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The Geopolitics of Renewable Energy

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A prior version of this document served as the discussion paper for that workshop. This working paper reflects discussions at the Berlin workshop and the contributions of those present. The authors are grateful for the insights of all participants and for the support of IRENA, the German Federal Foreign Office, and the Norweigan Ministry of Foreign Affairs for their assistance with the conference.

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Executive Summary

For a century, the geopolitics of energy has been synonymous with the geopolitics of oil and gas. However, geopolitics and the global energy economy are both changing. The international order predominant since the end of World War II faces mounting challenges. At the same time, renewable energy is growing rapidly. Nevertheless, the geopolitics of renewable energy has received relatively little attention, especially when considering the far-reaching consequences of a global shift to renewable energy.

The paper starts with a discussion of seven renewable energy scenarios for the coming decades: the IEA's World Energy Outlook 2016, the EIA's International Energy Outlook 2016, IRENA's REmap 2016, Bloomberg's New Energy Outlook 2016, BP's Energy Outlook 2016, Exxon-Mobil's Outlook for Energy 2016 and the joint IEA and IRENA G20 de-carbonization scenario.

Some of these are forecasting while others are backcasting scenarios. While all the forecasting scenarios envisage growth in renewable energy, none anticipate a revolution in which renewable energy use surpasses consumption of any of the fossil fuels in the next several decades. In contrast, the backcasting scenarios posit a future in which the world employs a radically different energy mix where consumption of renewables eventually surpasses that of fossil fuels. In all three backasting scenarios covered here, the share of renewables of total primary energy reaches 30-45% in 2035 or 2040 and 50-70% in 2050.

The paper then discusses seven mechanisms through which renewables could shape geopolitics.

Critical materials supply chains. As the transition to renewable energy accelerates, cartels could develop around materials critical to renewable energy technologies. Even if these cartels are unable to achieve the kind of impact that OPEC did in the 1970s oil market, they might be able to exert influence over consumers of these materials. Rare earth elements are widely used in clean energy technologies, including solar panels and wind turbines. Although rare earths elements are found in many countries around the world, they are usually found in dilute concentrations and are often difficult to extract. Today almost all mining, production and processing of rare earth elements takes place in China. Lithium, cobalt and indium are also widely used in clean energy technologies and might in some circumstances present opportunities for cartelization.

Technology and finance. In a world in which renewables are the dominant source of energy, capital for investment and technology may increasingly become sources of international cooperation or rivalry. First, increased tensions between developing and developed countries could develop over the transfer of technology. Second, conflict over renewable energy infrastructure could develop, especially if new asymmetric dependencies arise between major producers and consumers of renewable energy. Finally, it is not clear whether the expansion of renewable energy will involve a shift to more decentralized and distributed energy generation (similar to farming) or to larger companies with the financial and scientific clout to keep pace in an intense global race to continuously improve technology and cost-cutting (similar to mobile telephone manufacturing).

New resource curse. The prevalence of the resource curse could be affected by a rise of renewable energy in at least three ways. First, as oil and gas lose their dominance in the energy mix, petro-states will lose access to the high rents associated with the resource curse. Second, there is the question of whether countries that produce large amounts of renewable energy are likely to become subject to the resource curse, just as major oil and gas producers have been. However, it is also possible that countries producing renewable energy for export may actually end up with more diversified economies than they would otherwise, as the requirements for developing renewable energy resources are quite different from the petroleum sector. Third, there is potential for a new resource curse in countries rich in rare earth elements.

Electric grids. Renewable energy technologies may lead to greater electric interconnections between nations, more widespread distributed energy generation or both. The potential geopolitical implications are complex. On the one hand, greater cross-border trade in electricity could create geopolitical vulnerabilities for electricity importers. On the other hand, greater electric interconnection could increase interdependence among nations, reducing risks of conflict. Renewable energy technologies will affect the vulnerability of electric grids to cyber attacks, potentially creating new vulnerabilities while at the same enhancing resilience with more widespread microgrids and distributed energy technologies.

Reduced oil and gas demand. To the extent that renewable energy reduces demand for oil and gas, there could be significant geopolitical consequences. For oil and gas producers, the decline in revenue generated from fossil fuel energy exports can provide an impetus for political reform and economic diversification. However, a decline in petroleum revenue could also lead to political instability, especially in the short to medium term. Consumer countries would improve their trade balances and their room to maneuver in the international system. The development of renewable energy is already a game changer for Chile, Jordan, Morocco, and several island states in terms of energy security.

Avoided climate change. Reduced greenhouse gas emissions as a result of expanded use of renewable energy should logically reduce the risk of conflict and instability that climate change would otherwise generate. One region where large-scale deployment of renewable energy may have significant geopolitical consequences is Africa.

Sustainable energy access. Access to modern forms of energy is one of the preconditions for achieving sustainable development. The geopolitical impacts of access to energy are important, as such access can contribute to lasting solutions to instability and conflict. It is possible that renewables not only have an impact on geopolitics but that geopolitics, particularly in risky and institutionally unstable environments, can also influence investments in renewable energy by increasing the cost of capital.

These categories do not offer a comprehensive assessment of the ways in which renewables affect geopolitics. The purpose of this paper is to provide food for thought for a broader discussion on the ways in which greater renewable energy and geopolitics intersect. Accordingly, the final section (Section III) suggests areas and directions for future research.

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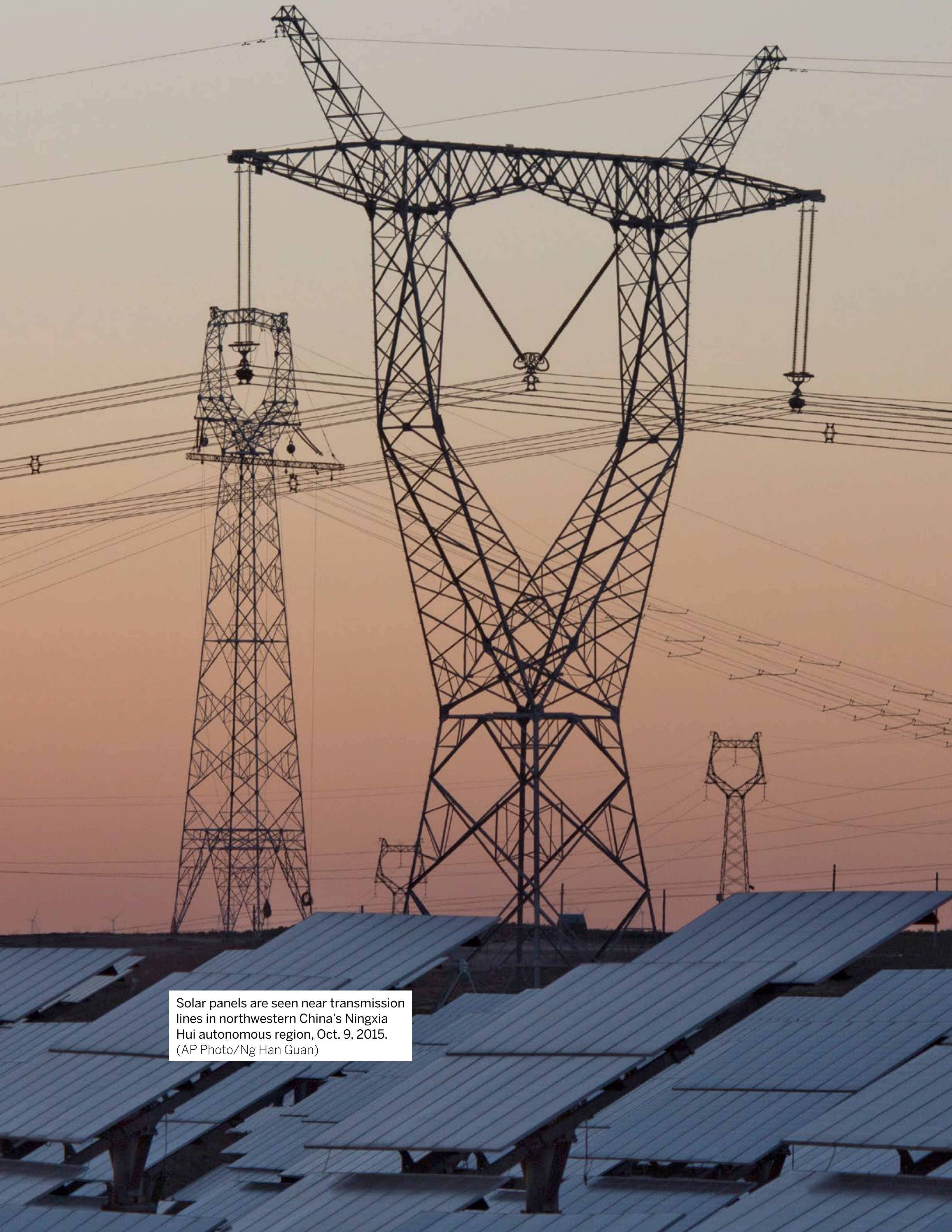
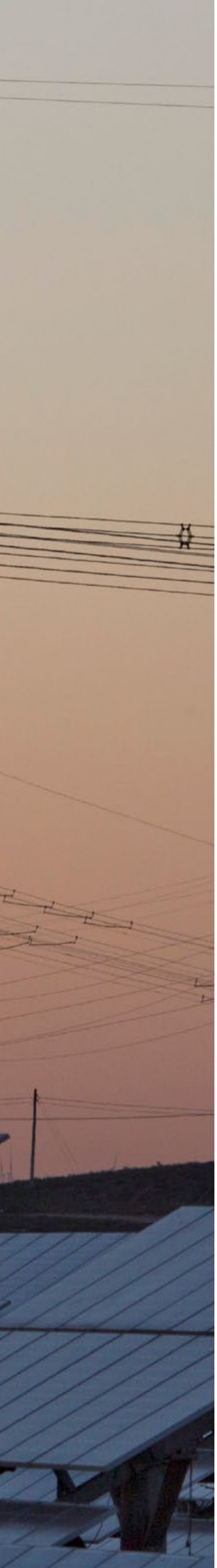


Solar panels are seen near transmission lines in northwestern China's Ningxia Hui autonomous region, Oct. 9, 2015. (AP Photo/Ng Han Guan)



Introduction

For decades, the geopolitics of energy has been largely synonymous with the geopolitics of oil and gas. The focus on how oil and gas shapes the way states develop, interact with one another, form alliances and wage war has made a certain amount of sense. Oil and gas account for more than half of global energy consumption and captured close to 70 percent of total investment in energy supply from 2000-2015.[1] The world's transportation systems—and therefore national economies—depend almost completely on supplies of oil.

Yet geopolitics and the global energy economy are both changing. The traditional definition of geopolitics is the influence of geography upon the foreign relations of states. However in recent years the role of non-state actors in international relations has both grown and become increasingly well recognized. Leaders and policymakers are more and more consumed by transnational threats, which pose challenges to multiple countries and cross borders; cyber and terrorism are two of the most prominent examples, alongside climate change. At the same time, many of the concerns of earlier decades have resurfaced in recent years, as challenges have mounted to the international order that has been predominant since the end of World War II. Great power conflict—while unimaginable only a few years ago—is now again in the realm of the possible.

Meanwhile the costs of solar and wind power have dropped dramatically, helping renewable energy make significant inroads into the global energy mix. Sales of alternative fuel vehicles, while still small as a percentage of total vehicle sales, have climbed sharply, especially in China. Cross-border renewable energy trade has caused international tensions, including solar trade disputes between the European Union and China and between the United States and India. Investment in renewable energy is crossing international borders and in some cases is overtaking fossil energy investments. Non-energy companies are

1 US EIA, International Energy Outlook 2016 -- http://www.eia.gov/outlooks/ieo/exec_summ.cfm - at Figure ES-2 (with respect to energy consumption); IEA World Energy Outlook 2016, Executive Summary, pg 2, https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExecutiveSummaryEnglish.pdf (with respect to investment).

investing in major renewable energy projects across the globe, such as Google's investment in the Lake Turkana Wind Power Project in Kenya (Africa's biggest wind farm and the largest single private investment in Kenya's history when completed).[2] Distributed renewable energy is helping address energy poverty. In India, more than a million households are benefiting from solar energy, with over 10,000 remote villages securing basic electricity through distributed renewable power alone.

Nonetheless, the geopolitics of renewable energy has received relatively little study.[3] The literature review carried out for this report finds that the geopolitical consequences of a transition to renewable energy has received far less attention than the geopolitical consequences of, for instance, fracking. Most research on the geopolitics of renewable energy to date has been conducted by Dutch and German research institutions and largely consisted of gray literature (working papers, online reports, dissertations etc.). (See the annex for further detail).

One reason for the dearth of research on this topic may be that the geopolitics of renewable energy differs considerably from that of oil and gas, making it difficult to apply familiar frameworks and concepts. Another may be that renewable energy's role in the global economy has not until recently been large enough to lead all but a few observers to consider its geopolitical impacts. Most of the academic and policy work on renewable energy to date has focused on how to achieve the transition to a low carbon future, not on the impacts of a successful transition on global politics or the power of states.

Policy makers, corporate leaders, and academics alike could benefit from a better understanding of how a rapid expansion of renewable energy could affect the geopolitical status quo. This paper suggests an analytic framework for exploring this topic.

2 The Guardian (09.10.2015) "Africa's largest windfarm set to connect remote Kenya to the grid", https://www.theguardian.com/environment/2015/oct/09/africas-largest-windfarm-set-to-connect-remote-kenya-to-the-grid (last accessed 02.02.2017)

3 Overland, I. (2015) "Future Petroleum Geopolitics: Consequences of Climate Policy and Unconventional Oil and Gas," Handbook of Clean Energy Systems, Chichester: Wiley, pp. 3517–3544, https://www.academia.edu/15717140/Future_Petroleum_Geopolitics_Consequences_of_Climate_Policy_and_Unconventional_Oil_and_Gas

The paper is focused on the geopolitics of renewable energy. It does not address the geopolitics of a low carbon future more broadly. Other strategies for decarbonization—including a shift from coal to natural gas and growth of nuclear power—may have important geopolitical consequences that merit study as well. This study, however, focuses solely on the geopolitical implications of a large-scale shift to renewable energy.

I. Renewable Energy Deployment Scenarios

There are dozens of long-term projections offering different views on the global energy mix and how it will affect specific regions or countries. In this paper, we consider the projections of six major agencies and companies: the *IEA World Energy Outlook* (WEO) 2016, the *EIA International Energy Outlook* (IEO) 2016, the IRENA *REmap* 2016, Bloomberg *New Energy Outlook* 2016, the BP *Energy Outlook* 2016, Exxon-Mobil *Outlook for Energy* 2016 and the IEA's and IRENA's G20 de-carbonization scenario (2017). Each of these is based on different assumptions and methods, leading to different scenarios for the decades ahead.

In examining these scenarios, we distinguish between forecasting scenarios and backcasting scenarios. Forecasting scenarios start with assumptions about technology, policy and other topics such as global growth and population. They then describe one or more futures based on these parameters projected forward. Often, in "best-guess" or reference case scenarios, these scenarios tell us where the company or agency thinks the world is likely to end up assuming some version of current trends continue. Backcasting scenarios, in contrast, begin by staking out a particular future (usually a desirable one) and working backwards to demonstrate the sort of policy changes or technological advances required for that future to materialize. The two types of scenarios serve different purposes. For reasons explained below, we use backcasting scenarios from the IEA and IRENA as the principal analytical foundation for this study.

A) **Forecasting Scenarios**

The forecast scenarios surveyed in this paper contain different assumptions about the penetration of renewables in the future energy mix, arising from different sets of assumptions about policy, technological change, future economic, population growth and other matters.[4] One possible explanation for different outcomes is timing, as some forecasts focus on 2035, while others look to 2040. However, a mere five-year gap cannot explain much of the difference in outcomes. More significantly, the scenarios diverge in relation to how they define renewables or how they group together various categories when reporting data. For instance, the IEA includes marketed biomass (gathered wood) in its reporting on renewables, whereas some company forecasts, such as the one from BP, do not. The EIA includes biofuels along with oil and other liquids.

In addition, each forecast is based on a different set of assumptions about policy, technological change, and other matters. For example, scenarios are often built on different assumptions about how quickly China is able to transition its economy away from an export focus to a more service-oriented basis for growth; such assumptions affect China's overall coal use (and the balance of other fuels). Scenarios also contain different assumptions about global economic growth and the rate of the expansion of the world's population; both can influence the pace of energy demand growth. Another difference is the extent to which renewables permeate sectors outside the power ones. Finally, scenarios can differ on the speed and scope of the penetration of transportation by natural gas and/or electrification, which affects demand for oil, natural gas, and possibly many forms of renewables.

Despite these differences, one similarity among these forecasts is notable for purposes of this paper. While all the forecast scenarios see growth in renewable energy, none anticipate a revolution in renewable energy use. In their "best guess" or reference case scenarios, none see consumption of

4 For example, scenarios are often built on different assumptions about how quickly China is able to transition its economy away from an export focus to a more service-oriented basis for growth; such assumptions affect China's overall coal use (and the balance of other fuels).

renewable energy surpassing consumption of any of the fossil fuels (oil, natural gas, or coal) in the next several decades.[5]

The reference case forecasting scenarios we reviewed project a 4-7 percentage point shift from fossil fuels to renewables in the next 15-25 years. IEA's main scenario, the New Policies Scenario, forecasts that the share of renewables, including biomass, biofuels and hydroelectricity, in the energy mix will grow from 14.2% in 2014 to 19.3% in 2040. In contrast, the EIA's reference case forecasts growth from 12.2% in 2015 to 16.1% in 2040.

While such scenarios are important to consider, they are of limited value in assessing the geopolitical consequences of renewable energy. Indeed, by projecting that the transition to renewable energy in the coming decades is unlikely to be substantial, these scenarios raise questions about the need to consider the geopolitical consequences of such a transition.

There are, however, important reasons to consider the geopolitical consequences of renewable energy. First, many of forecasting scenarios have consistently underestimated the growth of renewable energy in the past.[6] Wind and solar installed capacity had to be adjusted upwards in almost every forecasting report over the last decade. It is therefore not unreasonable to surmise that the growth of renewables in the future may outpace current projections. Second, even small changes in the global energy mix could have significant geopolitical consequences. The global energy system is so vast—with trillions of dollars of legacy infrastructure—that even minor changes could have outsized impacts in some regions and sectors.

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5 The EIA has its "Reference Case;" the IEA has its main scenario called "New Policies Scenario;" BP has what it calls its "base case."

6 Aleklett, Kjell; Höök, Mikael; Jakobsson, Kristofer; Lardelli, Michael; Snowden, Simon; Söderbergh, Bengt, *The Peak of the Oil Age—Analyzing the world oil production Reference Scenario in World Energy Outlook 2008*, Energy Policy, 2010, Vol.38(3), pp.1398-1414; Rolf de Vos and David de Jager, "World Energy Outlook hides the real potential of renewables" EnergyPost: http://energypost.eu/world-energy-outlook-hides-real-potential-renewables/

Figure 1.

Year	EIA IEO2016		BPEO2016		IEA WEO2016	
	Share of Fossil Fuels	Share of Renewables (defined as "other" than liquids, gas, coal and nuclear)	Share of Fossil Fuels	Share of Renewables	Share of Fossil Fuels	Share of Renewables
2014		11.95%		9.22%	81.01%	14.16%
2015	83.25%	12.19%	85.43%	9.57%		
2016	82.62%	12.66%				
2020	81.26%	13.83%	83.01%	11.41%	79.04%	15.50%
2025	80.21%	14.66%	80.96%	13.28%	77.72%	16.50%
2030	79.33%	15.07%	79.10%	14.92%	76.34%	17.47%
2035	78.73%	15.61%	77.19%	16.65%	75.16%	18.41%
2040	78.24%	16.12%			74.04%	19.34%
% change (from earliest year to last available year)	**-5.01%**	**3.93%**	**-8.25%**	**7.09%**	**-6.97%**	**5.19%**
	"Liquids" category does not separate biofuels; biofuels are thus included in the fossil fuels category.		Biofuels and hydroelectricity are calculated as part of renewables here.		"Bioenergy includes the traditional use of solid biomass and modern use of bioenergy." Hydro is separate from renewables, which were reported as "other renewables."	

B) **Backcasting Scenarios**

Backcasting scenarios take a different approach, defining a desired endpoint and working backwards to identify the steps required to arrive at such an endpoint. Three backcasting scenarios may be helpful for this project: the IEA 450 scenario, the IRENA REmap Doubling Options scenario and Perspectives for the Energy Transition, the full decarbonization scenario produced in cooperation with both organizations.

1) IEA 450 Scenario (from World Energy Outlook 2016)

The IEA's 450 Scenario is a backcasting scenario from 2040 which starts from the assumptions that the world must limit atmospheric carbon dioxide concentrations to 450 parts per million. (According to the IPCC, this would result in a 50% chance of limiting the rise in global average temperatures to 2°C above pre-industrial levels by 2100.) A major advantage of this scenario is that it clearly states its assumptions and provides detailed consideration of emerging technologies, including carbon capture and storage (CCS), electric vehicles and biofuels. The 450 Scenario also offers a comprehensive overview of the global benefits of renewables based on an extensive analysis of fossil-fuel markets, and examines changes to industrial, commercial and residential electricity prices. This allows the report to spell out the consequences of such developments for the fossil fuel industry and fossil fuel producing countries. Moreover, for the first time, the 450 Scenario also looks at pathways towards limiting the increase to 1.5°C. The scenario also has the advantage of having been recently updated to reflect the Paris agreement and 190 separate Nationally Determined Contributions (NDCs).

Despite these benefits, the 450 Scenario also has downsides for the purposes of this study. To make the backcasting exercise work, the report adopts some bold assumptions, such as a carbon price of $140/ton by 2040 in power and industry in the United States, European Union, Brazil, China, Russia, South Africa, New Zealand, Australia, Japan, Korea, and

Canada. The scenario also assumes extremely strong public institutions capable of financing efficiency measures and giving clear policy signals. Another potential weakness is that the trade-offs between the three factors of environmental protection, economic growth and energy security could be better developed. Moreover, there is little detail on adverse side effects of technological advances, such as the negative impact of the growth of biofuels on food security or the temptation to increase fossil fuel consumption if better CCS technology becomes available.

2) IRENA REmap Doubling Options (IRENA REmap 2016 edition)

IRENA's Doubling Options scenario takes as its starting point a world in 2030 in which the total share of renewables in the primary energy mix (including biomass) has doubled to 36%. The main conceptual strength of the scenario is that it provides a detailed country-by-country roadmap for its member states to reach the 36% goal. In so doing, it reveals the extent to which the renewable energy opportunities vary among countries. Such discrepancies will be critical to the mapping of asymmetries between countries and regions—and anticipating the geopolitical consequences such disparities as these may cause. The specific focus on OECD countries, BRICS, and GCC countries may further facilitate this exercise. Another strength is the scenario's in-depth examination of specific sources of renewable energy. It individually explores the trajectories of wind, solar, and biofuels as well as the consequences of greater electrification. Similarly, it provides a sectoral analysis of transport, buildings, and industry. A final advantage is that the report makes a clear and convincing economic argument for doubling the share of renewables in the global energy mix and the falling price of renewables to their potential displacement of fossil fuels.

The large degree of geographical and sectoral differentiation, however, can also present a downside to the use of the IRENA Doubling Options scenario for the purposes of this study. The strong segmentation makes it more difficult to identify assumptions on a meta-level, or to find a middle ground between universal fulfillment of all individual country options and going into the detail for every single country. Moreover, given this difficulty to dissect and quantify the assumptions it is sometimes hard to assess their feasibility, especially since many assumptions appear dependent on immediate policy action in specific sectors. Perhaps the greatest weakness of the scenario, however, is that outside the power sector, it provides no detailed projection of how the doubling of renewables would impact other sources of energy (for example, in the transportation sector), which is critical for assessing the geopolitics of renewable energy.

3) IRENA and IEA's "Perspectives for the Energy Transition" (March 2017)

This joint venture of IRENA and the IEA was commissioned by Germany in the year of its G20 presidency, and conceived as input into G20 work on energy and climate. The effort produced two backcasting scenarios—one by each institutions—both of which take as a starting point a world in 2050 which is consistent with limiting the rise in global temperatures to 2°C by 2100 with a probability of 66%. Whereas each institution developed a different pathway for such a future, in both renewables make up a much more significant proportion of the total primary energy supply in 2050. The request from the German government was to illuminate the key elements of a low-carbon transition with particular focus on the G20 energy sector, including cost-effective investment in power generation, transport, buildings and industrial production with policy co-benefits.

The report considers, in detail, the implications of rising energy demand, the need for changes in investment patterns, the effects of climate change on food security and migration, air pollution in emerging economies, energy efficiency and in particular, the role of renewables in the context of rapid technological change. The IEA scenario anticipates 40-45% renewables in the primary energy supply by 2050, while IRENA envisions 65%. In either case, it is clear that meeting the Paris Agreement will have enormous implications for the role of renewables, as well as for the fuels renewable energy will displace.

The advantages of such a scenario for the purposes of this study are manifold. First, the cooperation between IRENA and IEA combines the above-described strengths in the approaches of both institutions. It draws on the comprehensiveness of the IEA's approach, in particular its detailed assessment of how other sources of energy will fare, and clearly stated assumptions about which overall technical advances will be necessary. It incorporates IRENA's strengths on detailed sectoral and geographical analysis for renewable energy deployment and maintains a focus on the economic consequences of such a radical energy transition in terms of investment, stranded assets, growth, trade and employment.

Crucially, the data analysis was conducted separately by both institutions, with very similar results, lending the findings additional credibility. The support and consultation of academic institutions such as the Institute for Sustainable Futures (Sydney), the Smith School of Enterprise and Environment (Oxford), and the IPCC endow the report with additional expertise and inter-institutional perspectives. At the time of writing, the IEA-IRENA scenario is the newest and most up-to-date scenario on offer.

II. Mechanisms

The backcasting scenarios summarized above portray a future in which the world employs a radically different energy mix. All three describe a future in which the share of renewables of total primary energy is between 30-45% in 2035/2040 and between 50-70% in 2050. In this section we consider the potential geopolitical consequences if renewables reach this level of deployment. The section is organized around five topics -- critical material supply chains, technology and finance, electric grids, reduced oil and gas demand and avoided climate change. We examine whether high levels of renewable energy deployment could have geopolitical consequences related to each of these topics.

A) Critical Materials Supply Chains

As the transition to renewable energy accelerates, cartels could develop around materials critical to renewable energy technologies. Even if these cartels were unable to generate as much impact as OPEC did with oil in years past, they might be able to exert influence over consumers of these materials. Some materials critical for renewable energy technologies are also critical in other sectors, such as consumer products and weaponry, raising the potential for competition between sectors as well.

Rare earth elements (including dysprosium, neodymium, terbium, europium and yttrium) are often considered to be critical components of renewable energy hardware.[7] Ironically, rare earth elements are not rare. They are found in many countries, including China, Russia, Australia, the United States, Brazil, India, Malaysia and Thailand. However, two countries—China and Russia—together hold 57% of global reserves, while the largest remaining country, Australia, holds a mere 2.4% of global reserves.[8] Furthermore, rare earths are found in dilute concentrations and are often difficult to separate, making mining, production and processing difficult

7 Resnick Institute. 2011. *Critical Materials For Sustainable Energy Applications*. Resnick Institute Report. http://resnick.caltech.edu/docs/R_Critical.pdf

8 U.S. Geological Survey. 2016. *Rare Earths.* U.S. Geological Survey: Mineral Commodity Summaries. https://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/mcs-2016-raree.pdf

and capital intensive. Today almost all mining, production and processing of rare earths is in China. Rare earths mined elsewhere generally must be exported to China for processing and then re-imported.[9] As demand for renewable energy technologies continues to increase, countries may be inclined to hold rare earth elements in reserve for themselves and compete over these resources.

Strategies for avoiding cartel development and geopolitical tensions with respect to rare earths include (i) developing supplies in additional countries, (ii) reducing the need for rare earths in renewable energy and other sectors through technological innovation, and (iii) improved re-use and recycling.[10] Absent such strategies, dependence on China as the overwhelmingly dominant supplier of rare earths for global commerce will continue.

Lithium is also critical for renewable energy technologies. Lithium ion batteries are used to help manage the intermittency of solar and wind power and in electric vehicles. They are also widely used in other industries, including personal electronics.[11] The world's largest lithium producers are Australia, Chile China and Argentina (in that order). Bolivia has significant lithium resources, but they remain largely untapped. Current calculations about the global demand for lithium are based on assumptions about the penetration rate of electric vehicles, which may change rapidly if more EVs become commercially available and cost-competitive with traditional automobiles.[12] Even if global lithium resources are adequate to meet global demand, short- and medium term mismatches between supply and demand could give leverage to producer nations. As with rare earths, strategies for reducing dependence include developing additional supplies,

9 Karen Smith Stegen. 2015. "Heavy rare earths, permanent magnets, and renewable energies: An imminent crisis." *Energy Policy* 79, 1-8.

10 See U.S. Department of Energy, Critical Materials Strategy (December 2011), 12

11 U.S. Geological Survey. 2015. *Lithium*. U.S. Geological Survey: Mineral Commodity Summaries. https://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2015-lithi.pdf, accessed 19 February 2017.

12 Tam Hunt (2015). "Is There Enough Lithium to Maintain the Growth of the Lithium-Ion Battery Market?" Greentech Media, https://www.greentechmedia.com/articles/read/Is-There-Enough-Lithium-to-Maintain-the-Growth-of-the-Lithium-Ion-Battery-M, accessed 19 February 2017.

developing synthetic substitutes, and recycling (though the latter is currently not economically viable).[13]

Indium and cobalt are also used in renewable energy technologies including solar panels and batteries. China provides roughly half the world's indium. DR Congo provides more than half the world's cobalt.

Geological reserves are not absolutes, but a function of factors including: demand; investment in geological exploration; technologies available for geological exploration, extraction and processing, and their costs; introduction of robots and artificial intelligence in mining operations; scale economies at all levels; the accounting regulations and choice of financial model for calculation of reserves that are commercially viable to extract. The size of global reserves and their distribution among countries are therefore subject to significant changes over time.

Demand for minerals is a function of the prevalent technologies at any moment. Advances in engineering often make it possible to replace one material with another within a technology. In addition, entire technologies are sometimes replaced once scarcity develops or innovation creates viable alternatives.

In many countries, lead times for the development of mines can be in the range of 10 years. In addition some minerals critical to renewable energy technologies are mined mainly as by-products of other minerals. As a result of these and other factors, supply shortages may arise if demand increases unexpectedly or too fast. However as supplies tighten, previously uneconomic deposits may become viable, providing additional sources of supply in the medium- to long-term.

13 Steve H. Mohr, Gavin M. Mudd, and Damien Giurco (2012). "Lithium Resources and Production: Critical Assessment and Global Projections," *Minerals* 2.3, 65-84.

B) **Technology and Finance**

Significant investment will be required to develop the renewable energy technology and infrastructure contemplated in the backcasting scenarios. As a result, intellectual property may be especially important in a world dominated by renewable energy. Although intellectual property is highly valuable in the fossil fuel sector as well, a country with substantial fossil resources and limited technological competence can nevertheless receive significant revenues. In the renewable energy sector, resources are much more widely distributed and thus intellectual property rights may become more important in relative terms. This may be an advantage for countries with strong innovation cultures and research capacities.

This reality may create a shift in the source of power from securing access to energy resources (as is the case with oil and gas) to strategic positioning in infrastructure capacity and management system efficiency. As a result, in a world in which renewables are a dominant source of energy, investment and technology may increasingly become a source of cooperation or a node of geopolitical rivalry. In this context, below are three possible macro trends.

First, increased tensions between developing and developed countries over the transfer of technology: As Criekemans indicates, "from an external-geopolitical perspective, those countries that today invest in renewable energy sources and technology may become the dominant geopolitical players tomorrow."[14] Countries' R&D expenditures may need to be assessed from not only an economic or environmental perspective, but also from a geopolitical one. However, while economics and the environment are frequently considered positive-sum games where absolute gains matter, geopolitics is often seen as a zero-sum game in which relative gains are more important. As a result, trade of technology may become an area of cooperation if countries consider technology and trade primarily in economic or environmental terms, as it would then be in the interests of developed countries to share technology even at low prices. This trend is best exemplified by the emergence of "Mission Innovation" in 2015, a global initiative of 22 countries and the European Union to dramatically

14 Criekemans (2011: 8)

accelerate global clean energy innovation through governments making commitments to double their investments in research and development over five years.

Related to this, it is also important to consider how collaborative private sector platforms and multilateral institutions could influence technology transfer, whether in the form of the Breakthrough Energy Coalition, a partnership committed to broad investment in new energy technologies from public and private sources, or the Green Climate Fund. However, if countries choose to view technologies as geopolitical rather than economic or environmental assets, it should also be considered how companies—who often own the technology—might try to incentivize countries to cooperate when these countries may have little interest in doing so.

In reality, the distinction between economic, environmental and geopolitical dimensions is of course much more blurred. Yet, it is important to keep these countervailing interests in mind when trying to understand why there is tension between developing and developed countries when it comes to the sharing of renewable energy technology or why certain countries have taken particular positions. For instance, the government in Tehran is not considered to be internationalist, yet it is one of the most vocal proponents of research cooperation. Another example of where economic reasons coupled with geopolitical considerations have trumped environmental objectives is the EU's anti-dumping and anti-subsidy duties on imports of solar cells and solar panels from China.[15]

A second related trend would be potential competition with respect to renewable energy infrastructure. German energy companies are already undergoing deep transformations as they attempt to adapt to the new emerging energy landscape. The energy companies of many countries could follow. In 2015, the biggest locations for renewable energy investment were China (far out in front at $83.3 billion) and the United States ($38.3 billion), with Japan taking third place ($35.7 billion). India was up

15 European Commission: "Commission imposes duties to prevent imports of dumped and subsidised Chinese solar panel components via Taiwan and Malaysia", http://trade.ec.europa.eu/doclib/press/index.cfm?id=1461 (last accessed 02.02.2017)

14% at $7.4 billion.[16] While Asia was expected to be the major consumer region for the conventional energy, in the renewable energy dominant world, the region will have a substantial renewable energy capacity. One possibility of how China might parlay this into geopolitical leverage is if it moves ahead with its proposed $50 trillion worldwide wind and solar power grid, the "Global Energy Interconnection," which China envisions could be in operation by 2050.[17] The project envisions both global power connectivity and global power generation from the North Pole to the farms in the equator. How would other countries respond? How would this project and the technological transfers involved tether other countries to China? (See the discussion below on "supergrids.") What would happen if a new technology emerged providing a cheaper and more efficient way of transporting renewable energy, for example related to hydrogen?

Sovereign wealth funds and institutional investors could also come to play important roles, both by choosing what new energy infrastructure or technology to invest in, and through the resulting control over these assets.

Finally, one could argue that the nature of renewable energy makes its development better suited to smaller companies and privately funded start-ups, rather than the large state-owned companies predominant in the world of oil and gas. This is in part because renewable energy lends itself to a more decentralized and distributed energy generation system than fossil fuels. Cheap solar, innovative business models, and a new breed of entrepreneurs are revolutionizing how energy access issues are addressed: new players focused on "off-grid" or "mini-grid" solutions are challenging the assumption that only an expanded hub-and-spoke power grid can meet the needs of the world's 1.2 billion with inadequate access to power. These startups are mostly privately-funded and between them had raised over $450m cumulatively in case of year-2015.[18] The rise in the number of these successful start-ups that enable demand response is leading to increasingly more distributed energy systems. In turn, these more distributed systems

16 Bloomberg New Energy Finance, "Global Trends in Renewable Energy Investment 2015," Frankfurt School-UNEP Centre/BNEF, 2015; Rebecca Harrington, "The US is actually leading the way on clean energy" 6 May 2016. http://www.businessinsider.com/us-2015-renewable-energy-investments-2016-5

17 World Economic Forum, "China wants to build a $50tn global wind and solar power grid" (5 April 2016)

18 ClimateScope 2016, http://global-climatescope.org/en/blog/2016/12/15/Climatescope2016-launch/.

may require a broadening of the decision-making power away from a concentrated set of a few countries and large players to one that empowers more individuals and smaller players.

However, the opposite may be more nearly true: companies with substantial balance sheets may be best positioned to succeed in the renewable energy sector as it grows. In recent years large oil and gas companies have started to move into the renewable energy market in a significant way.[19] For example, Total's expansion into renewables has included the acquisitions of SunPower, a U.S. solar panel manufacturer for $1.4 billion and Saft a leading battery designer for $1 billion. Related, Statoil is committed to building a renewable energy business and will see in 2017 its second conventional offshore North Sea wind farm coming online, the 402 MW Dudgeon, and the 30MW Buchan Deep project, the world's first floating array.[20] The impact these seemingly deeper capital pools for investment in renewables will have in deployment and market adoption has not yet been fully analyzed but could also affect country positions toward cooperation or competition.

C) New "Resource Curse"

The high rents associated with the production and sale of fossil fuels have sometimes been associated with a variety of developmental ills, collectively referred to as the resource curse.[21] Particularly when oil and gas are produced in countries with weak institutions, the rents extracted may lead to any or all of the following: an overvalued exchange rate, a decline in non-tradeable sectors of the economy, increased corruption, authoritarian institutions, and domestic and international violent conflict.[22] The

19 Macalister, Terry. "Green really is the new black as Big Oil gets a taste for renewables," *The Guardian*, 21 May 2016.

20 Snieckus, Darius. "Ones to Watch 2017: The world's oil giants are all too aware that the tide is turning so expect more activity in wind and solar this year, writes Darius Snieckus", *Recharge News*, updated 30 January 2017.

21 Frankel, J.A. (2010) The Natural Resource Curse: A Survey. *NBER Working Paper*. www.nber.org/papers/w15836

22 Humphreys, M., Sachs, J. and Stiglitz, J. (2007) *Escaping the Resource Curse*; Overland, I. (2012) "Slippery slopes: pitfalls for the rulers of resource-rich states," in Andreas Heinrich and Heiko Pleines (eds), *Challenges of the Caspian Resource Boom: Domestic Elites and Policy-Making*, Houndmills: Palgrave Macmillan, pp. 35-45.

prevalence of the resource curse could be affected by the dominance of renewable energy in at least three ways.

First, as oil and gas lose their dominance in the energy mix, the rents associated with their production will diminish. As a result, oil and gas-producing countries will lose access to the high rents associated with the resource curse. Alternatively, without rents, which helped provide a critical supplemental income stream to certain countries, those countries may be more vulnerable to domestic unrest or conflict. This issue area is dealt with in more detail in the section below on reduced demand for oil and gas.

Secondly, there is the question of whether countries producing large amounts of renewable energy are likely to be subject to the resource curse, just as large oil and gas producers have been. A renewable energy resource curse seems unlikely to materialize for a number of reasons. Renewable energy resources are not point-source and mainly require surface area, which—in spite of possible conflicts over land ownership[23]—is less scarce and concentrated than oil or gas. Some areas have much higher renewable energy potential than others—e.g. Chile's Atacama Desert—yet potential developers may nevertheless choose to build renewable capacity domestically when faced with the national security premium of being in thrall to another state for electricity supply, or if the cost of transmission is too high. The fact that successfully deploying renewable energy requires a country to have a high governance capacity and the involvement of multiple sectors, including rare earths and metals, technology, skilled labor, manufacturing and construction, reduces the chances of "Dutch disease" (the idea that disproportionate income from one sector causes the appreciation of a country's currency, leading to the weakening of other sectors and increased long-term vulnerability). Instead, countries "specializing" in renewable energy may actually end up with more diversified and progressive economies than they would otherwise.

Finally, there is potential for a new resource curse, which would be less associated with a country's potential for renewables themselves than with its position within the energy value chain and its possession of rare earths

23 In contrast to point source resources, the construction of large solar and wind farms (with transmission lines) could require support from a wider range of stakeholders, depending on the country's land ownership patterns. There is certainly potential for valuable areas to be permitted and exploited illegally or in contravention of international transparency norms (cf. EITI standards).

and metals. As noted above, the rise in renewable energy will increase dependence on advanced raw materials to build the machines to produce solar PV panels, wind turbines, etc.—many of which require highly specialized manufacturing processes and rare earth elements concentrated in particular countries. The production and sale of these elements, in a renewable-energy intensive world, could carry significant rents, which may in turn shape the development of domestic institutions in some places as oil and gas did in the past.

D) **Electric Grids**

1) Supergrids

"Supergrids" are multinational electricity grids. Supergrids were originally designed with one principal purpose: to enhance the reliability of participating countries' electric systems. In recent years several supergrids have been proposed, with broader purposes. The Desertec project[24], the North Sea Offshore Grid[25] and the Asia Super Grid[26] are all designed for 1) resource-sharing and 2) economies of scale.[27] In these multinational supergrids, countries lacking renewable natural resources import energy, and resource-rich countries export energy to countries with high electricity prices. For instance, IRENA has found that Ukraine has a renewable energy potential of 60 TWh/yr for wind power, and 38.2 TWh/yr for solar power.[28] In January 2017, Ukraine exported electricity worth USD 21.6 million to Hungary, Poland and Moldova, while importing electricity worth USD 267,000 from Russia, USD 7,000 from Moldova and USD 4,000

24 DESERTEC. 2017. The Desertec Concept. http://www.desertec.org/the-concept

25 ENTSOE. 2017. The North Seas Countries' Offshore Grid Initiative (NSCOGI). https://www.entsoe.eu/about-entso-e/system-development/the-north-seas-countries-offshore-grid-initiative-nscogi/Pages/default.aspx

26 Nobuo Tanaka: "Asia's Tangled Power Lines: Ensure Energy Security by Building a Smarter Grid", Foreign Affairs, August 1 2012.

27 Ryan, Eamon. 2015. "The Power of a European Energy Union," *Project Syndicate*, February 23. https://www.project-syndicate.org/commentary/european-energy-union-by-eamon-ryan-2015-02;

28 IRENA, REMAP 2030: Renewable Energy Prospects for Ukraine (April 2015), https://www.irena.org/remap/IRENA_REmap_Ukraine_paper_2015.pdf

from Belarus.[29] Some proponents of supergrids argue that energy interdependency facilitated through supergrids can foster regional peace.[30]

However, there are many reasons why the rise of supergrids may have a geopolitical Janus face. The central question is this: does the interdependence and cooperation necessary to build and facilitate a supergrid mean actors become less likely to engage in various kinds of regional conflict? In a supergrid region, a country may be able to use energy as a weapon, for example by shutting off its supply to others. Before any project is finalized, there are many geopolitical tensions that could arise. In the previous example with Ukraine and its neighboring nations, given geopolitical tensions in the region the possibility of developing flexibility measures such as interconnectors to facilitate renewable energy development remains uncertain.

Another known tension that can arise is supergrid "shirking." In order to minimize the "energy weapon" threat, some actors will seek to reduce reliance on the supergrid, for example through engaging in other bi- or multi-lateral grid arrangements. Importer countries may also try to tie the supergrid "free trade" agreement to other development issues, like infrastructure finance, thereby increasing their individual (or bloc) influence over exporter countries. Furthermore, if a supergrid is to be fueled by renewables only, what happens to exporter countries' non-renewable resources in the ground and its "stranded assets?" Are they allowed to continue using or exporting non-renewables to non-supergrid countries? Moreover, both importer and exporter countries will be interested in bolstering security arrangements in the region. [31] Supergrids make all participating countries equally vulnerable to security threats; a threat to one country is a threat to all supergrid countries.[32] Exporter countries have their own various interests they will push for: who will pay for the interconnectors? Who will maintain them? Will there be a local sourcing

29 Lilliestam, Johan, and Ellenbeck, Saskia. "Fostering Interdependence to Minimise Political Risks in a European-North African Renewable Electricity Supergrid," *Green*, Vol. 2 (2012), pp. 105-109; Yu, Phelan. 2016.

30 "Tanaka Advocates Peacekeeping Through Energy in Asia," *Harvard Crimson*, September 26. http://www.thecrimson.com/article/2016/9/27/tanaka-advocates-energy-peacekeeping/

31 *The Economist*. 2017. "Electricity now flows across continents, courtesy of direct current," January 14. http://www.economist.com/news/science-and-technology/21714325-transmitting-power-over-thousands-kilometres-requires-new-electricity.

32 Yu, Phelan. 2016. "Tanaka Advocates Peacekeeping Through Energy in Asia," *Harvard Crimson*, September 26. http://www.thecrimson.com/article/2016/9/27/tanaka-advocates-energy-peacekeeping/

requirement? How will the supergrid contribute (e.g. through pooled financing) to expanding exporter countries' own national grids? Such potential areas of conflict raise questions of what institution regulates the supergrid countries' activities. How strong is that regulator, and who will be the most powerful players in that institution?

An important part of the dynamic in such cases will be the asymmetry in the interdependence of countries that are involved. In a way that is very similar to pipeline politics, the inter-state politics of building, maintaining and running a supergrid, how its exact locations are chosen and how the questions listed above will be answered to a large extent will depend on the geopolitical weight of the various participants.

These factors will also play into the domestic politics of countries. National politicians would need a "political sell" that explains why their country cannot rely on domestic production of renewables, and why its own economy should be put in jeopardy owing to a fluctuation or cutting of access someplace else on the supergrid.[33] There is also a clear appetite for "off-grid," local energy production: what becomes of this when a supergrid is built?

2) Micro-Grids and Off-Grid Solutions

While it is possible that a world reliant on renewable energy would be based on supergrids, developments might also go in the opposite direction, towards micro-grids, off-grid solutions and greater decentralization.[34] Such a development would involve reduced interdependency between states. Thus on the one hand, there should logically be reduced geopolitical competition over fossil fuel resources. On the other hand, reduced interdependency might also mean reduced incentives to avoid conflict due to dependency on fossil fuel resources. For example, in the current conflict between the Russia and the West over Ukraine, the EU has ensured that

33 Oxford Analytica, 2011. "AFRICA: Solar power industry grows more competitive," *Oxford Analytica Daily Brief* Service, September 12. http://search.proquest.com.ezp-prod1.hul.harvard.edu/docview/888387001/.

34 Overland, I. (2016) "Energy: The Missing Link in Globalization," Energy Research and Social Science, 14, pp. 122–130, http://www.sciencedirect.com/science/article/pii/S2214629616300093

natural gas is largely exempt from sanctions—in the process limiting the impact of sanctions and the level of Russian-Western conflict.[35] If the EU were better supplied with solar and wind power and no longer so dependent on Russian gas it is less likely that it would have kept sanctions away from natural gas.

It is also possible that the two opposing developments might take place at the same time, with supergrids in some places and proliferation of locally produced energy and micro-grids in other places. What geopolitical trend would be likely to accompany such a scenario is a complex question.

Off- and micro-grid solutions that can function independently from larger national or regional grids are becoming increasingly popular as a way to provide broader energy access in poor and remote areas in developing countries with underdeveloped national grids. If energy storage technology improves, they could also become widespread in developed parts of the world. Such off- and micro-grid solutions, however, also have significant disruptive potential for geopolitics, by significantly weakening the control of centralized government in several ways.

First, off-grid solutions are not only a way to significantly enlarge broader energy access in poor areas, but also to create greater options for a decentralized access to education, health, and ultimately wealth. As a result, these services, which are often provided by centralized governments—and often used by them for political leverage—will become increasingly regionalized and localized. This could challenge the social contract of many societies. Thus, citizens who provide for their own energy and have increased access to education, health and wealth independently of government programs may feel emboldened to ask for more political participation or in some extreme cases, even promote secessionist tendencies.

Second, micro- and off-grid solutions could challenge the revenue models of many governments, particularly those reliant on royalties and other centralized sources of income. The decentralization of renewables might

35 Fjaertoft, D. and I. Overland (2015) "Financial Sanctions Impact Russian Oil, Equipment Export Ban's Effects Limited," Oil and Gas Journal, Vol. 113, No. 8, pp. 66–72, https://www.academia.edu/15717548/Sanctions_Impact_Russian_Oil; I. Overland (2017) "The Hunter Becomes the Hunted: Gazprom Encounters EU Regulation", in S. Andersen, A. Goldthau and N. Sitter (eds) *Energy Union: Europe*'s New Liberal Mercantilism?, Basingstoke: Palgrave MacMillan, pp. 115-130.

incentivize better tax collection systems due to the small, fragmented revenue streams they produce, but the capacity for consumers to move off-grid (hence out of the tax system) is a risk that states should anticipate.[36]

Thirdly, centralized governments will lose much of their ability to pressure insurgent or secessionist regions that strive for more autonomy into submission by controlling the supply or price of energy. One such example are events in Yemen in 2014, when a surge in off-grid energy sources allowed many individuals and communities to keep power supply stable even as the capital descended into political chaos. Decentralized electricity production based on renewables could also reduce the ramifications of political turmoil in specific regions (when compared to fossil fuels dependence) since such events would only undermine a small part of total energy production.[37]

3) Cyber Risks

For several reasons, renewable energy technologies may be more vulnerable to cyber attacks than conventional energy systems. For other reasons, renewable energy technologies may be less vulnerable to cyber attacks. The balance between these will depend on number of factors.

As a starting point, renewable energy technologies have the same basic cyber vulnerabilities as any other industry controlled by Supervisory Control and Data Acquisition Systems (SCADA). Critical infrastructure and the computer systems used to manage energy generation and distribution must be protected from cyber intrusion and attack to ensure continuity of service.

However to the extent that large-scale deployment of renewable energy is associated with development of supergrids, there could be increased vulnerability to cyber-attacks. First, the cyber vulnerabilities of the weakest

36 Kolstad, I. and Wiig, A. (2009) "Is transparency the key to reducing corruption in resource-rich countries?" World Development 37(3): 521-532.

37 Casertano, Stefano (2012) *Risiken neuer Energie—Konflikte durch erneuerbare Energien und Klimaschutz* (Risks of New Energy—Risks Posed by Renewable Energy and Climate Protection). Brandenburg Institute for Society and Security (BIGS), No. 9.

country on the supergrid are likely inherited by all other countries reliant upon that grid. Second, a cyber-attack on one country may impact other countries reliant upon the same supergrid. Finally, a skilled cyber attacker might be able to use the interconnected nature of the supergrid to selectively generate mistrust or create conflict between nations reliant upon the same infrastructure. If one nation, among the many that rely on that supergrid, finds itself without power, it may accuse a neighbor of being responsible for the shortage, especially in the face of limited or confusing evidence.

In addition, some renewable energy sources rely on batteries for periods of limited energy generation. These systems rely on computers to manage, charge and discharge the batteries, which has thermal side effects. If intentionally mismanaged as a result of a cyber intrusion, a battery fire is possible, which presents significant issues in the form of challenging fire suppression, high cost damage to infrastructure and release of toxins.

However, to the extent that renewable energy technologies are part of micro-grids or off-grid solutions, they might reduce vulnerability to cyber attack. Off-grid solutions might survive an attack on the grid, providing power in emergency situations. Even micro-grids that are not fully islanded from the main grid could provide backup power in the event large central generation facilities were disabled by a cyber attack.

E) **Reduced Oil and Gas Demand**

Increasing deployment of solar and wind power could lead to significantly reduced oil and gas demand. However, this is by no means automatic or guaranteed. First, solar and wind power produce electricity, yet only 5% of global electricity generation comes from oil and 22% comes from natural gas.[38] In many places, solar and wind power may be more likely to displace coal than oil and gas. Moreover, solar and wind power cannot displace oil in the transportation sector unless they are accompanied by widespread deployment of electric vehicles. Finally, natural gas-fired generation is one of the leading tools for managing the intermittency of solar and wind power, so in some places the technologies may grow together.

However to the extent that solar and wind power, together with biofuels, reduce demand for oil and gas, there could be significant geopolitical consequences. We explore these below.

1) Impacts on Producers

A world in which renewables become a dominant source of energy would involve some obvious challenges for oil and gas producers, particularly those which have long relied heavily on oil and gas exports. The sharp oil price decline of the past several years provides an example of those challenges. Oil producers including Saudi Arabia, Russia and Venezuela have faced significant fiscal challenges from declining oil revenues. In the United States, the oil price drop has created significant unemployment in oil producing regions. The renewable energy industry certainly has potential to fill that gap, but with inevitable time lags and geographical adjustments that may prove disruptive to labor markets. A further question to consider is the position of oil majors vis-à-vis producer and consumer states.

38 http://www.tsp-data-portal.org/Breakdown-of-Electricity-Generation-by-Energy-Source#tspQvChart

For oil and gas producers, a significant shift toward renewables could have two possible effects. First, the decline in revenue generated from fossil fuel energy exports can and has provided a huge impetus for political and economic reform and for the diversification of the economies of these countries. Second, a decline in these revenues, if not spurring economic and other reforms, could create significant short-term strains and have adverse implications for political stability. For example, some current oil and gas producers, such as Russia or Nigeria, may face both relative losses vis-à-vis fast-advancing competitors and absolute declines in their growth rate. In these countries and elsewhere, the failure of government to maintain spending could lead some to question the government's authority and lead to pressures on regime survival.

The relationship between renewables, low oil prices and the so-called decline of the rentier state is far from clear, and may not be as automatic as often described. In some cases, lower oil prices have spurred serious efforts at economic reform in Saudi Arabia, the UAE, Malaysia and Indonesia. Yet in other producing countries, real efforts to diversify have not been observed, including Russia, Iraq, Venezuela, Libya, Nigeria and Angola. In Azerbaijan's case, the state has invested heavily in strengthening its security apparatus over the course of the price decline. Another group of states to consider is those with significant undeveloped oil and gas resources that may find production pathways close off as the energy transition progresses.

Regardless of whether eventual diminished demand for oil, gas, and coal lead to successful reform and diversification, or severe strains, or regime stabilization, a transformed energy mix would affect the relationships between and among countries. This could potentially affect the relative balance of power between countries, increasing the relevance of Graham Allison's Thucydides Trap. (Allison's theory postulates that big shifts in the balance of power often spurs global conflict; even simply the fear of the rise of a new power at the expense of an oil producer can be enough to spur conflict.)

Finally, one cannot conclude definitively that a world in which renewable energy is dominant is necessarily one in which the region of the Middle East loses influence or importance. Many scenarios anticipate that with less demand for oil, high cost resources will no longer be commercial to be produced. As a result, the world's remaining oil production will be concentrated in low-cost regions of the world, most notably the Middle East. Such a concentration could well bring new geopolitical power to that part of the world.

2) Impacts on Consumers

At the same time, countries formerly dependent on imported fossil fuels could see an alleviation of this burden and a consequent augmentation in domestic and international political power, or at least freedom. IRENA's "Renewable Energy Benefits" shows that the economic benefits of a transition to renewables—though overwhelmingly positive for most countries—are often unequally distributed. Nevertheless, many of the countries to date that have made significant progress in scaling up the deployment of renewables, including Morocco, Chile, Jordan and several island states, are big importers of fossil fuels. The development of renewable indigenous energy sources is a game changer for these countries and others in terms of energy security.

REmap 2030 finds that USD 275-315 billion p.a. in fossil fuel imports could be reduced in the G7 countries by 2030 and highlights the important role renewable energy can play in improving "the robustness of the energy system to external energy security shocks by exploiting economic, domestic renewable energy sources for electricity and to meet energy demand in the transport, industry and residential and commercial sectors." Related, the socio-economic benefits associated with the renewable energy sector from job creation, drivers of innovation, and in some cases enhancing the access to critical resources such as food and water, are also important to highlight. These serve as opportunities for countries with a high penetration of renewables to demonstrate domestic and international political strength, while also creating incentives for countries dependent on fossil fuel exports to take steps toward more sustainable energy diversification. Volatility in crude oil and gas prices is a major consideration for consumers, adding a significant premium on investment in either commodity and uncertainty. As national climate policies evolve, policy uncertainty is likely to be a significant factor.

F) Avoided Climate Change

Large-scale deployment of renewable energy can help mitigate climate change by reducing greenhouse gas emissions below levels that they might otherwise achieve. This, in turn, would avoid some of the geopolitical consequences of a changing climate.

In recent years, experts from a range of disciplines have devoted increased attention to the potential geopolitical consequences of climate change, including those experts engaged in national security planning and defense in countries around the globe.[39] There has been increasing concern that accelerating climate change will exacerbate resource scarcity (particularly water and food insecurity), lead to increases in the incidence and severity of sudden-onset natural disasters, and drive involuntary internal displacement and cross-border migration, especially among vulnerable populations. Any of these factors could lead to political instability, intra- and inter-state violence and even state failure. Attribution to climate change of specific cases of severe weather or even long-lasting droughts is a source of considerable dispute in the scientific community, but many researchers are prepared to point to climate change as the clear underlying cause of large-scale human privation. To date, the most emblematic such case has been the Syrian civil war. The scientific literature shows that the historic drought from 2006 to 2011 drove rural-to-urban migration throughout the country.[40] Subsequently, newly-arrived migrants formed a core of the anti-Assad movement in the early days of the Arab Spring.[41] This is not to say that climate change alone *caused* the uprising in Syria,

39 See, inter alia, National Security Council (2015). *National Security Strategy*. National Security Strategy Archive. http://nssarchive.us/national-security-strategy-2015/, accessed 19 February 2017; G7 (2015). *A New Climate for Peace: Taking Action on Climate and Fragility Risks*. G7 https://www.newclimateforpeace.org/#report-top, accessed 19 February 2017; Australian Department of Defence (2016). *Defence White Paper*. Australian Department of Defense, http://www.defence.gov.au/WhitePaper/Docs/2016-Defence-White-Paper.pdf, accessed 19 February 2017.

40 Colin P. Kelley et. al. (2015) Climate change in the Fertile Crescent and implications of the recent Syrian drought. Proceedings of the National Academy of Sciences 112.11, http://www.pnas.org/content/112/11/3241.abstract; Peter H. Gleick, "Water, Drought, Climate Change, and Conflict in Syria," 1 July 2014, American Meterorological Society, http://journals.ametsoc.org/doi/abs/10.1175/WCAS-D-13-00059.1; Benjamin Cook, et al (4 March 2016), "Spatiotemporal drought variability in the Mediterranean over the last 900 years", Journal of Geophysical Research, http://onlinelibrary.wiley.com/doi/10.1002/2015JD023929/full

41 Caitlin E. Werrell and Francesco Femia (editors), The Arab Spring and Climate Change: A Climate and Security Correlations Series, https://climateandsecurity.files.wordpress.com/2012/04/climatechangearabspring-ccs-cap-stimson.pdf; John Wendle, "The Ominous Story of Syria's Climate Refugees," Scientific American, 17 Dec 2015 https://www.scientificamerican.com/article/ominous-story-of-syria-climate-refugees/

which arose from a wide variety of factors, but that the complexion of the conflict would likely be different had it not been for those climate change impacts.[42]

As a result of the increased focus on climate change and national security, the imperative for international efforts to reduce greenhouse gas emissions as much possible (the Paris Agreement calls for policies and measures sufficient to limit climate change to "well below" 2 degrees Celsius) takes on an important conflict prevention dimension. Strategies to greatly expand the amount of low and-zero carbon energy sources could reduce conflict risk. Such calculations would likely become an increasingly important part of state strategies in international climate negotiations. In fact, it is reasonable to expect that champions of a high-renewables or other low-emissions future could over time enjoy significant soft power and credibility advantages over states not prepared to respond adequately to the threat of climate change.

Thus, to the extent that high penetration of renewables leads to a reduction in greenhouse gas emissions, the probability of conflict and instability could fall, or could fail to rise as much as they might otherwise do. Regardless of the challenges of "attribution" today, reducing greenhouse gas emissions could help avoid runaway climate change, which would make conflict prevention substantially more difficult.[43]

Renewables themselves also have the potential to be an important source of sustainable development, including in countries badly needing to alleviate energy poverty. Renewable energy development can contribute directly or indirectly to achieving all the Sustainable Development Goals (SDGs). As analysis from IRENA notes, "Renewables contribute to SDGs aimed at environmental sustainability by mitigating the local and global environmental impacts of energy consumption. They support human development by facilitating access to basic services, improving human health and supporting income generation activities. Finally, renewables also contribute to sustainable economic growth by generating economic benefits such as new

42 Colin P. Kelley et. al. (2015) at note 40.

43 World Bank, *Turn Down the Head: Confronting a New Climate Normal,* (2014) http://hdl.handle.net/10986/20595

jobs and industries."[44] The case for renewables, in turn, can be bolstered by important—but politically complex—policy choices. Most significantly, the removal of economically-inefficient subsidies supporting the development and consumption of fossil fuels would create a level playing field in which renewable energy projects could thrive, bringing all the attendant climate and economic benefits.

One region where wide-scale deployment of renewable energy may have especially significant geopolitical consequences is Africa. Few if any parts of our world are more vulnerable to climate change and its attendant risks, including mass migration and conflict. In Africa, the impetus for poverty alleviation and economic development intersects with the need to increase resilience against a variety of potential climate change impacts.[45] Furthermore many African nations have not made fossil fuel legacy investments and can thus avoid carbon "lock-in." States on the continent enjoy several opportunities for accelerating the clean energy transition. An Overseas Development Institute report on the low-carbon transition cites sub-Saharan Africa's solar radiation potential.[46] Many states with robust official development programs have focused on bridging energy gaps in Africa and that focus is likely to continue with the implementation of the Paris Agreement.

One important challenge to be recognized is that a sense of urgency over the response to climate change may not only stimulate the effective use of renewable energy and other low-carbon energy systems. Some may call for geoengineering solutions out of a belief that we need to apply emergency measures to limit climate change. This could lead to challenging—perhaps intractable—policy debates, with adherents asserting that geoengineering will help buy time with less aggregate climate change, and opponents arguing that it will introduce still further uncertainty in our climate system.

44 IRENA, *Rethinking energy 2017*, p. 95-96.

45 African Development Bank (2011), "Low Carbon Development and Energy Access for Africa," ADB, accessed 1 March 2017, https://www.afdb.org/en/cop17/programme/low-carbon-development-and-energy-access-for-africa/

46 James Ryan Hogarth, Caroline Haywood, and Shelagh Whitley (2015), *Low-carbon development in sub-Saharan Africa: 20 cross-sector transitions*, ODI, accessed 1 March 2017, https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9878.pdf.

G) Access to Sustainable Energy

Access to modern forms of energy is one of the key preconditions for achieving sustainable development. Yet, some 1.06 billion people world-wide still have no access to electricity and some 3.04 billion people still do not have access to clean cooking.[47] The situation is particularly critical in sub-Saharan Africa and developing Asia, the two regions characterized by the highest levels of energy poverty. Africa, for example, represents 16% of the global population but less than 6% of the global energy demand.[48] Widespread energy poverty stands in stark contrast to large energy reserves in Africa, including oil, natural gas, coal and various sources of renewable energy.[49]

The implications of energy poverty are manifold.[50] First and foremost they include adverse effects on human health, economic development, employment opportunities and the environment. Access to energy is also essential for the provision of education and the participation in the internet and more broadly telecommunication services. As such there are at least two aspects to take into account when assessing geopolitical implications. First, energy poverty has been described as a "threat multiplier", which means that it can enhance already existing challenges and lead to political instability and unrest.[51] Second, poverty and instability are two crucial push factors leading to an increase in global migratory pressures. It follows that by providing sustainable livelihoods, access to modern energy sources can reduce both the risk of internal unrest and the need for people to emigrate from poverty. This energy-security-nexus has not received sufficient attention in research and policy and should be further assessed in more detail.

Fossil fuels are likely to continue to play a role in providing energy access, especially where on-grid generation is feasible. However, renewable energy sources have significant potential for providing sustainable and reliable services to the poor. In particular, decentralized renewable energy systems

47 GTF (2017) Global Tracking Framework. http://gtf.esmap.org/data/files/download-documents/eegp17-01_gtf_full_report_for_web_0511.pdf

48 IEA (2016), World Energy Outlook 2016, IEA/OECD, Paris.

49 BP (2016), BP Statistical Review of World Energy, June 2016.

50 Behrens, A. et al. (2012), Escaping the Vicious Cycle of Poverty: Towards Universal Access to Energy in Developing Countries, CEPS Working Document No. 363, March 2012, Brussels

51 Bazilian, M. D. (2015), Power to the Poor, Foreign Affairs, Volume 94, Number 2, March/April 2015.

such as hydro, solar, wind and modern biomass can provide the opportunity for clean and cost-effective electricity and heat generation especially in rural off-grid areas. According to UNEP, 70% of people without access to electricity can be reached through such decentralized off-grid solutions.[52] These kinds of small-scale, mini-grid and off-grid solutions in sparsely populated rural areas often turn out to be more successful and cheaper than providing large-scale and on-grid solutions.[53] In this way, renewables can provide for cheaper alternatives and avoid an unnecessary rise in greenhouse gas emissions and the related "carbon lock-in". In addition, they can provide direct rural employment opportunities and reduce urbanization pressures.

All of this is also linked to the achievement of the Sustainable Development Goals (SDGs). SDG7 calls for universal access to affordable, reliable, sustainable and modern energy services and can be considered as an "enabling factor" for sustainable development due to its links with progress towards other SDGs. The SE4All initiative lists some of the positive impacts of energy access on "eradicating poverty, increasing food production, providing clean water, improving public health, enhancing education, creating economic opportunity, and empowering women".[54] The geopolitical impacts of access to energy are thus important, as it contributes to lasting solutions to instability and conflict.

52 UNDP (2016), UNDP Support to the Implementation of Sustainable Development Goal 7, http://www.undp.org/content/undp/en/home/librarypage/sustainable-development-goals/undp-support-to-the-implementation-of-the-2030-agenda/

53 Behrens, A. et al. (2012), Escaping the Vicious Cycle of Poverty: Towards Universal Access to Energy in Developing Countries, CEPS Working Document No. 363, March 2012, Brussels

54 SE4All (2014), SE4All Energy Access Committee Report, 20 August 2014, http://www.se4all.org/sites/default/files/l/2014/12/Energy-Access-Committee-Report.pdf

III. Uncertainties

Increased use of renewable energy may bring greater predictability in some ways, but greater uncertainty in others. Oil markets are notoriously unpredictable, but in some ways renewable energy may bring new uncertainties even compared to oil. First, although the oil price is inherently difficult to forecast and is affected by numerous exogenous factors, it is at least dependent on international oil markets, an established and familiar system that has existed for a long time. Second, similar to most other commodity markets, the oil trade is subject to cycles of oversupply and undersupply; highs are ultimately followed by lows, and lows by highs. With the current growth of renewable energy, we are instead dealing with the disruption of old markets and the creation of new ones, which are not known yet. Third, while there is considerable technological uncertainty in the petroleum sector—as exemplified by the unexpected improvements in fracking (and in the future, possibly the use of microwaves to exploit oil shale or technologies for extracting gas hydrates)—the technological uncertainty of renewable energy is significantly greater. This is because it involves several entirely separate types of energy sources, and energy generation, transportation and storage.

IV. Options for Further Analysis

There are several options for further analysis of the geopolitical consequences of a transition to renewable energy:

Scenario building

Foresight methodology was developed by Shell to deal with the uncertainties in the petroleum sector. This approach makes some sense when it is not possible to make more accurate predictions, and its main purpose is to raise consciousness about the range of possible outcomes, the interaction between different factors and ways in which one might position oneself for the future or try to shape it. Despite its lack of rigor, this approach has become the default for handling large-scale, complex and unpredictable systems and processes, especially when large financial values are at stake. Foresight scenarios are often most useful to those who participate in their making, while they can be difficult to communicate to an external audience.

Modeling

For some academics and policy makers, formal modeling of the global energy system and its transformation would be preferable to the subjectivity of foresight methodology. However, it is difficult to model a situation where a system is not only affected by some factors, but the entire system is transformed into something else. It is also generally more difficult to model politics than economics, and availability of relevant data may be a significant challenge. An attempt at modeling the geopolitical consequences of a transition to renewable energy would require relevant competence and a large amount of funding, and might be most appropriate for an international financial institution.

Index of geopolitical vulnerability

It would be possible to create an index to map the geopolitical sensitivity of different countries to a full makeover of the global energy system. This would have the advantage of being more rigorous than foresight scenario building, while also being more feasible than modeling. Such an index could be based on indicators drawn from secondary data, for example:

- Business climate for renewable energy
- Innovation capacity
- Governance capacity
- Renewable energy resource potential (wind, solar, hydro, geo, bio)
- Trade surplus/deficit related to hydrocarbons, consumption, reserves

Geographically based review

It would be possible to do a more qualitative, geographically based review of the possible consequences of a transition to renewable energy, country-by-country, or region-by-region. Such a review would have to focus on selected countries and regions, for example:

- African oil producers (Angola, Nigeria)
- East Asia (China, Japan, Korea)
- Latin American oil producers (Brazil, Colombia, Mexico, Venezuela)
- EU
- MENA oil and gas producers
- Post-Soviet oil and gas producers (Azerbaijan, Kazakhstan, Russia, Turkmenistan)
- USA
- Major industrialized oil and gas exporters (Canada, Netherlands, Norway)

If one were to select two highly relevant geographical areas to focus on, they might be Russia and MENA. Russia because it is the only (former/potential) great power that is a major oil and gas exporter; MENA because it has such a high concentration of petroleum resources, such a long history of foreign intervention and such great solar power potential.

Such an analysis could also attempt to identify significant dyadic trade relationships, both those that exist in the current energy system (and which might fade with a transition to renewable energy) and those that might emerge in a future energy system dominated by renewable energy.

- EU—Russia
- EU—Maghreb
- Russia—post-Soviet neighbors
- Saudi Arabia—US
- Saudi Arabia—Iran
- China—Gulf
- China—Russia

Analytical distinctions

Cutting across the analytical design options outlined above are several different analytical distinctions. These could be used to structure the analysis, or choices could be made to focus on some and exclude others.

- Changes in the energy system itself versus geopolitical consequences of these changes.
- Fading of old versus emergence of new energy system.
- Risks versus benefits.
- Transition period versus end state.
- Shifts in geopolitical power versus interests versus alliances.
- Winners versus losers.

- Typological distinctions (oil exporters, oil importers, major coal producers, countries with large renewable energy resources, low and high governance capacity).
- Assumptions versus uncertainties.

V. Conclusion

It has long been evident to strategists and policymakers that energy is a significant driver of foreign affairs. For nearly a century, the intersection between energy and geopolitics has centered around fossil fuels. As this preliminary paper suggests, the importance of renewables as a significantly growing portion of the global energy mix could have significant implications for geopolitics as well. This will include both opportunities and challenges.

Having highlighted the considerable uncertainty involved in anticipating how a transition to renewable energy will affect the political situation in the world, it is worth noting that uncertainty does not necessarily mean conflict. There are reasons to believe that at least in the long term, a global energy system dominated by renewable energy will be more stable, peaceful and just than one dominated by fossil fuels and nuclear technology. The geopolitical path towards this end state is, however, unknown. Further developing the ideas above, as well as new ones not set forth in this paper, is the first step in helping the world anticipate the new geopolitics of renewable energy.

Annex I: **Literature review**

Oil and gas have long been the main object of geopolitical analysis. Unconventional oil and gas developments led to a flurry of analysis of the possible impacts on oil and gas markets, as well as political and geopolitical consequences. Although unconventional oil and gas has had a dramatic effect on supply and demand in the global oil market and on US import dependency, these effects are still shifts within the current energy system. A large-scale transition to renewable energy would likely be far more disruptive, but paradoxically this prospect has received much less attention. This difference between the attention to the geopolitics of oil and the geopolitics of renewable energy is illustrated superficially in Table 1 with some results of queries in ISI Web of Science, Google Books and Google Scholar.

Table 1. Searches for geopolitics, oil and renewable energy (January 9th, 2017)

	Search string A: "geopolitics AND oil"	**Search string B:** "geopolitics AND renewable energy"	**Ratio**, search string B / A
ISI Web of Science	132	12	0.09
Google Books	29 600	1 840	0.06
Google Scholar	48 000	23 000	0.48

There is a literature on the geopolitics of climate change, but this is a broader issue and only sometimes relevant for the geopolitics of a transition to renewable energy. And much of this literature ignores the geopolitics of the replacement of fossil fuels by renewable energy. For example, a special issue of the journal *Climate Policy* from 2013 on the geopolitics of climate change pays scant attention to the question of how climate policy will affect petroleum exporters and importers or oil companies (Streck and Terhalle, 2013). The topic has also been ignored in other analyses of geopolitics and climate change that might have been expected to cover it (e.g. Falkner, 2010).

In sum, it is paradoxical how little analysis has been done of the geopolitical consequences of renewable energy compared to the geopolitics of oil. However, as Table 1 shows, it would also be erroneous to claim that no research has been done on the geopolitics of renewable energy. In the following sections we provide an overview of the existing research.

Overview

Researchers from Germany and the Netherlands have taken the lead in examining the geopolitics of renewable energy. This may be due to the emphasis on a transition to renewable energy in the domestic energy policies of these two countries, as this is likely to raise both consciousness about the potential consequences and lead to funding opportunities. Scholars and experts based at German research institutes and think tanks and other institutions dealing with energy issues pioneered the field: Krewitt et al. (2009), Westphal (2011), Casertano (2012), Westphal and Droege (2015) Huebner (2016), Strunz and Gawel (2016). They were later followed by scholars based in the Netherlands who have done some of the most substantial work to date: Bosman and Scholten (2013), De Ridder (2013), Sweijs et al. (2014), Scholten (2016).

The most thorough research on the renewable energy–geopolitics nexus today is that by Criekemans (2011), Scholten and Bosman (2013), Sweijs et al. (2014) and Paltsev (2016). A reader interested in getting an overview of the central issues might turn to those works.

Much of the existing research in this field is in the form of gray literature, i.e. working, papers, reports, dissertations, etc. The work that has been published by proper journals and book publishers is spread among many different publishing outlets, suggesting that so far no journals or book publishers have focused on this issue-area over time.

In the next sections we survey the literature in thematic clusters.

Geopolitical benefits

Peters (2002) was one of the first scholars who argued that developing renewable energy would lead to a more equitable energy distribution and lower geopolitical tensions. Thus Peters was a pioneer in this field, but it should also be noted that given the fast pace of change in the petroleum and renewable energy sectors, as well as in climate policy, any literature more than a few years old is likely outdated.

Verrastro et al. (2010) and Johansson (2013) argue that, contrary to the assumptions of actors who are concerned about intermittency, renewable energy may strengthen energy security while at the same time it will inevitably lead to the emergence of new interdependencies between the countries. According to Kostyuk et al. (2012), renewable energy expansion is likely to lessen the role of geopolitics in international relations. In their view, renewable energy will increase the availability of energy and thus make it less prone to political tension. They conclude that the world is presently at an important crossroads in terms of the future energy path. Hoggert (2014) notes that small-scale photovoltaics (and nuclear power) technologies are likely to promote a secure low carbon transition with reduced geopolitical risks. Krewitt et al. (2009: 23) indicate that the creation of international solar energy partnerships would have geopolitical advantages because they could "reduce economic imbalances between the North and the South and create global markets for future-oriented energy technologies without having to fear conflicts over scarce resources."

Ministerio de la Defensa (2015: 11–12) argues that a world in which renewables are the main sources of energy will allow a high degree of energy self-sufficiency in all countries, shifting the focus from securing an external supply of fossil fuels to managing the internal supply of renewable energy. According to Casertano (2012), decentralized electricity production based on renewable energy can greatly reduce the risks compared to fossil fuels because local events can only undermine a small part of total energy production. Renewables are less geographically concentrated than traditional energy sources, making it difficult for individual countries to control or limit the energy supply and manipulate the market price.

Sweijs et al. (2014: 73) note that

> … the pathway to a renewable energy transition on a global scale is not only a story of painful adjustment and social unrest. If extractive rentier regimes in countries highly dependent on fossil fuel exports are toppled, it could pave the way towards more inclusive forms of government, provided there is enough 'critical mass' among the general population. This could open the door towards greater democratization in rentier states. In this sense renewable energy can act as a beacon of opportunity for impoverished nations whose economies thrive on a single commodity and who are ruled by secretive, non-accountable, extractive regimes.

Geopolitical downsides

Other authors note that energy transition generates new types of conflicts and that renewable energy may take over the role that has been played by fossil fuels and become a driver of new geopolitical tensions in its own right (Sujatha 2013; Laird 2013). Dirmoser (2007) notes that the increased use of renewable energy and energy efficiency had made little impact on energy security yet. However, the picture may look different now.

In case of a large-scale renewable energy production and transportation across borders in the form of electricity (rather than for example hydrogen), the principle of territorial control will be similar to that for oil and gas pipelines. Potential renewable energy exptoring countries like Algeria, Mexico or Morocco, or transit countries, or actors such as the Islamic State, could still try to leverage their geographical position and in case of conflict they could threaten to interrupt electricity supplies.

Various scholars argue specifically that the transition phase between the old energy system(s) and one dominated by renewable energy poses numerous geopolitical risks (Rothkopf 2009; Westphal and Droege 2015; Westphal 2011). For Westphal and Droege 2015), the metamorphosing global energy mix will bring more diversity, but also less security. Paltsev (2016) argues that supply and demand for energy will remain an important factor influencing the global balance of power in the future. Rothkopf (2009: 1) argues that while energy transition will eliminate some conventional security risks, other new risks will emerge and geopolitical tensions will intensify. He notes that the energy transition causes instability and that while oil wars are likely to come to an end, "…there will be new types of conflicts, controversies, and unwelcome surprises in our future (including perhaps a last wave of oil wars as some of the more fragile petrocracies decline)." He concludes that the decline of the petrostates will have complex consequences.

Vulnerable states

Mecklin (2016) notes that transition to a global energy system dominated by renewable energy will create new geopolitical winners and losers. De Ridder (2013) notes that the main losers of the new geopolitics of minerals for renewable energy are the resource-poor countries of the developing world which have limited financial resources available to purchase new technologies. Numerous studies explore risks related to stranded fossil fuel assets and assess the imperative for divestment (Caldecott et al. 2015a; Caldecott et al. 2015b; Ansar et al. 2013; Generation Foundation 2013; OECD 2015; Caldecott et al. 2014; Carbon Tracker Initiative 2013). Except for Rothkopf (2009), Sweijs et al. (2014) and Hache (2016), this literature is however focused on companies and financial risks for investors rather than the power and survival of states and is thus not always directly relevant for geopolitics.

Table 2 summarizes the work by Sweijs et al. (2014) on the short-, medium- and long-term impacts of energy transition on international security dynamics. We should note that Sweijs et al. focus more on the end state of a transition to renewable energy and premise that the whole world adopts more renewable energy, while acknowledging that the path to increased renewable energy "is likely to be bumpy" (Sweijs et al 2014: 15).

Table 2. Impact assessment of energy transition on global security dynamics

Drivers	Security implications	Examples	Short- and medium-term impact	Long-term impact
Structural inequalities reduced by EU renewables policy	More fossil fuels resources available for rest of the world	More fuels to burgeoning economies in Asia and Africa	EU: gradually less need to be involved in international disputes, but international tensions over energy could still increase	Positive impact on overall energy-related conflict worldwide if rest of world also makes transition to renewable energy
Developing and accessing new resources	Less pressure to secure new resources off- or onshore	Less tensions in South China Sea, Arctic Sea	Tensions concerning access to new resources could increase if demand goes up	Tensions could decrease if supply outstrips demand
Energy as a coercive instrument	Energy will be less useful as stick or carrot	Russia, Gulf States, Venezuela	No price decreases expected now, energy as coercive element remains useful	Should prices decrease, energy less useful to coerce other countries

Source: Sweijs et al. (2014: 60).

Sweijs et al. (2014) also analyze the degree of dependency and vulnerability of different countries to the EU energy transition and conclude that the following countries are the most exposed to vulnerability:

- Russia (most exposed)
- Algeria
- Egypt
- Qatar
- Saudi Arabia
- Kazakhstan
- Libya (least exposed out of these countries)

Table 3 lists the risks and impact of the energy transition on security dynamics in rentier states. In addition to the impact of the EU's energy transition, transitions in major non-European importing countries such as China, India, and the US can be expected to have a significant effect on other countries. The rise of shale gas and oil in the US had a powerful impact on US oil imports and on natural gas and especially oil prices around the world. A transition to renewable energy in the US might have an even greater impact.

Table 3. Impact assessment of EU energy transition on rentier states

Drivers	Effect	Examples	Short- and medium-term impact	Long-term impact
Lower demand for fossil fuels in Europe	Loss of export revenue for hydrocarbon producer countries that export to Europe	Russia, Algeria and Libya lose a signi cant share of their export revenues	Erosion of government in Algeria, Libya, Russia. Risk of social unrest. Other exporters may limit effects by rerouting exports to emerging economies.	Erosion of government in countries such as Qatar, Saudi Arabia if emerging economies adopt similar energy transition
Lower attractiveness to establish access to and permanent control over oil and gas resources	Less government focus on wealth accumulation from oil and gas. Fewer energy-driven conflicts, coup d'états and secessions.	Fewer long term tensions in West Africa, Sub-Sahara Africa, Latin America, and the Middle East	Could in short term lead to social unrest as tacit dissatisfaction with the ruling regime rises to the surface, possibly toppling autocratic governments	Opportunity cost for overthrowing the government to gain control over the country's 'prize' is raised. Could open door towards greater democratization
Downward pressure on oil price	Fuel subsidies become untenable. Slashing subsidies out of austerity raises risk of popular unrest	Weaker purchasing power in MENA, Russia, Caspian Region, West Africa, Sub-Sahara Africa	Street protests over erosion of living standards, possibly toppling autocratic governments	Less authoritarianism in rentier states as attractiveness of control over natural resources declines. Incentive to diversify the economy.

Source: Sweijs et al. (2014: 73).

Dreyer (2013: 1) argues that "the politics of renewable energy has remained largely connected to national boundaries and has had few international ramifications" and that despite potential benefits, "it is hard to identify a geopolitically significant 'renewables' dimension to global security or energy politics." She claims that renewable energy is not currently providing a foundation for EU diplomatic action, as other energy sources previously did, but can and should be used more actively in the future. For her, increasing renewable energy imports to the EU from the neighboring countries would help orient these countries towards Europe rather than the Middle East. Thus, increased interdependence with those countries would benefit of the EU. Dreyer calls for a more active role for international organizations such as the OECD (including the IEA) and the WTO.

Uncertainty

Paltsev (2016: 394) holds that the future geopolitics of renewable energy will be similar to the post-cold-war situation, where it was often uncertain "what the next challenge will be, what form it will take, or where it will come from." One of the reasons for this is that energy transition forces many countries with low technological competence to take decisions that have geopolitical ramifications. Bradshaw (2010) notes that energy transition brings uncertainty in terms of energy supply and demand and that it is unclear how energy transition will be attained. According to Stang (2016) and Umbach (2016), the geopolitical implications for energy markets of the Paris climate agreement are numerous and need to be better understood.

Bosman and Scholten (2013: 1) argue that an energy system based on renewable energy sources has implications which remain "highly uncertain." They conclude that "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." Hache (2016) notes that the challenges posed by energy transition could be as complex as the present geopolitics of fossil fuel energy. He notes that the combination of local and decentralized relations as well as technical, economic, sociological, behavioral, spatial and legal dimensions add to the overall complexity and create new unexpected and unexplored interdependencies among the states.

Changes in the international system

Casertano (2012: 6) notes that renewable energy "democratizes" the energy supply and creates new network structures that can be called "Internet of Energy". Rifkin (2011: 37) argues that deployment of renewable energy can lead to a "Third Industrial Revolution" and democratize the international energy system. Criekemans (2011: 8) indicates that "from an external-geopolitical perspective, those countries that today invest in renewable energy sources and technology may become the dominant geopolitical players tomorrow… Some predict a duo-multipolar order (led by the US and China), others think that the external-geopolitical landscape of a world run on renewable energy will be more in terms of a multipolar world where power is spread more equally across the globe."

Ladislaw et al. (2014) and Chevalier and Geoffron (2013), frame energy transition as the emergence of new geopolitics. Paltsev (2016) notes that the expansion of renewable energy on a global scale will inevitably lead to the emergence of new hubs of geopolitical power with supply-side geopolitics being sidelined. He argues that low-carbon energy geopolitics, perhaps to an even greater extent than oil and gas, depends on a multitude of factors (e.g. access to technology, power lines, rare earth materials, patents, storage, unpredictable government policies), thus making renewable energy governance more complex. He emphasizes that in a new energy system the players are more decentralized compared to the players in the old system driven by fossil fuels. Scholten and Bosman (2016) draw up scenarios and conclude that most likely we will see a mix of the characteristics of the old system and new characteristics.

De Ridder (2013: 19–20) envisages that an energy transition will lead to the emergence of new players and will move the international system towards greater multipolarity. She lists three major geopolitical implications: 1) countries with reserves of important industrial minerals will become more powerful; 2) parts of the world with major mineral reserves, such as the Arctic and the South China Sea, will rise in strategic importance; 3) there will be a gravitational shift towards countries that control technologies and know-how on minerals and technologies for renewable energy. De Ridder notes (2013: 20) that "countries with high R&D expenditures on renewable energy, such as Japan and China, and countries with strong growth in renewable energy capacity such as Denmark and Germany, will gain [geo-political] power."

Huebner (2016) explains that renewable energy will have an important role to play in the global energy supply, but only in the medium term. He lays out a vision in which renewable energy leads to new forms and levels of regional cooperation. Thus, he sees a transition to renewable energy as still involving trade, but at a regional rather than a global level. Endeo (2014) highlights the potential for cooperation between the states on the northern coast of the Mediterranean coast and those on the southern coast, as well as the potential contribution to EU energy supplies.

Scenarios and typologies

Bosman and Scholten (2013) and Scholten and Bosman (2016) present what they refer to as scenarios for renewable energy expansion based on thought experiments, dividing countries into different groups according to their renewable energy potential. They conclude that, compared to a fossil-fuel dependent energy system, in a system dominated by renewables infrastructure management is more important than access to resources. Geopolitical tensions and risks should therefore recede, due to falling energy imports and reduced interdependence between countries. Scholten and Bosman (2016: 281) note that the "presence of 'prosumer countries' lessens cross-border energy trade and in turn reduces geopolitical tensions to those related to clean generation technology imports."

Metals and industrial minerals scarcity

Grandell et al. (2016) argue that a shift to renewable energy is inevitable and model the global transition of the energy sector taking into account the availability of critical metals. They conclude that the scenarios put forward by 5th Assessment Report of the International Panel on Climate

Change (IPCC) are partly unrealistic from the perspective of critical metals as they "do not consider material availability aspects" (Grandell et al. 2016: 61). Exner et al. (2015), Hurd et al. (2012) and Rothkopf (2009) argue that while renewable energy helps reduce dependence on oil and gas, it also increases dependence on metals (which are also geographically concentrated resources). De Ridder (2013) argues that the ambitious renewable targets set by different countries boost demand for certain minerals, which in turn raises international competition and may also have geopolitical implications. According to a report of the International Council of Mining and Metals (2012: 6), various metals are needed as inputs for low carbon technologies (including renewable energy) but "[T]he exact nature of the low carbon transition on both minerals and metals demand will differ depending on which technologies are favored."

Other aspects

Several scholars discuss other implications of an energy transition. Overland (2015) provides a comprehensive overview of the geopolitical consequences of climate policy, many of which are also relevant for a transition to renewable energy. Salzman (2016) argues that energy transition and climate change policies in Europe may have serious geopolitical effects but this will hardly have any impact on the EU–Russia relationship. Szarka (2016) discusses that prospects of energy transition in the EU, including a switch to 100% in renewable energy and its implications. He notes that some of the EU member states have differing visions and plans on energy transition compared to that of the EU Commission—ambitious vs modest plans. Pascual (2015), taking the case of the US as his starting point, highlights the existing gaps in our understanding of the new energy geopolitics driven by climate change. Fischhendler et al. (2015) note how geopolitical arguments relating to the energy independence of Israel are used to mobilize decision-makers in favor of renewable energy. Strunz and Gawel (2016) use the example of Germany's Energiewende and conclude that renewable energy reduce energy import dependence for the country without elaborating on potential implications of that trend. Overland and Kjaernet (2009: 1) present the transition to renewable energy as a "global strategic race", in which successful countries will gain an economic advantage over other countries.

Methodological note

The literature search was carried out using ISI Web of Science, Google Scholar and Google. We searched in English, French, German, Russian, and Spanish. (Adding Arabic, Chinese, and Japanese might have enabled us to further expand the literature review.) We covered the period 2000–2015 and the same keywords and combination of keywords were used in each language. In addition to searching these databases, we examined the bibliographies of those works we found.

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Annex II: **Workshop Program**

Workshop—the Geopolitical Implications of Renewable Energy

March 22-23, 2017

German MFA, Kurstrasse 36, Berlin, Germany

Agenda

DAY 1

12:30-14:00 **Lunch with Welcoming Remarks**

Director General Miguel Berger, Head of the Department of Economic Affairs and Sustainable Development, Federal Foreign Office and Director General Adnan Amin, IRENA

14:00-15:15 **Session 1.** Renewable Energy Deployment Scenarios: finding an analytical basis for geopolitical analysis. (See Section I of the framework paper)

Introductions by Michal Taylor and presentation of the REmap and G20 Decarbonization Study by Dolf Gielen, IRENA.

DISCUSSION QUESTIONS:

- What are different projections for renewable energy in the future?
- What are the specific strengths and weaknesses of the different scenarios; where are they similar and where do they differ?
- Which scenario provides the best analytical basis for geopolitical analysis?

15:15-15:30 Coffee Break

15:30-16:45 **Session 2.** Critical Material Supply Chains: the implications of the unequal distribution of minerals, metals, and technologies needed for renewable energy. (See Section II.A of the framework paper)

Moderator/Introduction by: David Sandalow, Columbia

DISCUSSION QUESTIONS:

- Where are key natural resources for renewable energy located, and how will the nature of these resources affect energy supply and security in the future?
- To what extent could mineral inputs needed for renewable energy—as well as renewable energy technologies and intellectual property—create the potential for new cartels, threats of scarcity, or conflict over resources?

16:45-17:00 Coffee Break

17:00-18:15 **Session 3.** Topic A: Technology and Finance: a shift in the sources of power from resources to infrastructure capacity and management system efficiency? (See Section II.B of the framework paper)

Topic B: Resource Curse (Section II.C of the framework paper)

Moderator: Petter Nore, Norwegian MFA and introductions by Melanie Nakagawa, Columbia

DISCUSSION QUESTIONS:

- To what extent will increased renewable energy investment or finance for such investment become a tool of geopolitical leverage?
- Will trade in technology or the sharing of intellectual property become a basis for greater cooperation between countries or lead to competition between them?
- Do countries who become either big generators of renewable energy or renewable energy technology run the risk of developmental challenges akin to "the resource curse?"

19:00 **Reception hosted by Norwegian MFA/NUPI**

Welcome remarks by Director Vegard Kaale, Energy Section, Norwegian MFA and Director Ulf Sverdrup, NUPI.

Radisson Blu Hotel Berlin, Karl-Liebknecht-Strasse 3

DAY 2

08:45-10:00 **Session 4.** Electricity Grids: the geopolitical dynamics of super-, micro- and off-grid solutions and their vulnerability to cyber attacks. (See Section II.D of the framework paper)

Moderator: Indra Overland, NUPI; introductions by Daniel Scholten, Delft University of Technology; Antonella Battaglini, CEO of Renewables Grid Initiative

DISCUSSION QUESTIONS:

- Could the regionalization of markets through supergrids increase regional interdependence and cooperation—or is it more likely to create further geopolitical tensions?
- What are the potential implications of decentralized grids carrying renewable energy for the control centralized governments wield over their peripheries?
- To what extent will new forms of energy infrastructure bring new and potentially unique energy security problems through increased vulnerability to cyber-attacks?

10:00—10:15 Coffee Break

10:15—11:30 **Session 5.** Reduced Oil and Gas Demand: the transformation of energy markets and the implications for the geopolitical landscape. (see Section II.E of the framework paper)

Moderator: Meghan O'Sullivan, Harvard; introduction by Giacomo Luciani, Graduate Institute Geneva

DISCUSSION QUESTIONS:

- In what way could the growth of renewable energy affect global demand for fossil fuels?
- What would be the implications of such demand shifts for producer countries and how can they best prepare themselves for these trends?
- What would be the implications for consumer countries and how would the growth of renewable energy usage change the balance of power between producer and consumer countries?

11:30—11:45 Coffee Break

11:45-13:00 **Session 6.** Avoiding Climate Change: renewable energy and the geopolitics of climate change. (see Section II.F of the framework paper)

Moderator: Andris Piebalgs, FSR; introductions by Jonathan Elkind, Columbia and Peter Fischer, German FFO

DISCUSSION QUESTIONS:

- To what extent can policies designed to reduce carbon emissions help reduce the geopolitical risks associated with climate change—such as state failure and large-scale involuntary migration?
- Will greater ambition by some countries in addressing climate change confer more influence or soft power in the UNFCCC and other forums?

13:00-14:00 Lunch

14:00—15:15 **Session 7.** Wrap-up and Next Steps. (see Section III in the framework paper)

Moderator: Hans Olav Ibrekk, Norwegian MFA. Input from session rapporteurs.

Annex III: **Workshop Participants**

Last name	First name	Professional title	Institution
Abdel-Latif	**Ahmed**	Special Assistant Office of the Director General	International Renewable Energy Agency (IRENA)
Amin	**Adnan Z.**	Director General	International Renewable Energy Agency (IRENA)
Battaglini	**Antonella**	Chief Executive Officer	Renewable Grid Initiative
Bazilian	**Morgan**	Fellow	Center for Global Energy Policy, Columbia University
Behrens	**Arno**	Senior Research Fellow	Centre for European Policy Studies (CEPS)
Berger	**Miguel**	Director General, Head of the Department of Economic Affairs and Sustainable Development	Federal Foreign Office, Germany
Bridle	**Richard**	Senior Policy Advisor	International Institute for Sustain-able Development (IISD)
Clark	**Alex**	Fellow	Harvard University Kennedy School
Cremer	**Tobias**	Fellow	Harvard University Kennedy School
de Jong	**Sijbren**	Strategic Analyst	Hague Centre for Strategic Studies (HCSS)
Elkind	**Jonathan H.**	Fellow and Adjunct Senior Research Scholar	Center on Global Energy Policy, Columbia University
Fischer	**Peter**	Deputy Director General for Energy & Climate Policy and Export Control	Federal Foreign Office, Germany
Gielen	**Dolf**	Director	International Renewable Energy Agency (IRENA)
Hammbelbo	**Kirsten**	Senior Advisor	Ministry of Foreign Affairs, Norway
Hongyuan	**Yu**	Director	Shanghai Institute for International Studies
Hoshi	**Hisashi**	Director	The Institute of Energy Economics, Japan (IEEJ)
Höysniemi	**Sakari**	Doctoral candidate	University of Helsinki
Ibrekk	**Hans Olav**	Policy Director	Ministry of Foreign Affairs, Norway

Klee	**Kerstin**	Assistant Desk Officer, Foreign Energy and Commodity Policy	Federal Foreign Office, Germany
Koeppel	**Hans**	Head of Unit for Foreign Policy Issues of Energy Transition	Federal Foreign Office, Germany
Kraemer	**R. Andreas**	Senior Fellow	Institute for Advanced Sustainability Studies (IASS)
Kuntze	**Lennart**	Associate Programme Officer	IRENA
Lemphers	**Nathan**	Visiting Research Fellow, NUPI	University of Toronto
Lidner-Olsson	**Erik**	Junior Professional Associate	International Renewable Energy Agency (IRENA)
Luciani	**Giacomo**	Professor	The Graduate Institute Geneva
Molier	**Eveline**		Ministry of Foreign Affairs, the Netherlands
Nakagawa	**Melanie**	Non-resident Fellow	Center on Global Energy Policy, Columbia University
Nehls	**Estelle**		Federal Foreign Office, Germany
Noll	**George**	Counselor for Global Affairs	American Embassy Berlin
Nore	**Petter**	Chief Energy Analyst	Ministry of Foreign Affairs, Norway
Orpana	**Pekka**	Ambassador and Senior Adviser on Energy and Climate Change	Ministry for Foreign Affairs, Finland
O'Sullivan	**Meghan**	Professor / Director of the Geopolitics of Energy Project	Harvard University Kennedy School
Pedersen	**Mikkel Frøsig**	Senior Advisor	Norwegian Institute of International Affairs (NUPI)
Piebalgs	**Andris**	Senior Fellow	Florence School of Regulation (FSR), EUI
Radtke	**Frank**	Analyst	Strategic Energy Security Initiative, Germany
Sandalow	**David**	Inaugural Fellow	Center on Global Energy Policy, Columbia University
Scholten	**Daniel J.**	Assistant Professor	Delft University of Technology
Schulz	**José**	Head of Division for Foreign Energy and Commodity Policy	Federal Foreign Office, Germany
Scholz	**Benjamin**		Wintershall

Stevens	**Paul**	Professor	Chatham House
Svenningsen	**Tobias**	Counsellor	Norwegian Embassy, Berlin
Sverdrup	**Ulf**	Director	Norwegian Institute of International Affairs (NUPI)
Taylor	**Michael**	Senior Analyst	International Renewable Energy Agency (IRENA)
Töpfer	**Klaus**	Professor	Institute for Advanced Sustainability Studies (IASS)
Vakulchuk	**Roman**	Senior research fellow	Norwegian Institute of International Affairs (NUPI)
Velautham	**Sanjayan**	Executive Director	ASEAN Centre for Energy (ACE)
Westphal	**Kirsten**	Senior Associate	Stiftung Wissenschaft und Politik (SWP)
Østevik	**Malin**	Junior Research Fellow	Norwegian Institute of International Affairs (NUPI)
Øverland	**Indra**	Research Professor	Norwegian Institute of International Affairs (NUPI)

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