy content during the transportation of coal, oil, and natural gas from producers to consumers, possibilities for easy storage, and the compartmentalized nature of the physical infrastructure of fossil fuels poses hardly any obstacle to long-distance energy trade. Of course, because coal is relatively widespread, there is the possibility to save on shipping by buying it nearby. Moreover, natural gas pipelines involve relatively high capital expenditures and require operational management to control pressures; there might be cheaper options if the distance gets too great. The combination of the locations of supply and demand and the infrastructural options have created a truly global oil market, regional gas markets (divided into Asia's LNG market, the Russian-European market, and the North American market), and more national/regional coal markets. The downside of fossil fuel transport lies with the fact that it is open to geostrategic action. There are plenty of bottlenecks on open seas such as the Malacca Straight or Suez Canal and on land in the form of lack of alternative pipeline routes. Such corridors allow a country to target sections of the infrastructure and certain consumer

[6] According to Amineh and Guang (2010, 8) "[i]nternational conflicts over the control of global oil and gas become more likely as consumption and imports rise, availability of oil and gas decreases, prices of these commodities increase, and environmental conditions deteriorate."

countries specifically, not hurting other consumers and producers active in the same market.[7] Of course, such bottlenecks are also vulnerable to terrorist attacks.

### 3.3 Strategic Considerations of Fossil Fuels

In today's age of increasing scarcity, "producer, transit and consumer countries are positioning themselves geopolitically so as to safeguard their energy security" (Criekemans 2011, 4). Most attention has gone to consumer countries' security of supply concerns and possible policy responses. This is not surprising: in a setting of increasing oil and gas scarcity; they are the ones most challenged. The main question is how to get access to oil and gas resources? The policy framework, with which security of supply[8] 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). To the former, "[s]ecurity of supply does not seek to maximize energy self-sufficiency or to minimize dependence, but aims to reduce the risks linked to such dependence" (Egenhofer and Legge 2001 citing EC 2001, 2). "Security of supply [hence] becomes a cost-effective risk-management strategy of governments, firms and consumers" to ensure against supply risks (Egenhofer and Legge, 2001). The latter, in contrast, point out that while they recognize the market as the "most economically effective and efficient for [energy supply security], all consumer regions […] promote intervention to reduce their economies' exposure", i.e. their dependence and vulnerability (Gnansounou 2008, 3735).[9] The wake-up call in this regard seems to have been the Ukrainian gas crises of 2006 and 2007, though the re-nationalization wave of energy companies in producing countries, such as Russia and Venezuela, throughout the previous decade should have already hinted at the return of bilateral deals over more market based approaches. Either way, consumer states have responded with policies of diversification of source, origin, and transport network and holding strategic reserves as short-term means, policies promoting energy conservation and the use of demand side management in the medium-term, and policies to develop new energy technologies and renewable energy sources and carriers as a long-term solution to

[7] Amineh and Guang (2010, 6) refer to this situation as structural scarcity, i.e. "a situation in which there is a supply-induced scarcity caused by the deliberate action of a major power or non-state actors, such as transnational oil companies." For example, a major power may opt to hinder the transportation of energy between two countries, the global community may pose international sanctions on a producer, or countries may form cartels like OPEC.

[8] 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).

[9] For consumer states, the concept of energy security is heavily linked to the issues of dependence and vulnerability. Dependency refers to "the share of national energy consumption which is produced domestically vis-à-vis energy imports." 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).

ensure energy security. In addition, they rely on trusted transnational oil companies (TNOCs) to deliver oil and gas. Besides being important suppliers of finance, technical know-how, and operational experience, TNOCs are often associated with specific countries and may form an extension of national interests.

The current focus on energy consumers poses the risk of neglecting the issues of producers or transit states. These countries are equally important as they make up the other side of the energy market. Energy producers, while often seemingly in charge of global energy markets, are also generally rather dependent on oil and gas revenues to fuel their economy and fill state budgets, and try to avoid the challenges associated with the Dutch disease and falling victim to the resource curse. Generally, producers aim to diversify demand and supply routes to ensure a save arrival of their energy to consumers and limiting their dependence on a few consumer and transit states on the short-term, keep prices high to earn as much revenue as possible from energy sales and use these energy revenues to diversify and develop their economy (while handling inflationary pressures and rentierism by the political-industrial-military elite) on the medium-term, and develop long-term alternatives to the oil, gas, or coal they are exporting so as to maintain their position of energy exporter in the future. Energy transit countries, finally, seem interested in maintaining their position as energy corridors in the complex game that is pipeline politics, giving them international leverage on the political scene and a fair rate for the services they provide (also to maintain the network). Some may even manifest themselves as energy hubs in the global energy market. Policies to achieve such ambitions include offering favourable conditions for energy companies to invest or convenient locations for refinement, storage, and transfer stations.

The combination of these strategies continuously reshapes existing patterns of energy-related cooperation and conflict, of which three constants stand out. First, there are strong interests in both the ability to buy and sell energy which may lead to a variety of alliances: while consumers may compete for (access to) resources, they also share interests in keeping energy prices low; while producers compete for markets, they share interests in keeping prices high; and while consumers and producers rely on each other for energy and revenues respectively, they try to minimize their mutual dependence and vulnerability. Second, the policy responses of individual countries cannot be understood in isolation. The risk here lies in a race towards distrust. A strategy of diversification of suppliers or consumers carries the risk that the other party does the same, creating a costly 'energy arms race' into uncertainty and untrustworthy reputations. In this light, while diversification of supply or demand might seem logical from a consumers' and producers' perspective, embracing mutual dependence (while instinctively risky) may well yield more energy security and revenue security in the long run. Finally, though, the geographical distribution of oil and gas resources and their increasing scarcity favours producers over consumers. Energy security strategies of consumers may soften the adverse effects of this situation, but will not be able to alter this reality until cheap, large-scale renewable energy comes about. In the end, this setting seems to imply a struggle for resources and increasing geopolitical tension.

## 4. The Geopolitics of Renewable Energy; a thought experiment

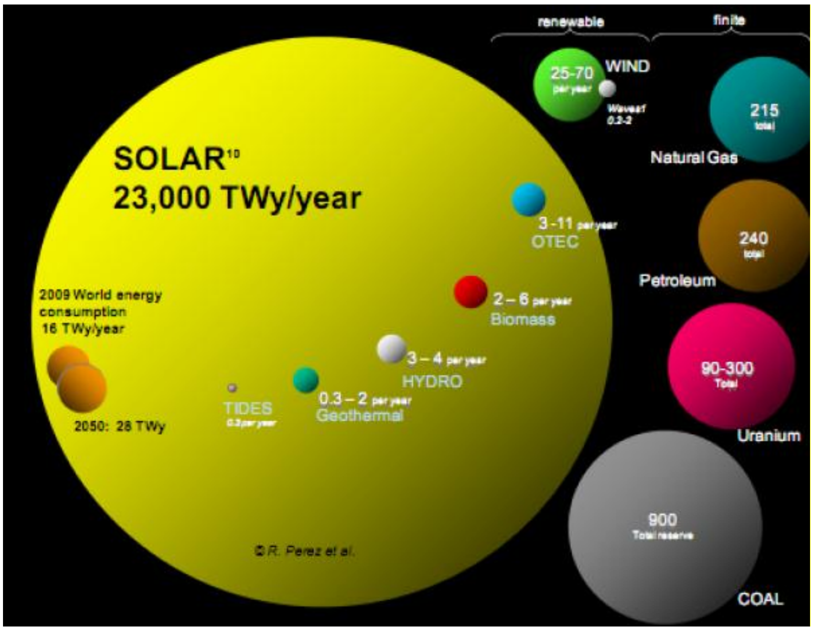
Increasing fossil fuel scarcity and deteriorating environmental conditions call for a transition towards a more sustainable energy system (Dorian et al. 2006; Rifkin 2002; Loorbach and Verbong 2012). Renewable energy sources and supporting technologies are to be the cornerstone of such a future. According to the International Energy Agency (IEA) "[r]enewable energy is energy that is derived from natural processes that are replenished constantly [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).[10]

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. In 2011, the share of all renewables in global final energy consumption stood at 16.7% (REN21 2012). Yet without large-scale hydropower and traditional biomass, renewables like wind, solar, small hydro, modern biomass, geothermal, and biofuels only accounted for a mere 4.9% (REN21 2012). In contrast to this low figure, however, stands that renewable energy based electricity power stations (excluding hydropower) have more than tripled at a global scale between 2000 and 2008 according to the American National Renewable Energy Laboratory (NREL 2008, 43-45). Moreover, an analysis of the Bloomberg New Energy Finance (BNEF) shows that global investments in clean energy have risen from $54 billion in 2004 to $269 billion in 2012 (BNEF 2013a). In addition, this growth is expected to continue in the future. The costs of renewable electricity generation vis-à-vis fossil fuel based generation are falling, making renewable energy sources more competitive (Cowan and Daim 2009, 337). According to BNEF "renewables will account for between 69% and 74% of new power capacity added by 2030" (BNEF 2013b). The growing role of renewables is also demonstrated by the founding of the International Renewable Energy Agency (IRENA) in 2009, an intergovernmental organization tasked with promoting worldwide renewable energy adoption.

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). Figure 3 shows the (untapped) potential of various renewable energy sources as compared to fossil fuel reserves (in yearly terawatts / energy yield). Especially solar and wind have large untapped potential.

[10] The defining aspect of renewables is that they replenish themselves in a natural way. Renewable energy sources hence stand in contrast to conventional, exhaustive energy sources such as coal, oil, and natural gas. The concept 'renewable' should not be confused with sustainable. "Sustainable development can in general be described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Criekemans 2011, 7; World Commission on Environment and Development (Brundtland Commission) 1987). Most renewable sources are sustainable, but this is not always the case.

Figure 3. Primary energy provided or potential yearly by renewable sources compared to total reserves of fossil and uranium fuels




Source: Perez et al., d.u.

Let us now explore what the geographic and technical characteristics of renewable energy systems might imply for energy relations among states and the considerations statesmen and decision makers have to keep in mind when thinking about the geopolitics of renewables by walking through the same steps that guided our discussion on fossil fuels. To investigate this we now start the thought experiment in which we imagine a purely[11] renewable based energy system to replace the current fossil fuel based system. Please note that this is not necessarily a possible future, but an alternate reality. One implication of this choice is that we end up with electricity being the dominant energy carrier, allowing us to ignore possibilities for biogas for the sake of the argument. Not only are most renewable sources intended to be converted into and transported and used as electricity, but also especially those renewables with the most potential (solar and wind as we saw in Figure 3). Further, we assume today's technology and that renewables would be sufficient to meet all demand. This way we can more clearly contrast the potential political implications of a renewables based energy system to those of fossil fuels based systems. Finally, we assume today's political-economic context and socio-cultural values, though we treat them as the exogenous environment

[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.
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.

within which the renewable energy system is placed and which does not affect our reasoning (see also section 2).

### 4.1 The Geo-technical Ensemble of Renewables

Renewable energy sources are not as geographically limited as fossil fuels. Every country has access to at least some form of renewable energy, be it wind, solar, biomass, hydro, or geothermal. 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 6). Let us briefly discuss the different sources and their optimal generation locations.

Solar radiation can be captured as heat by solar thermal collectors, both in low temperatures which can be used for heating air and water and in high temperatures which can be used as input for industrial processes and for electricity production. The latter is generally referred to as concentrated solar power (CSP), which needs direct insolation, and therefore preferred spots are sunny and arid areas such as deserts. Solar radiation can also be turned into energy with the help of photovoltaic (PV) cells. This technology also works with indirect insolation and is therefore also fit for areas with more cloud cover (Boyle 2004).

Wind energy is usually captured with wind turbines, turning the kinetic energy of the wind into electricity. However, also new concepts, using kites for example, are being developed. Wind is currently developed both onshore and offshore, North Sea projects being a prominent example of the latter. Primary wind locations are further away from the equator and closer to coastal areas.

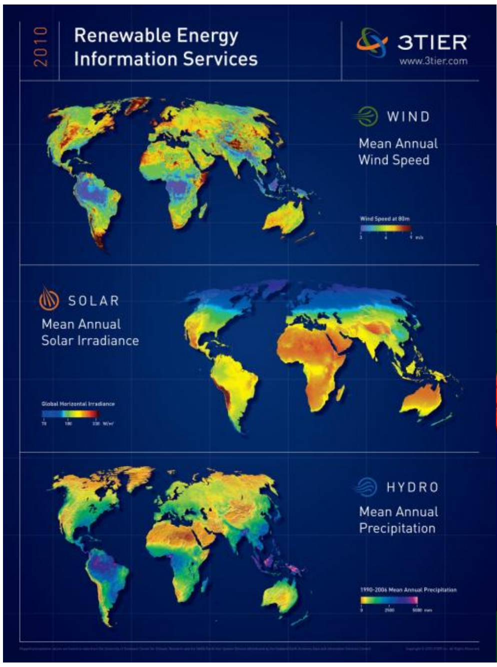
Hydropower utilizes turbines to turn kinetic energy extracted from falling water into electricity. Generating hydropower requires two things, ample water supply and height differences (head). Three different types of hydropower stations can be distinguished, namely: run-of-river, reservoir, and pumped storage. In a run-of-river hydropower plants, either the natural flow of the river is used, or part of the flow is diverged and led through a turbine. The reservoir type uses a dam to create an impoundment. The pumped-storage type involves a lower and an upper basin and can work in both directions: water can be pumped up when no electricity is needed and let down again when there is enough demand. Reservoir and pumped storage hydropower can be used to deliver power on demand. Such hydropower is most utilized in mountainous locations and areas with generally high levels of precipitation.

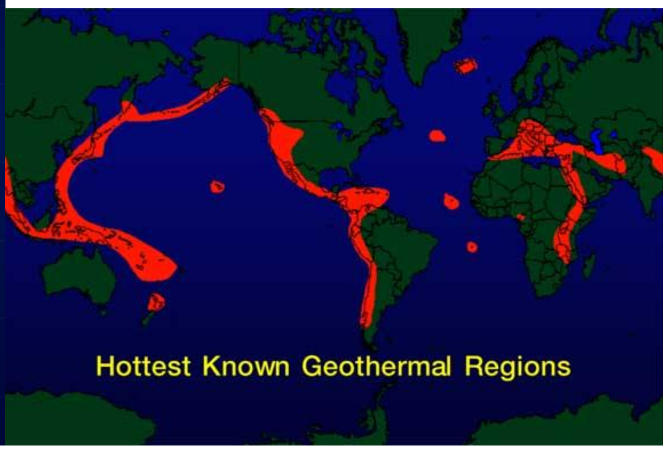
A special form of hydropower is ocean energy, which can again be split into three forms: 1. tidal energy using the height differences of the tides to produce energy; 2. wave energy, using the movement of the waves as sources of energy, and 3. ocean thermal energy, using the temperature differences between different layers of the ocean to produce energy. Figure 4 shows the locations for highest potential tidal ranges.

Biomass is organic material mostly from plants but also (municipal) waste. Biomass can be converted into energy either through thermal or (bio)chemical conversion. The most productive regions for biomass are generally those with high precipitation and insolation, such as the tropics. Traditional biomass, like wood, is still widely used in many developing countries in the world.

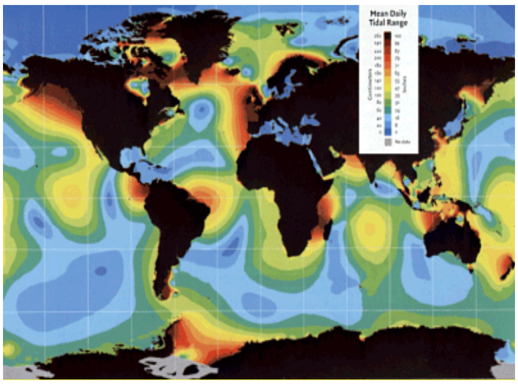
Geothermal energy is derived from heat sources in the earth's crust resulting mostly from radioactive decay of minerals. Geothermal sources of energy can be found everywhere on the planet, when drilled deep enough. However, hotspots, areas where heat sources are closer to the surface, can be found near tectonic plate boundaries. Geothermal energy can be extracted by pumping water or another medium through hot areas in the ground. The hot medium can be used directly, i.e. to heat buildings, or it can be fed through a turbine to generate electricity.

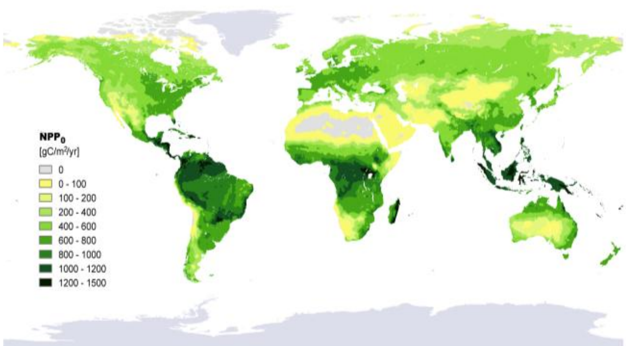
Figure 4. Renewable Energy Potential of Countries and Regions




Global solar, wind and hydropower potential     Global geothermal hotspots



Global distribution of mean tidal range Global biomass potential

Source: solar, wind, and hydro: 3Tier 2010; tidal: EPRI, d.u.; biomass: Haberl et al. 2007; geothermal: GEO, 2000.

From a demand perspective, we consider the same major consumer regions for this thought experiment as for fossil fuels: the traditional OECD countries (located in North America, Europe, Australia, and Japan) and newly industrializing BRIC countries (Brazil, Russia, India, and China).

Considering that most renewable energy sources and especially those with the most potential (solar and wind) will be converted into electricity and either used directly on-site or transported to user centers via an electricity grid, it can be expected that the importance of electricity will grow in a renewable energy system. Of course, there may be notable exceptions like biogas or biofuels. Nevertheless, contrary to the solid, liquid, and gaseous fossil fuels, most renewable energy systems will know electricity as the energy carrier. The nature of a renewable electricity grid implies a much more 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. 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 caused by blackouts or deliberate cut-offs may cascade throughout the entire grid and affect all parties in a matter of seconds. This in turn requires immediate accident response measures and redundant assets to manage. While storage methods are existent (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.

Regarding electricity generation from renewable sources, some 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. In addition, the nature of renewable energy 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 energy self-sufficiency of countries, local communities, or even households, who may either consume the electricity themselves (onsite or in local networks that operate either independent from or connected through a backbone with the grid) or feed it back into the grid. A last observation regarding renewable electricity generation relates to the rare earth materials that are sometimes used in renewable electricity production technologies. These resources may need to be imported.

### 4.2 Energy Market Structure of Renewables

The geographical and technical characteristics of renewable energy systems show five things. First, every area has access to at least some form of renewable energy. Second, some areas are endowed with more renewable energy sources than others. Third, electricity is the energy carrier for those renewable sources with the largest potential (solar and wind). Fourth, renewable energy sources may be intermittent in nature and electricity generation distributed in character. Fifth, renewable energy production requires new materials.

These observations have three major implications for our hypothetical renewable energy based markets. First, the abundance of renewable sources and possibility of producing energy domestically fundamentally changes power relations between producer and consumer countries as compared to the fossil fuel situation. 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. As a consequence, energy trade patterns between producers, consumers, and transit countries may continuously rearrange themselves according to their changing interests. The only limitation to customer switching seems to be that all would like to switch to the most cost-efficient producer. Concerning the latter, the 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 and switch to domestic production only. The result of this empowerment of consumer countries is a market setting that is more akin to that of perfect competition compared to that of fossil fuels 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 be out of the way, 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 productive and/or 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.

Second, 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 a locally oriented, likely to involve a mix of private and communal companies.

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 of sun or wind the market is hence flooded with extremely cheap electricity. Of course, the opposite also holds: in times of little sun or wind, electricity is likely to have a much 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 are very low. On the one hand, such fluctuations could send strong price signals to consumers and producers to either balance their energy use over the day or produce electricity from those renewables that can be harvested at peak-demand, given the presence of those resources at that time and on the spot pricing. On the other hand, what are the effects on energy markets and the renewables mix? What about returns on investment in needed solar capacity if one knows that the installation can only deliver electricity in times of low demand? Will there be sufficient capacity built? Will there be reliable electricity (read non-intermittent) in times of peak-demand? How to bill electricity with such big fluctuations; are spot markets a fair possibility in this setting or do we need two types of contracts: one for long-term non-intermittent base-load capacity and one for short-term peak-demand spot-trading? These questions all signal the need for balancing capacity, not just for operational reliability, but also for market stability's sake. Options 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. These all help to balance energy prices. Put differently, storage makes cheap electricity expensive and expensive electricity cheap (because reserves can be added at times of peak demand).

### 4.3 Strategic Considerations of Renewables

When discussing the geopolitics of fossil fuels in section 3 we considered producer, consumer, and transit countries and their specific strategic realities. To discuss the geopolitical implications of renewables, we need to do justice to how the make or buy decision and central or decentral option could play out. 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). Examples of visions that resemble such an energy system are the European Roadmap 2030 and plans to source renewable energy from favourable locations such as deserts or the North Sea and then transport it to end users using long distance high voltage direct current (HVDC) lines (Verbong and Geels, 2010). 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). 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). We call this the 'National' scenario. Let us now elaborate them.

#### *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. In the context of Europe, for example, this could imply that Mediterranean solar energy (Spain, Italy, North Africa) and North Sea wind (UK, Netherlands, Germany) are both fed unto the same 'copperplate' grid that spans the continent. This scenario is both similar and different to the current fossil fuels situation with regard to the strategic concerns of producer, transit, and consumer countries.

What may be expected in the continental grid, as compared to fossil fuels, is that concerns regarding security of demand and supply are not expressed in diversification policies and the like, but in a power struggle over the ownership and decision rights with regard to control and management of the grid. Put differently, political tensions become arguably less geographic and more economic in origin. Let us explain. Renewables are far less geographically constrained than fossil fuels. Only the most endowed regions or generation sites and (hydro) storage locations may be truly geographically determined; but even then all regions have some sun or wind and there exist other storage options (less efficient perhaps, but still). The implications of this shift, as we saw, was that dependencies will shift from countries with large fossil fuel supplies to those endowed with favourable conditions to produce renewable sources of energy, that consumers are no longer dependent on getting access to foreign resources, but find themselves in a buyer's market, and that the electricity infrastructure is much more integrated and require more stringent management whereas before compartmentalization and strategic buffers created some leeway. In the renewable electricity based system, geopolitics becomes business politics; when there is abundant supply then low prices and control of the market take center stage. In network industries this implies control over the most strategic asset: the grid. Hence political concerns shift from getting access to resources to managing the infrastructure (and in this way dominating related markets). The key issue here is the allocation of costs and benefits of developing and utilizing a centralized renewable energy system. Who owns, manages, and protects the grid? Who finances projects, where are facilities to be located, what about employment and electricity prices? Who is going to be the main responsible for operations and in case of disturbance response? How will damages in one area incurred by fluctuating power in another area be resolved? How to manage the intermittency of power generation in cross-border networks; what new modes of operating these systems may be required? Clear agreements to cover the commodity and monetary flows seem a prerequisite to avoid opportunistic behaviour and conflicts.[12]

The focus on the grid as the strategic asset has several strategic consequences. First, geopolitical interdependencies shrink to the size of the grid that connects different producing, transit, and consuming countries. 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 more need for global energy import or demand diversification policies, only within the limits of the physical connection.

Second, as all countries are physically interconnected to the same grid, 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 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

[12] The Continental scenario implies an important role for large business. Building and operating energy generating capacity will be in hands of large companies, most likely these are current utilities, as they have experience in building and operating large power plants. Regarding operation of the continental grid, it will be likely that this will be operated by state-owned companies, because of the strategic interests. Such 'supergrids' could be managed by supranational bodies in which all countries connected to the supergrid will have a stake. Securing this supergrid will be of high interest, therefore one can expect large business opportunities in security services, such as preventing physical and cyber attacks to the grid.

country, it would be practically impossible to do so without also affecting other members connected to the grid and even itself (at least in terms of reputation). 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 strategic reserves. 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 energy supply.

Third, countries with large-scale storage potential, (possessing standing reserves) that can deliver at times of peak demand, and with great interconnector capacity play an important role in managing the grid. The reliable operation of electricity infrastructures requires direct supervision of energy flows and means to handle the difficulty of storing electricity and the intermittency of renewable sources. If a country is very beneficial to stability of the interconnected grid, for example by being able to balance power efficiently through large storage capacity, it will be possible for this country to exert indirect geopolitical pressure, because the rest of the connected countries would be willing to accommodate its demands to make sure the country continues to provide these balancing services. Looking at today's state-of-the-art, there are several ways to match demand and supply; either by storing excess supply and delivering power on demand in times of undersupply (both upward and downward); having sufficient standing reserve capacity[13] (upward only); continental interconnection to level intermittent production and peak demand, and demand management.

Storing electricity would be the preferred means, but is difficult. Of the storage means that could be used in the renewable grid of our thought experiment, the largest potential lies in hydropower (impoundment and pumped storage) or compressed air energy storage capacity. This makes countries with favourable geographical conditions like mountainous areas or underground caverns especially interesting. Norway has already (reluctantly) been coined 'the battery of Europe' (Seidler 2012) because of its beneficial geographic features. Such countries would find it easy to strategically position themselves as key balancers in the continental grid (instead of those countries where the electricity is produced) and would be able to make sure that they receive ample payment for their services. Still, it will be possible for other countries to develop their own storage and balancing capacities.

Next to storage, those countries with high standing reserve capacity or the ability to produce renewable electricity at times of peak demand and those countries with large interconnector capacity may also take up strategic positions. Regarding the former, the difficulty with intermittency and storing large quantities of electricity make prices much more volatile than that of fossil fuels. Therefore, for producers

[13] The lower marginal cost of operating renewable energy generation technologies as compared to fossil fuel power plants, however, does improve the issue of efficiency associated with starting-up and shutting-down plants.

being able to produce energy at times of peak-demand (perhaps via gas turbines running on biogas used as standing reserves) will have added value in developing a well-functioning electricity market that enables the efficient allocation of energy according to demand and supply in the interest of all countries. In this light, technologies such as smart meters and grids and policies that enable real time pricing could be implemented to match demand to supply. Concerning the latter, the benefit of a continental grid would be that its size allows balancing the variable energy inputs of one area with those of another. Countries that facilitate this effect through large interconnector capacity also may position themselves favourably.

*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' model energy consumer countries source all or a significant share of their energy domestically[14] (Loock et al. 2010) and production and consumption of energy takes place much closer to each other, thereby exercising control over their energy supply. The National scenario implies a fundamental shift, a 'transition' (Grin et al. 2010) in the way the energy system is organized as compared to the fossil fuel situation.

A first shift entails that geopolitical implications 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 energy system, in which dependencies are present throughout the supply chain. It hence makes no sense to discuss cross-border geopolitical implications in terms of producer, transit, and consumer country jargon. 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. 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 be mostly around various regions and local communities within a

[14] The prosumer concept usually refers to households and businesses within countries, but is here adapted to countries operating in the international political arena.

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. A key issue here is whether household electricity is fed back into the grid or not. If there is no net production, than the business model of the national grid does not change much, just that households first consume their own energy and then utilize the grid as fall back option. If there is net production, then it becomes interesting for households and firms to sell it to those areas where there is no net production. This, however, would require setting up local energy markets and accompanying regulatory frameworks to facilitate energy trade among local individual private parties (households and firms) and/or communities. If so, energy moves out of the geopolitical realm all together and becomes a 'mere' market commodity. Of course, some political issues remain: how to integrate these new (decentral) renewable production technologies into existing grids; how will incumbent energy companies respond? Such questions, however, fall outside the scope of this paper.

#### *4.3.3 Some Overall Remarks*

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. However, it is of course most likely that the eventual result will be a combination of both scenarios. In a National scenario there would be opportunities for efficiency gains through cross-border trade: if a country has an overall energy surplus, it could store energy in times of oversupply to be used in times of undersupply. Another solution could be trading energy with other regions that have a surplus at the moment of demand in the first region. A combination of these two, or by trading with countries that have large storage capacity, is very interesting. 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.

Finally, 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. Koroshy 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, China has been active in acquiring control over a large share of the world's rare earth resources. Estimates go up to China controlling 95% of the world's rare earths. 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.

**5. Conclusion**

This paper started by asking what the potential political implications of the geographic and technical characteristics of renewable energy systems are, noting that renewable energy sources are eventually going to replace fossil fuel resources. Are the political concerns between energy producer, consumer, and transit countries similar or different to those of fossil fuels? To investigate, we proposed a thought experiment in which we imagined a purely renewable based energy system where electricity was the main energy carrier, keeping all else equal.

The paper noted that the geopolitics of fossil fuel energy are induced by scarcity of those fuels and their limited presence in few regions. Figure 3 then showed that renewable energy has the potential to relieve such restraints. Scarcity of the fuel will no longer be the restraining factor. Rather, the focus will shift to those technologies that capture renewable energy and the physical infrastructure to transport and store these sources. Still, some areas are endowed with more sources of renewable energy than others. This presents countries with a make or buy decision, i.e. should they invest in infrastructure to harvest renewable energy themselves or import renewable energy from countries that are better endowed with such sources? How this make or buy decision will play out shapes the outline of the renewable energy system to a large extent. This article identified and discussed two extreme scenarios, a centralistic Continental scenario and a more decentralised National scenario.

In the Continental scenario cost-efficiency is the leading driver and energy is produced where it is cheapest and then transported to consumer countries via one interconnected grid. The conventional categorization according to producer, consumer, and transit countries largely remains intact, although with different players than in the current fossil fuel based energy system. The Continental scenario therefore implies a mere shift in dependencies between countries compared to the current situation. The most important shift is that while minor dependencies exist to those countries that can produce most efficiently, consumers and transit countries have the option to switch producers and possibilities for domestic production exist. Consequently, consumer countries will no longer be too concerned about getting access to foreign resources. Instead, all countries have an interest in exercising control over the management or ownership of transportation grid (and in this way dominate related markets). This shifts concerns to the allocation of costs and benefits of developing and utilizing a centralized renewable energy system. Who owns, manages, and protects the grid? Who finances projects, where are facilities to be located, what about employment and electricity prices? Another important difference is that geopolitical realities shrink to the size of the grid, as all energy demand is served by it, and the interconnected nature of the grid. The latter issue makes political action like targeting to cut-off a single country largely unworkable. Yet if it can work, the near impossibility of developing strategic electricity reserves makes cut-offs immediate and more severe. Finally, as renewable electricity will be the main energy carrier, strategic value is no longer found in availability of fuels and the maintenance of strategic reserves but in grid capacity and storage or balancing power to facilitate markets. Therefore, countries with ample supplies of dispatchable hydropower, standing reserves or production capacity during peak demand, or interconnector capacity play a key role.

In the National scenario, the make or buy decision tends towards ‘make’, because decision makers put more value on security of supply than on cost-efficiency. As consumer countries become producers (prosumers) and the need for cross-border transport becomes smaller or non-existent, the distinction between producing, consuming, and transit states starts to blur. Thereby this scenario forms a landslide in energy dependencies. Geopolitical implications become limited to the supply of materials to build energy production capacity. Once this is in place, countries own their energy supply, which drastically reduces strenuous energy relations compared to the current predominantly fossil fuel energy supply. Geopolitical issues were to be found between regions in a country as areas vie for projects (good for employment and finance) or try to keep them away due to NIMBY backlashes. Possibilities for distributed generation also hint at a very different business model altogether that could upset the position of incumbent energy companies and the way the national grids are operated.

Distinguishing between these two (extreme) scenarios gives the impression that a choice has to be made, that it is either one or the other. However, the most likely outcome 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. In whatever way such a renewable energy system will take shape, three observations stand out when compared to 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* transit countries. Finally, for most countries the possibility exists to become a ‘prosumer’ country, thereby greatly reducing any form of geopolitical concern.

These statements of course need to be seen within the boundaries and assumptions of the thought experiment. As stated in section two, the political-economic or more socio-cultural environment within which the renewable electricity system was placed was kept exogenous to the experiment. One could, for example, make the political-economic global order more or less peaceful, globalized, or multilateral / institutionalized in nature and in this way influence country preferences for security of supply versus cost-efficiency. 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. While it is easy to criticize such a thought experiment for its assumptions, 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.

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