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European Energy policy: Roadblocks to meeting the 2050 GHG reduction targets

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European Energy policy: Roadblocks to meeting the 2050 GHG reduction targets

Rebecca H. Wortzman and G. Cornelis van Kooten

Abstract: European energy policy must address two primary issues: (1) energy insecurity because Russia is the principal supplier of petroleum and natural gas, and (2) how to reduce greenhouse gas emissions that could require economic restructuring and infrastructure investments. It took the EU nearly half a century to coordinate energy and environmental policies, although Member States continue to exercise power in these jurisdictions, which will make it increasingly difficult for the EU to meet the stringent climate mitigation goals it has committed to achieve. However, a major obstacle to its CO_2 emissions reduction targets could just as well be physical as opposed to political.

Key Words: Energy and environmental policy; electricity; renewable energy; climate change

1. Introduction

The European Union was created in 1958 by the Treaty of Rome (1957) as the European Economic Community (EEC) consisting of Germany, France, Italy, Belgium, The Netherlands and Luxembourg. It arose out of the 1952 European Coal and Steel Community (ECSC) that subsequently lasted for 50 years. However, the Treaty of Rome had little if anything to say about energy or the environment, except that coal was important to the ECSC and nuclear energy was a key component of the European Atomic Energy Community, which had been created by the Euratom Treaty of 1957. As Europe's economies began to grow rapidly after WWII, energy consumption and imports rose in tandem because large amounts of energy are needed to create wealth and provide citizens a high standard of material wellbeing (Smil, 2003).

From 1965 total primary energy consumption in Europe climbed from just under 1,000 million tonnes of oil equivalent (Mtoe) to nearly 1,850 Mtoe by 2006, or at an annual rate of 1.5%, as shown in Figure 1.[1] Consumption fell at a rate of 1.6% per year after 2006 to a level of about 1,620 Mtoe, partly as a result of recession but also because of environmental awareness pertaining to climate change. There is a political will within the EU to reduce fossil fuel energy use through conservation and by switching to renewable energy sources (which are counted as a component of primary energy). The latter shift is detailed in Figure 2, which indicates a reduction in the consumption of all energy sources except renewables. Today renewables account for some one-quarter of the energy consumed in the EU, although the vast majority of this is accounted for by hydropower and biomass & wastes (Figure 3).

Energy consumption per person rose from 2.2 tonnes of oil equivalent (toe) to over 3.0 toe over the half century since 1965, or at a rate of some 0.6% per year. Evaluating electricity consumption per person, we see consumption rose from approximately 25.6 megawatt hours (MWh) per person to 35.1 MWh, reaching a high of 40.7 MWh (3.5 toe) per person on several occasions in the first decade of this millennium. Again, efficiency and conservation came into play, causing per capita consumption to rise slower than the total increase in primary energy consumption. That is, Europe's population increased at a faster rate than improvements in energy efficiency and conservation, at least until 2006 after which the rate at which efficiency and conservation reduced per capita consumption outstripped the rate of energy growth due to population increase.[2]

[1] Data on consumption in Figures 1- 3, exclude Estonia, Latvia and Lithuania prior to 1985 and Slovenia prior to 1991. The conversion of the oil measure to an electricity measure is: 1 tonne of oil equivalent energy (toe) = 11.63 megawatt hours (MWh) = 0.01163 gigawatt hours (GWh).

[2] It should be noted that the population data include all current EU countries as if they were members in 1965. Given that the rate of per capita energy use in the countries that joined the EU after 1965 was likely lower, the increase in per capita energy use is underestimated.

The first section of this paper outlines historical factors that lead to the development of environmental and energy policy, and their eventual merger into integrated Climate and Energy Packages. This is followed by a closer look at the issue of energy security, which constrains the available policy options for mitigating climate change and adapting national energy policies. We then focus on physical and economic limitations that may arise while attempting to meet GHG reduction and renewable energy targets. To do so, we briefly survey electricity markets and grid infrastructure in the EU in order to evaluate the possibility for higher degrees of penetration of intermittent wind energy. The final section investigates issues that may arise with a large increase in demand for wood products, as wood pellets are projected to account for a significant portion of future biomass demand and renewable energy production.

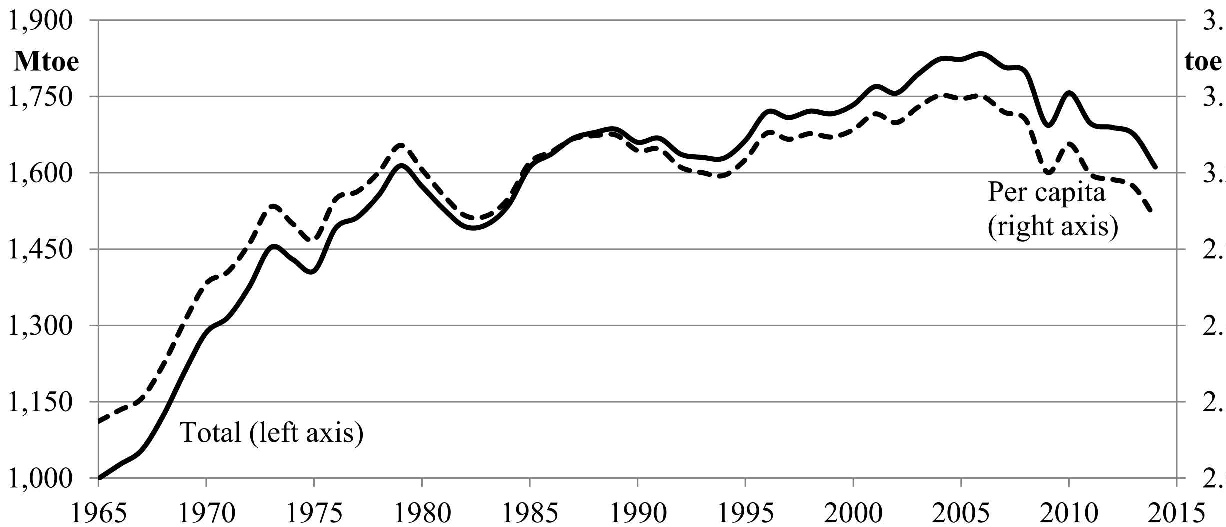

Figure 1: European Union Total Primary Energy Consumption (Mtoe) and Consumption per 1,000 Persons (toe), 1965-2014
Source: Derived using data from http://www.bp.com/statisticalreview

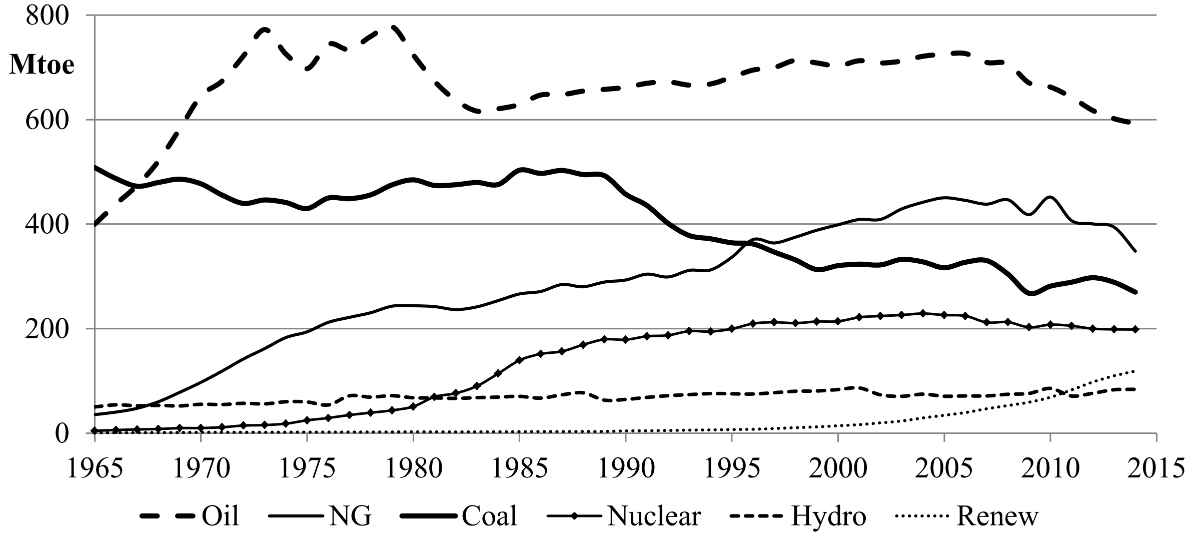

Figure 2: European Union Primary Energy Consumption by Source, 1965-2014, Mtoe
Source: Derived using data from http://www.bp.com/statisticalreview

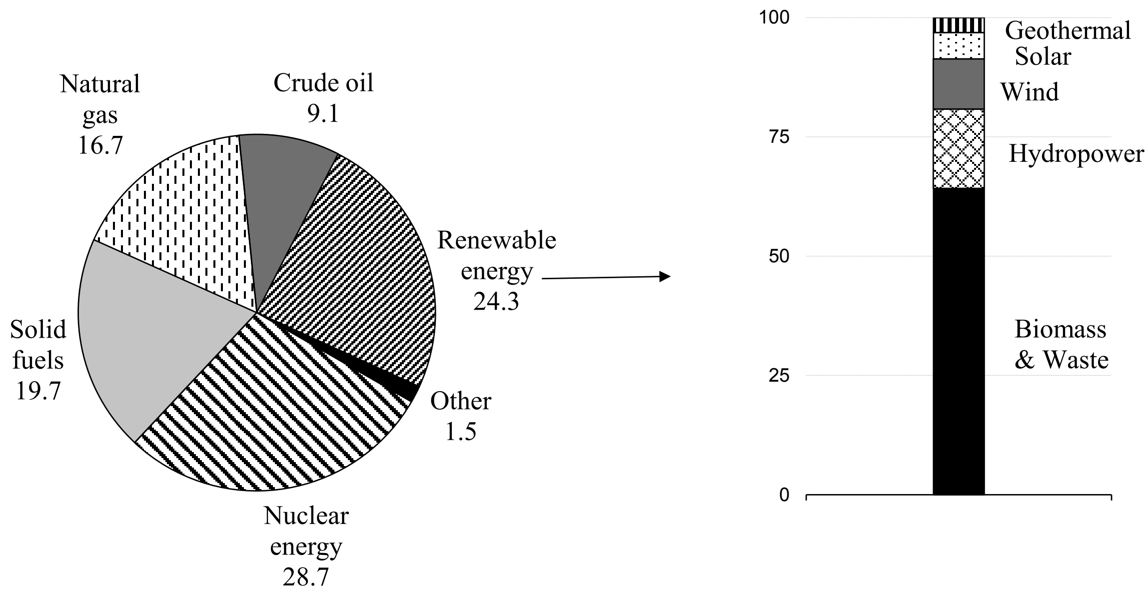

Figure 3: Production of Primary Energy, EU-28, 2013 (Based on Mtoe)

2. History of Energy and Environmental Policy

Although the energy sector was at least notionally included in early EU institutions, an integrated approach to energy policy did not begin until the late 1990s. Nonetheless, Europe remains the world's largest energy importer, energy markets and energy policy remain fragmented and Member States still maintain substantial control and competencies in this policy area. Likewise, early European treaties and institutions made no explicit mention of environmental policy or regulations and it was not until the Single European Act (SEA) of 1987 that the European Commission gained treaty authority to do so. Unlike energy policy, environmental regulations and legislation began prior to its inclusion in SEA, and extensive institutional support exists in the environmental policy arena.

Environmental Policy

Activity in the environmental policy arena began in earnest in the 1970s, almost two decades prior to SEA, when it was officially included as a treaty objective. Environmental policy started out with command-and-control style directives on water quality, air pollution and waste disposal and amounted to piecemeal, oftentimes industry specific directives (Knill & Liefferink, 2007). The surge in environmental legislation over the past several decades can be viewed as a by-product of the EU integration process, though policies far exceeded the regulatory requirements for a harmonized market.

The beginning of the new millennium marked the beginning of a new phase in environmental policy and regulation in the EU. The 5th EAP outlines many of these changes, which include a move away from the command-and-control regulation towards market based approaches, and an explicit desire to integrate policy objectives and set longer term goals under the rubric of sustainability (European Commission, 2005).[3] During this time, the EU began to take a more prominent role as a global leader in international climate change negotiations, particularly lobbying for more stringent CO_2 reduction targets (Delreux, 2011).

The EU's approach to environmental policy is now dominated by its role as an international player in climate negotiations. At the 21st Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UN FCCC) held in Paris in December 2015, the European Union committed to "a binding target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990".[4] This exceeds the EU's earlier commitments to reduce emissions of greenhouse gases, principally carbon dioxide, by 20% from the 1990 baseline emissions as part of its "20-20-20" target – a 20% reduction in CO_2 emissions with 20% of energy coming from renewables by 2020 (European Commission, 2013). Under the more ambitious target for 2030, renewable energy is expected to account for 27% of the EU's total energy production (European Commission, 2014a). Although renewables accounts for 24.3% of energy production, they accounted for merely 7.4% of total primary energy *consumption* in 2014

[3] The EU is currently operating under the 7th EAP, which prioritizes the need to meet the EU's climate objectives by 2020 (European Commission 2013).
[4] Latvian Presidency of the European Council (2015).

(Figure 2), making GHG reduction targets a tremendous challenge.

The EU is hoping to achieve these reductions by increasing its reliance on renewable energy, improving energy efficiency and strengthening the European Emissions Trading System (EU-ETS). The EU-ETS was implemented after EU ratification of the Kyoto Protocol in 2005 (European Commission 2016) and is the largest international system for trading emission allowances covering about 45% of total EU greenhouse gas emissions. Although the ETS has suffered from a surplus of allowances as a result of including carbon offsets (e.g. activities that reduce CO_2 emissions in developing countries, carbon sequestered due to tree planting projects, etc.) and slow growth after the 2008 crisis, it has undergone significant restructuring to recover from collapsed prices (below €3/tCO_2 in 2013). Under Phase III (2013-2020) this price seems to have been corrected.[5] This should raise the cost of emitting CO_2, thereby incentivizing conservation, the use of non-carbon sources of energy and research and development in alternative energy sources.

The EU is currently operating under the 7th EAP, which prioritizes the need to meet the EU's climate objectives by 2020. Previously under Kyoto, Member States agreed to individual targets and means for meeting them so that overall the EU could achieve its target. However, given the priority attached to reducing CO_2 emissions, the European Commission and European Parliament have taken on a greater role as a result of the Paris Agreement. Member States no longer have individualized targets, with the decisions for meeting targets now vested at the EU level. The merger of energy and environmental policy is addressed in the next section.

Energy Policy

Energy policy in the EU is characterized by three primary goals: (1) ensuring secure supply, (2) integrating the internal energy market to ensure liberalization and competitive (and thereby affordable) prices, and (3) minimizing the environmental impacts of energy consumption, which primarily entails achieving CO_2-emissions reduction goals. Despite being fundamentally linked to early EU institutions through the ECSC and Euratom, energy policy did not garner the same attention as environmental policy in the early stages of European integration. Member States have far more direct control over energy policy than environmental policy with near total discretion in their choice of energy mix and how they exploit their natural resources (Vogler, 2013, p. 629).[6] This results in disunity and frustration in energy negotiations because various national positions can override a unified EU position. Member states continue to enter into bilateral energy trade agreements, which reinforce an already fragmented internal energy market, with efforts to create a common energy policy resisted by Member States (Vogler, 2013). It was

[5] The emissions cap will be reduced by 1.74% annually and an increasing proportion of permits will be sold at auction, with 40% already sold that way in 2013; after 2020, the cap will be reduced by 2% per annum.

[6] The TFEU replaced the original 1958 Treaty establishing the European Economic Community (TEEC or Treaty of Rome), and came into force with the Treaty of Lisbon (2009).

not until 2009, with the Treaty of Lisbon, that energy policy became a shared competency area, giving rise to the possibility of Europe-wide energy policy coordination, and energy security became a specific EU objective. In 2015, the EU launched the Energy Union Framework Strategy, the latest step towards achieving integrated energy policy goals and a unified position.

Three factors have persistently characterized the EU energy scene well before the rise of an integrated energy policy. First, the European Union continues to be the world's largest energy importer. In the 2000s, domestic energy production began to slow and the EU expanded to include Central and Eastern European Countries (CEEC), which gave rise to new security concerns as many of these countries' energy supplies are not diversified (see next section). Today, there are still six member states that rely on Russia as their single external supplier of gas imports (European Commission, 2015).

Second, energy policy has also been shaped by efforts to create more competitive and liberal energy markets, including the liberalization and reform of national electricity markets that occurred primarily in the 1990s. These efforts focused on opening retail markets to increased competition, but failed to create the necessary pricing institutions, network access or wholesale markets, and led to high electricity prices and insufficient vertical and horizontal restructuring (Joskow, 2006; 2008). In 2005, the Commission launched an inquiry into energy markets to identify barriers to competition. This was triggered by the lack of cross-border trade, high market concentration and high prices relative to the US, particularly in the gas and electricity sectors which had policy makers concerned over the competitiveness of EU industry (IEA, 2014c; European Commission, 2015). These factors lead to the creation and implementation of the 'Third Package' in 2007, legislation that aimed to unbundle transmission and generator companies and increase competition in the internal energy market (IEA, 2014c). Completing the internal market, including the completion of infrastructure projects (with a priority on Projects of Common Interest (PCIs)) to support cross-national connections and an influx of renewable energy sources, and ensure diverse supply across the EU remains a central focus of EU energy policy.

Lastly, it became clear that in order to achieve ambitious climate goals an integrated approach to energy and environmental policy would be required. The energy sector accounts for 80% of the EU's greenhouse gas emissions (European Commission, 2012), and energy production and consumption put considerable pressure on the environment (Taylor et al., 2005).

Subsequently, energy legislation has been put in place to address these specific areas of concern, and the EU has attempted to take an integrated approach to policy through new policy frameworks. In 2008, the EU began the first conception of integrating climate and energy policy through recommendations that fed into the 2020 Climate and Energy Package. This package provided a legal framework for the implementation of 2020 emission targets, as well as broader attempts to integrate energy and climate policy. It is administered under the newly created DG Climate Action, rather than the DG environment, which has subsequently been responsible for the 2030 goals and the Roadmap to a Competitive Low Carbon Economy in 2050. In 2014, the European Commission presented new energy security strategies, and then in 2015, the Commission created the Energy Union, a framework strategy to address goals of energy security, competition, climate goals and liberalization of energy markets (European Commission, 2015).

Security concerns and the clear overlap with environmental policy has forced European policy makers to take a more integrated approach to tackling climate and energy policy, but much work remains to be done.

3. Energy Security

When it comes to energy security, the EU is highly dependent on foreign sources, particularly Russia. The EU is dependent on Russia for more than one-third of its primary energy imports. In 2013, more than 45% of oil imports into the EU come from Russia (33.5% of imports) and Norway, followed by the Middle East and other OPEC sources. Together, Russia (39.0%), Norway and Algeria account for 81.3% of natural gas imports, with the remainder from the Middle East. As indicated in Figure 4, over 70% of petroleum is imported, and nearly half of the natural gas used in the EU is imported, primarily via pipelines from Russia, and often transiting through Ukraine[7].

Ukraine's role as a transit country is the product of post world war tension, as Poland and the German Democratic Republic were not considered reliable transit routes by the soviets (Hafner & Tagliapietra, 2015). European import reliance leading up to the first Climate and Energy Package was a great concern due to rising energy prices, and repeated Russo-Ukraine gas crises (as in 2006 and 2009). The Russo-Ukraine gas crises shaped subsequent European legislations directly, as policy makers pushed to strengthen the internal market and employ a more integrated approach to energy policy, and indirectly, as Russia has sought to diversify its transit routes away from Ukraine[8]. Although a unified energy policy may curtail security concerns by allowing

[7] Although the EU has made investments in new LNG terminals, supplies are re-exported to Asia, as Asian demand, and therefore prices, remain high (IEA, p.16, 2014a; IEA, 2014b).

[8] Until 1991, all gas exports to the EU transited through Ukraine, but by 2014, only 15% of EU imports arrived through Ukraine (IEA, 2014c). The Yamal-Europe pipeline running through Belarus and Poland, Blue Stream, which connects Russian gas plays to Turkey through the Black Sea, and finally the demise of the long planned South Stream project and rise of a new line called Turkish Stream that bypasses Ukraine has completed Russia's diversification strategy (Hafner & Tagliapietra, 2015).

the community to leverage its role as a large energy importer, it is resisted by some Member States who still enter into bilateral agreements with external suppliers and are reluctant to forgo their current market standing. For example the Nord Stream pipeline, which runs 1,222 km under the Baltic Sea from Russia to Germany, thus by-passing countries of eastern Europe is favoured by Germany but seen to weaken Ukraine's position causing tension among Member States.

Although security of supply is a key objective of energy security, there has been little work done to integrate Common Foreign Security and Policy (CFSP) (a policy arena dominated by national autonomy), and energy security concerns. Much of the EU's efforts to ensure secure and diverse supply and increase competition in the natural gas market have been resisted by Russia, who has attempted to prevent any new EU legislation and/or international agreements that restructure European energy markets and thus effect Gazprom's position as a monopoly supplier.[9] For example, the demise of the South Stream Pipeline project, originally proposed as a 900km long offshore pipeline across the Black Sea, with onshore sections accommodating gas from Ukraine, can be, in part, attributed to Russia's opposition to granting third-party operators access to Gazprom pipelines, which is seen as a violation of the Third Energy Package.

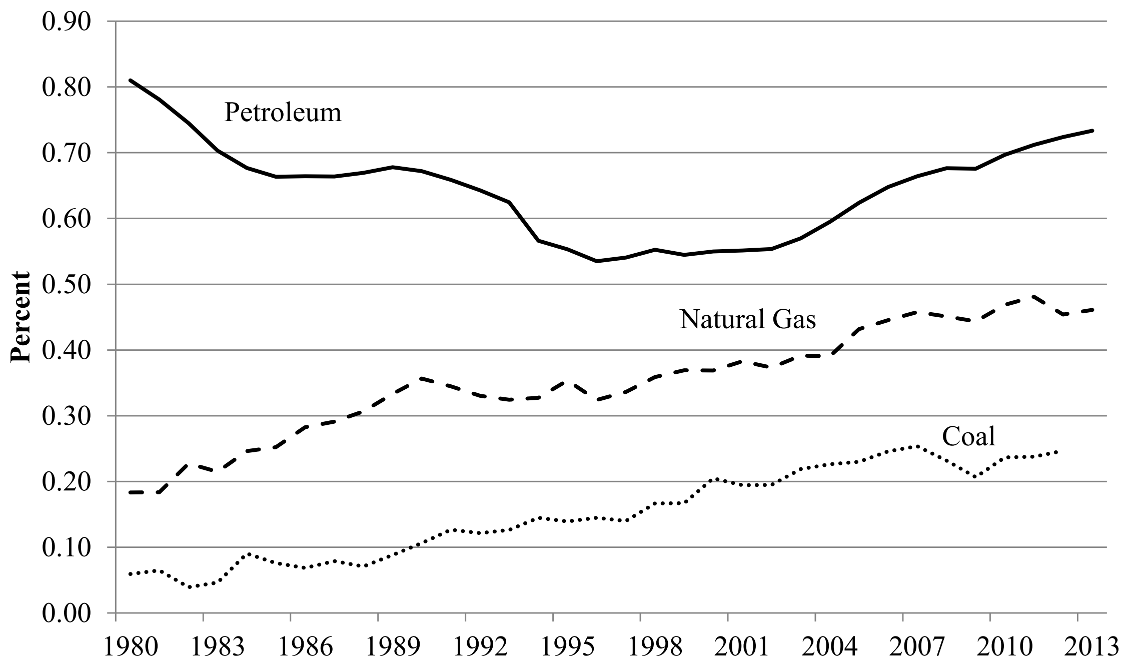

Figure 4: Fossil Fuel Import Dependency, EU, 1980-2013

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[9] Russia has strongly resisted new structural rules governing gas and electricity infrastructure, going as far as to file a dispute against the EU with the WTO over the 'Third Package', particularly requirements to grant access to network capacity to third-party operators (WTO, 2014).

Although some Member States have large domestic coal reserves, almost one-quarter of the EU's coal is now imported (compared to 6% in 1980) because imported coal is of a higher quality with a lower CO_2-emissions intensity than domestic coal (although 44% of coal generating capacity continues to rely on lignite).[10] Nearly three-quarters of imported coal comes from Russia (28.8%), Columbia and the United States, with South Africa and Australia accounting for much of the remainder; as the U.S. shuts down its coal plants, the EU can be expected to import more coal from the U.S. which has only recently become a major source of EU coal.[11] Overall, some 20% of the energy consumed in the EU comes from imports. For energy security reasons, therefore, the EU is increasingly seeking to diversify its energy portfolio, source fossil fuel imports from less risky sources, and reduce the energy employed per unit of GDP. Energy security and the heavy reliance on imports, as well as the geopolitical considerations that dominate bilateral energy agreements constrain the options available to mitigating climate change through EU level energy policy. The following section looks at this and the prospects for renewables in more detail.

4. Environmental Policy: Addressing Climate Change

To understand the difficulty of reducing CO_2 emissions, it is useful to employ the Kaya identity (Kaya and Yokobori, 1997). The identity is rather simple and is given by:

$$C = N \times \frac{Y}{N} \times \frac{E}{Y} \times \frac{C}{E} \qquad (1)$$

Here C refers to carbon emissions (measured in terms of CO_2), N is population, Y is gross domestic product (GDP), and E is total energy consumption. The first term on the right is population, the second term is per capita GDP (often denoted Y), the third term is the energy intensity of the economy, and the final term is the carbon intensity of energy. The Kaya identity indicates that there are only five ways to reduce CO_2 emissions:

1. Dramatically reduce population;
2. Drastically reduce GDP;
3. Generate the same or a higher level of GDP with less energy;
4. Generate energy with less CO_2 emissions; or
5. Some combination of the first four factors.

Dramatically reducing population or GDP is beyond what might be politically feasible at this

[10] According to Gutmann et al. (2014), the capacity of the EU's 30 dirtiest coal plants was 63,557 MW, of which 27,703 MW of capacity was based on low-energy, high-CO_2 emissions lignite coal. Surprisingly, some of the largest coal plants are of recent origin, constructed in 2011-12.

[11] As noted in the next section, the U.S. is also a primary source of wood bioenergy.

time. With concerns about an aging population (and support of their pensions) and the recent influx of refugees into Europe, population is unlikely to play a significant role in achieving the GHG reductions. Likewise, citizens would be unwilling to accept anything but minor reductions in their standard of living. Thus, apart from carbon capture or sequestration efforts, the burden of reducing CO_2 emissions will rest with efforts to reduce the energy required to produce output (better energy intensity) and to decarbonize energy (improve the carbon intensity of energy). The latter two options can be combined into a single 'technology option' as seen by rewriting the Kaya identity as:

$$\text{(2)} \qquad \text{Emissions} = \left[N \times \frac{Y}{N}\right] \times \left[\frac{E}{Y} \times \frac{C}{E}\right] = Y \times \frac{C}{Y} = \text{GDP} \times \text{Technology},$$

where technology (C/Y) is simply the ratio of CO_2 emissions to GDP.

The ratio of emissions to GDP – the carbon emissions intensity – varies greatly across countries depending on their energy sources, level of development, and their geography. The emissions intensity for the EU as a whole, the largest EU countries, and the U.S. and China are provided in Figure 5. Global carbon emissions intensity fell from 0.78 kg of CO_2 per \$ of GDP in 1990 to 0.38 kg in 2011, or by about 0.019 kg of CO_2 per \$ of GDP each year – or at an average annual rate of 3.6%.

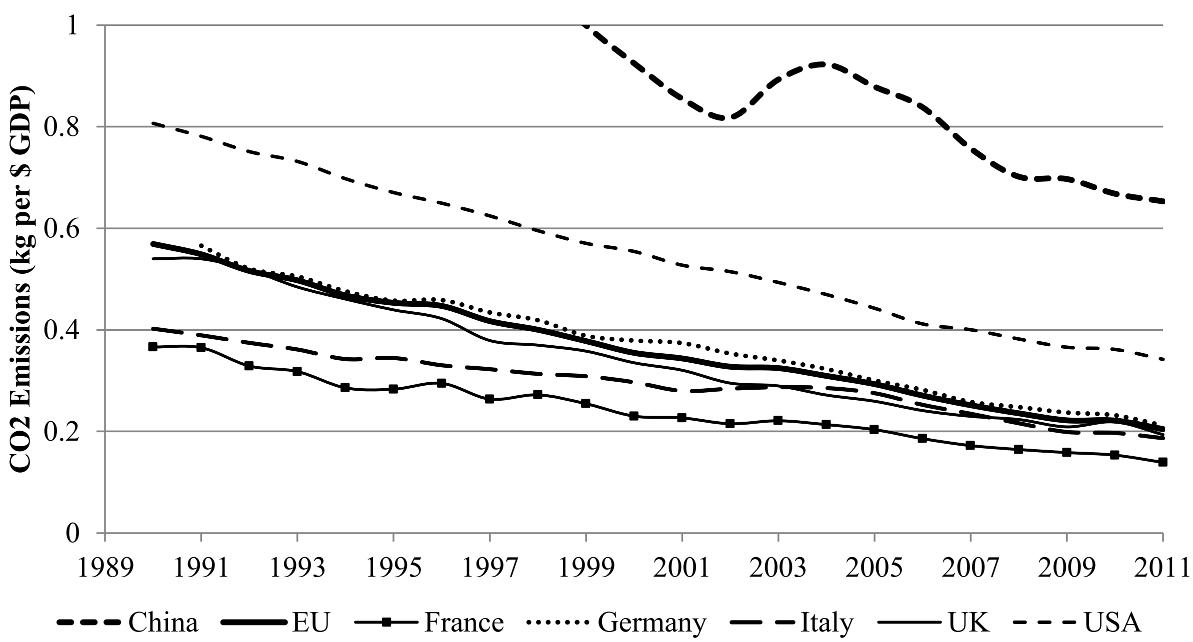


Figure 5: Emissions Intensity, kg CO_2 per \$ of GDP, EU and Selected Countries, 1990-2011

The average rate of decline in emissions intensity varies considerably from one country to another (Table 1). For example, since 1990 many rich countries have shed manufacturing output (e.g., aluminum production in Japan) to developing countries, or replaced coal-fired generating capacity with gas plants (such as the UK and U.S.) or nuclear power (most notably France, although much of this was done prior to 1990). After reunification of East and West Germany in 1989/1990, the country replaced inefficient power plants and manufacturing facilities with modern, less polluting facilities, or simply decommissioned plants. Spain and Denmark invested heavily in wind power, while Russia was impacted by recession following collapse of the Soviet empire. Likewise, the recession that followed the 2008 financial crisis led to a reduction in emissions intensity.

Table 1: Emissions Intensity Ratios, Selected Regions and Countries, 2011

Region or Country	% rate of decline in emissions intensity, 1990-2011	Region or Country	% rate of decline in emissions intensity, 1990-2011
European Union	5.0%	OECD	4.1%
France	4.7%	Japan	2.5%
Germany	4.8%	Canada	4.0%
Italy	3.2%	U.S.	4.2%
Spain	4.0%	China	6.0%
UK	5.0%	India	3.2%
Russian Federation	7.0%	Brazil	1.7%
Denmark	5.5%	Indonesia	0.4%
Norway	5.0%	Sub-Sahara Africa	3.6%

Source: Authors' calculations based on the World Bank's development indicators.

The emissions intensity data raise three concerns about efforts to mitigate global warming. In 2011, France had an emissions intensity of 0.139 kg of CO_2 per $ of GDP, which is the lowest among developed countries.[12] Many poor countries have C/Y ratios that are much lower than those of France; indeed, CO_2 emissions per $ of GDP are almost negligible in countries such as Chad (0.02 in 2011) and Mali (0.05), where the ratios have varied considerably over the period in question (1990-2011) because economic growth has been spotty. Before many of the poorest countries can even reach middle-income status, not only will GDP need to increase significantly, without dramatic technological breakthroughs, those countries' emissions intensity will also increase. This is unlike China in one way: China began the period with a C/Y ratio exceeding 2.0 (Figure 5). Although China's C/Y ratio fell at an annual rate of 6.0% between 1990 and 2011, its total emissions of CO_2 grew at an average annual rate of 6.3% because of high rates of GDP growth. Therefore, if poor countries are given the opportunity to grow, policymakers should anticipate increasing global emissions of greenhouse gases. Because EU countries recognize this

[12] The emissions intensity is measured in kg of CO_2 per purchasing power parity (PPP) U.S. $ of GDP. The use of PPP explains why units are in dollars rather than euros.

phenomenon, they feel obligated to emission reduction targets that are far more stringent than those they would impose on developing countries.

The second issue is one more directly applicable to EU energy policy. The United Kingdom arguably had the most draconian climate legislation of any government in the EU: climate legislation passed in December 2008 requires the UK to reduce greenhouse gas emissions by 34% by 2022. The UK already has one of the lowest *C*/*Y* ratios amongst developed countries in the world, with *C*/*Y*=0.22 in 2010; among EU countries, France has the lowest carbon intensity index, with *C*/*Y*=0.15 in 2010. The reason for the low rates in both Britain and France is largely due to the recent recession, success in moving manufacturing offshore, the decommissioning of coal plants, and, in the case of France, heavy reliance on nuclear energy. Roger Pielke Jr. (2009, 2010) estimates that, to meet its climate policy targets, the UK would need to get to the French emissions intensity level in less than one-third the time it took France to make a similar improvement. He argues that this would require the immediate construction of 40 nuclear power plants, each with a capacity of 1,100 megawatts (MW).

The third issue relates to economic incentives. Because of cheap natural gas from shale plays, the U.S. has invested in gas plants that permitted it to decommission more expensive coal plants and rely less on coal-fired power. In Europe, however, natural gas prices have remained high. As a result, and also because of the desire not to invest in nuclear power, the EU has invested in coal plants rather than gas plants to meet baseload capacity.[13]

Prospects for Renewable Energy

The third issue pertains to the need to invest in renewable energy. One argument used to justify public spending on alternative energy is that the globe will run out of fossil fuels and that we need to prepare for that eventuality. From an economic standpoint, the idea that we will run out of oil (or gas or coal) is misguided (Mann, 2013). As fossils fuels become increasingly scarcer, supply and demand intersect at increasingly higher prices to ensure that the market clears – so there is always enough of the resource to meet demand. Higher prices, in turn, signal scarcity and thereby induce technological innovations that increase supply, reduce demand and lead to new sources of energy. This is evident from recent advances that have greatly expanded exploitable reserves of oil and natural gas. Indeed, scientists now argue that we might never run out of fossil fuels, especially natural gas (Mann, 2013). Therefore, arguments promoting renewable energy should not be based on energy security and/or the potential scarcity of fossil fuels. Rather, the only arguments for reducing or eliminating fossil fuels are related to either prices (renewables are less costly) or to address climate change, or both.

EU policymakers use subsidies to promote wind and solar energy based on the presumption that,

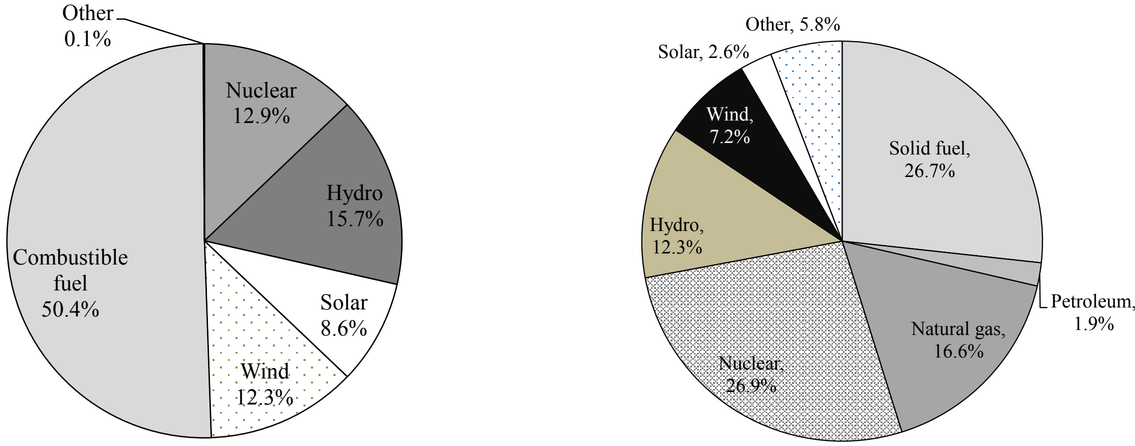
[13] More detailed discussion is found in van Kooten (2015a, 2016).

because wind and solar potentially displace coal and other dirty fossil-fuel generated electricity, the social benefits of installing wind generating capacity will exceed the social costs. However, both econometric and mathematical programming studies suggest that this is not generally the case (e.g., Kaffine et al., 2013; Cullen, 2013; Novan, 2015; van Kooten, 2010). Wind will substitute for power from the marginal generator at the time that the wind power enters the system. Because the marginal generator differs across generation mixes as well as with the time of day and by year, the extent to which carbon dioxide emissions are offset varies as well. Hence, more CO_2 emissions are avoided in systems that rely coal than those that rely more on gas, and hardly any CO_2 emissions are avoided when hydropower is the main energy source. Research concludes that subsidies for wind-generated power can only be justified if the generation mix has a great deal of coal. Although in 2012, coal accounted for only 28% of electricity generation in the EU, subsidies may be warranted for countries like Poland, Estonia, Greece, and the Czech Republic, where coal amounted to over 50% of electricity generation (IEA, 2014c).

The preferred alternative to subsidies is a carbon tax or carbon emission-trading scheme. The carbon tax targets emissions from coal to a greater extent than those of gas, thereby incentivizing dismantling of coal plants, especially older and less efficient ones. A carbon emissions trading scheme will do the same, except that such schemes can be difficult to implement and administer (as seen by the collapsed prices of the EU-ETS) and open to corruption (van Kooten, 2015a; van Kooten and de Vries, 2013). Despite these issues, politicians have historically favored subsidies and emissions trading (as seen in Kyoto process) over taxation.

The EU faces an enormous challenge if it is to meet its GHG emissions reduction targets chiefly since the evidence linking social objectives and increasing economic prosperity to access to affordable and reliable energy, in particular electricity is strong and well documented (Modi et al., 2005). The conversion of an economy to run on renewable sources of energy will require much greater reliance on electricity (Scott, 2007). Electricity is needed for mobility, whether it comes in the form of the hydrogen (viz., fuel cells) or via all-electric vehicles. Electricity is also required for space heating, replacing fossil fuels, and to power an increasingly digital age. The advantage of electricity is that it can be generated using any type of fuel, and is thus particularly suitable for integrating renewable energy technologies into the economy.

Currently, fossil fuels (coal, oil and natural gas) account for some 45% of electricity generation; when nuclear power and hydroelectricity are taken into account, 84% of electricity is generated by non-renewable sources (see Figure 6b). The remainder includes geothermal, wind, solar, tidal, wave, biomass and heat energy, where the latter refers to ‘waste’ heat that is used to produce power – this is known as combined heat and power (CHP) or cogeneration (‘cogen’). While this ‘renewable’ fuel share has increased tremendously in recent decades to nearly 16% today, the share remains small. More importantly, if we compare installed renewable capacity (21%) against actual production (16%) (see Figure 6), there remain questions regarding the reliability and cost of renewables. The challenge of reducing reliance on fossil fuels is even greater if nuclear energy is removed from the mix of options, which is the case for Germany, Sweden and France who are seeking to reduce their nuclear capacity.



(a) Capacity: Total = 956,416 MW *(b) Generation: Total = 3,261,537 GWh*

Figure 6: Generating Capacity and Production by Energy Source, EU, 2013
Source: Authors' calculations using data from Eurostat (2016)

To achieve its GHG emissions-reduction targets, the EU needs to consider its options. The two strategies that are on the policy table are so-called intermittent renewables, namely, wind and solar[14], and biomass. Wind and solar are intermittent energy sources because output varies from one moment to the next, depending on wind speeds, cloudiness and other factors. The remainder includes geothermal, tidal, wave, hydro and wastes. Although these sources are also being considered, their contribution to future electricity supply is expected to be minor. While the potential for increased hydro might exist, construction of new large hydroelectric dams is unlikely due to their adverse impact on ecosystems; one might expect some run-of-river generating capacity but it suffers from the same problem as wind and solar. The next section evaluates some of the indirect costs of integrating renewables into electricity systems. We then take a more detailed look at the issue of intermittency of wind energy and limitations to increasing demand for non-intermittent biomass energy.

Integration of Renewables into Electricity Grids

Econometric studies tend to neglect or underestimate the indirect costs of wind energy, which are associated with the impact that intermittent power has on the operation and management of an

[14] Current solar technology remains prohibitively expensive and is not discussed in detail here, although it suffers from the same intermittency issues as wind.

electricity grid. These costs are specific to particular electricity systems and the regulations operators face. Gaining a handle of these costs requires an understanding of how electricity systems operate – including generation, transmission, distribution and consumption, and how each of these components can and should be deregulated, if at all. It turns out that the wholesale (generation) and retail markets can be deregulated, but that transmission and distribution are likely best left in the hands of an independent system operator, which also organizes the market and guides investment in new capacity.

This regulation is necessary because the nature of electricity generation and consumption prohibit the existence of a purely competitive market. This is because electricity demand varies widely over the course of the year, cannot be stored, and supply and demand need to be balanced at every point on the network to avoid system collapse due to constraints on voltage, frequency and stability. In addition, system operators have a limited ability to control power flow to most consumers, and retail consumers have limited access or ability to react to real time pricing (Joskow, 2006, p.6).[15]

Because of these physical characteristics, electricity generated to meet peak load demand is fast-responding with high operating costs and are used for a relatively small number of hours in a year versus base-load capacity which runs nearly continuously, is expensive to ramp up and down, but has low marginal costs (e.g. nuclear or coal). In other words, power plants are dispatched according to their short run marginal costs, or merit order. These particularities play a role in the viability of integrating large amounts of intermittent wind energy into electricity systems.

Two major indirect costs associated with intermittent supply stem from (1) operating reserve requirements, as system operators are required to maintain reserves for the system as well as backup capacity in the event of low winds. If low winds coincide with peak demand, operators must ensure they have sufficient (expensive) fast-responding generators to meet peak demand, as well as cover what would have been generated by wind. This need for additional capacity will raise scarcity prices even higher. Since these prices are often capped by regulators, high penetration of wind energy will further distort incentives to invest in appropriate generating capacity and compound the so called “missing money” phenomenon (see Joskow 2006; 2008, and van Kooten 2015a). (2) Regulations that require operators to use wind when available (e.g. “must-run” requirements) are costly if wind enters the system at the margin displacing base-load generators, forcing them to ramp up and down (sometimes within a matter of minutes) causing wear and tear, or forcing them to run at inefficient levels for extended periods, potentially

[15] Joskow argues even with real time pricing, operators would still need to utilize rolling blackouts to overcome system imbalances to meet reliability criteria (p.6) and this remains the case even with the widespread introduction of smart grids to induce demand side responses (as in Italy).

increasing GHG emissions overall.

While a carbon tax or emissions trading will eliminate coal from the optimal generation mix when wind enters, gas capacity will need to increase in order to backstop wind. Indeed, mathematical programming models indicate that the increase in gas capacity required is almost 0.7:1 for coal displaced (van Kooten, 2016). Further, without a significant technological breakthrough in our ability to store wind energy (currently only possible behind hydroelectric dams), researchers have identified network instability and low capacity factors for wind power (the latter is discussed in the next section) as key limitations to the penetration of intermittent energy sources in electricity generation. In addition, studies conducted in the EU find that spacing turbines across large distances does not overcome the issue of intermittency, as wind levels are simultaneously low across the continent during conditions when electricity demand is high (Oswald et al., 2008).

In the EU, the implementation of the Third Package has increased cross-border trade and network rules and fostered greater independence of national regulators and TSOs through the creation of two agencies: the Agency for the Cooperation of Energy Regulators (ACER) and the European Networks for Transmission Operators—Gas and Electricity (IEA, 2014c). The EU now has an integrated day-ahead electricity market, but work remains to be done to fully integrate EU energy networks and markets as cross-border capacity remains low due to a lack of interconnections and network congestion, which largely confines system operators to national grids (IEA, 2014c). Retail prices remain high and there are concerns regarding future generation capacity as power plants and the nuclear reactor fleet, largely responsible for base-load generation are ageing and will need to be shutdown in the coming decades (IEA, 2014c).

To decarbonize the energy system, the electricity system will need to adapt and the market will need to send appropriate signals to generate investment in renewables, fast-responding capacity, and capacity to meet base-load demand. As the IEA admits "ensuring generation adequacy in a system with high shares of variable renewable energy and very low marginal operating costs is uncharted territory" (IEA, 2014c, p.17). This will require co-ordination across member states, large infrastructure investment, and integrating goals across policy arenas.

Intermittency: Just How Variable is Wind?

Despite these indirect costs, wind energy has become the poster child for the renewable energy sector. At the end of 2014, 128.8 GW of cumulative wind generating capacity had been installed in the EU, compared to nearly 370 GW globally; this accounted for only 10.2% of the EU's total electricity production in 2014 (GWEC, 2015, p.12). Nonetheless, at the end of 2014, installed wind power capacity reached 63% of the EU's 2020 target (ibid., pp.37-38). Prospects of wind power to meet future electricity needs often assume that the wind turbines would be operating at or near full capacity all the time – that they would generate 128.8 GW of electricity every hour of the year. In practice, a baseload coal plant might operate at a capacity factor (CF) of about 85% (85% of nameplate capacity), while a nuclear power plant might operate at a CF of 90%, but wind farms operate at much lower capacity factors.[16]

Winds are highly variable and wind turbines are unable to produce their maximum nameplate capacity most of the time. Unless the wind blows with sufficient strength, the blades of a turbine will not turn and no electricity is generated, although improvements in blade technology have reduced the threshold wind speed at which energy is produced. Likewise, at high wind speeds, the blades must be turned to avoid wind damage and no output is forthcoming, although technology has increased this threshold as well. Nonetheless, intermittency is unavoidable and thus capacity factors for wind turbines are much lower than for thermal power plants. The average CF for wind turbines in the EU is reported to be 22% compared with 33% for the U.S. and only 17% for China; based on 2012 data, wind energy accounted for 4.3% of global electricity production, which implied a CF of approximately 25% (Lacal-Arántegui and Serrano-González, 2015, pp.29, 60).

Lacal-Arántegui and Serrano-González (2015, p.36) provide projections of future installed wind generating capacity (with proportion of offshore wind capacity provided in parentheses):

Year	European Union	Global
2014	130 GW (7%)	371 GW (3%)
2020	208 GW (13%)	681 GW (6%)
2030	353 GW (32%)	1,391 GW (14%)
2050	503 GW (44%)	2,446 GW (22%)

Assuming a 25% capacity factor (although this number likely to improve with technological advances), wind would provide 1.1 PWh of electricity in 2050 or some one-quarter of the EU's electricity demand; solar energy, on the other hand, is expected to account for nearly 10% of 2050 generation.[17] Because fossil fuels and the infrastructure required to consume them are readily available, policies to replace them will likely require a combination of subsidies to producers of clean fuels, regulations forcing firms and individuals to rely more on non-fossil fuel sources, publicly-funded research and development (R&D), contracts to reduce risk, and taxes or cap-and-trade schemes that drive up fossil fuel prices to the point where it makes economic sense for consumers to switch to alternative clean energy sources (Newbery, 2011, 2012). Various policies have already been implemented by governments to incentivize investment in renewable

[16] The CF is the ratio of the actual amount of power generated in one year to the potential power that could be generated if the asset operated at full capacity each hour during the year.

[17] The data come from studies by Lacal-Arántegui and Serrano-González (2015) and the European Commission (2014b). The latter projects a lower wind capacity (413 GW in 2050) but a higher CF than the former.

energy technologies in the electricity sector including carbon taxes, carbon offset credits (to be sold in mandatory or voluntary carbon market), production and capital investment subsidies, and feed-in tariffs that provide producers with a guaranteed price irrespective of the market price (and whether there is even a buyer).

Supply and Sequestration: Questions Remaining for Increases in Bioenergy

An alternative to unpredictable wind and solar is wood biomass, which is reliable and currently accounts for about half of all renewable energy in the EU. Although reliable, wood biomass suffers from other limitations related to global supply. The EU's National Renewable Energy Action Plan projects bioenergy power production to more than double, from 5.4% of final energy consumption to 12.0% by 2020; wood pellets are to be the major future source of bioenergy, contributing 36% of the 2020 target (Beurskens and Hekkenberg, 2011). Mantau et al. (2010) argue that biomass consumption for power generation within Europe will grow by more than 227 million m^3 of wood biomass in a decade – from 346 million m^3 in 2010 to 573 million m^3 in 2020. However, as a result of the latest more stringent renewables target, biomass consumption for power generation could grow to 752 million m^3 by 2030, or by 4% per year between 2011 and 2030 (Mantau et al., 2010). This far exceeds the total Canadian biomass harvest of around 200 million m^3. Perhaps not surprisingly, there is no consensus on exactly how much biomass Europe will demand by the end of the target period.

The European Commission (2014b) envisions the use of biomass and waste combustion for power generation to increase both in pure biomass plants, which tend to be relatively small, and in large power plants where wood pellets are often co-fired with coal. The share of biomass in thermal power plants is forecast to achieve 16% in 2020, 19% in 2030 and 26% by 2050. Biomass is also projected to make a very significant contribution to CHP – contributing 33% in 2020, 35% in 2030 and 41% in 2050. By 2050, biomass plant capacity is expected to reach 66 GW in 2050, up from 25 GW in 2010. More than half of the biomass power will come from solid fuels, mainly wood pellets, with the remainder coming from biogas and wastes.

One problem with burning biomass is that, despite legislation that treats biomass as carbon neutral, biomass does not reduce CO_2 emissions from fossils fuels one-for-one when it replaces coal or gas in a power plant. It takes anywhere from 10 to 60 or even more years to recover the CO_2 released at the time of biomass burning by sequestering carbon in trees. The time is longer if tree species are slow growing, such as native species in northern climates, and shorter if fast-growing genetically-modified species are grown using fertilizers (whose production releases CO_2). If the bole of harvested trees is used as bioenergy, the CO_2 deficit may be worse that using coal because the carbon in biomass would otherwise have been stored for long periods in wood products such as lumber. The shortest times to recover the CO_2 released by generating electricity from wood biomass occur when residues from logging and sawmilling are used. The EU desires to use only residues to generate electricity because it argues that these combustible materials would otherwise decay in the forest or as waste. Thus, a report prepared for the UK's Department of Energy and Climate Change concludes that "in 2020 it may be possible to meet the UK's demand for solid biomass for electricity using biomass feedstocks from North America that result in electricity with GHG intensities lower than 200 kg CO_2e/MWh, when fully accounting for changes in land carbon stock changes" (Stephenson and Mackay, 2014, p.18).

The EU intention to source woody materials from North America will be severely limited by economic and ecological factors. Sawmill residues are already used to produce a variety of engineered wood products, such as oriented strand board and medium density fiber board, pulp for making paper, and electricity to heat manufacturing facilities. European demand for this fiber to produce wood pellets would raise prices to all users, including pellet producers. Other bioenergy scenarios considered by the EU would require the continuous removal of upwards of all coarse and all fine woody materials from North American forests, and faster rates of harvest (Stephenson and Mackay, 2014, pp. 8-11, 130-132). While there is some room to collect logging residues, roadside wastes resulting from trimming logs so they properly fit on trucks, and fiber from timber damaged by mountain pine beetle, studies indicate that extremely large EU subsidies would be required, while continued collection of such materials would not be sustainable, and forest management practices could not be certified (see van Kooten, 2015b for an overview).

5. Conclusion

European energy and environmental policy faces two main challenges: security of supply and achieving EU greenhouse gas reduction targets. Solutions to these issues will pose a challenge to physical infrastructure, and economic and political institutions. Policy goals may not always coincide (for example long term gas contracts promote energy security, but may conflict with goals of increasing market competition), so an integrated approach to these areas is necessary. Securing supply will require diversifying sources of imports and the mix of energy types used to meet demand, or most likely, some combination of both. As Member States still retain significant competencies in this area, implementing these policies without further fragmenting the internal energy market will require political coordination, as well as coordination of infrastructure projects to integrate new energy sources into existing electricity grids and across national borders.

Although renewable energy holds the promise of diversifying supply, reducing the reliance on fossil fuels, and helping achieve GHG reduction targets, it presents considerable challenges and costs. The best prospects for renewable energy are likely to be solar, wind and biomass, but these still face physical limitations, and expanding production to account for a significant share of the energy mix may prove costly, although technological advances could improve some of their prospects, especially if carbon taxes or emission trading increase the costs of traditional technologies.

From a practical standpoint there are limits to the amounts governments will pay to subsidize development of non-carbon (clean) sources of energy and to citizens' willingness to accept increases in the price of energy when cheaper fossil fuel alternatives are available. These considerations are exacerbated when countries act unilaterally by issues like carbon leakage, as decreasing demand for fossil fuels will decrease their price, which may lead to increased consumption elsewhere. An integrated approach may become increasingly difficult to implement, as the future of the European Union remains uncertain in light of the Brexit referendum and growing calls for increasing national sovereignty. Improvements in carbon capture and storage, technological advancements, changes in attitudes towards nuclear and energy efficiency may play a role in lightening the cost of decreasing GHGs.

References

Beurskens, L.W.M. and M. Hekkenberg, 2011. Renewable Policy Projections as Published in the National Renewable Energy Action Plans of the European Member States. Covering all 27 EU Member States. Report ECN-E--10-069, European Energy Agency. 1 February. 244pp. https://www.ecn.nl/docs/library/report/2010/e10069.pdf [accessed January 16, 2016].

Cullen, J., 2013. Measuring the Environmental Benefits of Wind-Generated Electricity, *American Economic Journal: Economic Policy* 5(4): 107-133.

Delreux, T., 2011. *The EU as International Environmental Negotiator.* Surrey: Ashgate Publishing Limited.

European Commission, 2005.*Towards sustainability: The European Community Programme of policy and action in realtion to the environment and sustainable development*. Retrieved 01 19, 2015 from European Union: EU by Topic: http://ec.europa.eu/environment/archives/action-programme/5th.htm

European Commission, 2012. *Energy. The European Union explained* . Luxembourg: Directorate-Generale for Communication.

European Commission, 2013. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A new EU Forest Strategy: Forests and the Forest-Based Sector. Brussels, 20.9.2013.Com(2013) 659 Final.

European Commission, 2014a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A policy framework for climate and energy I the period from 2020 to 2030. Brussels, 22.1.2014. Com(2014) 015 Final.

European Commission, 2014b. *EU Energy, Transport and GHG Emissions Trends to 2050 Reference Scenario 2013*. 176pp. Luxembourg: European Union. https://ec.europa.eu/energy/sites/ener/files/documents/trends_to_2050_update_2013.pdf [accessed January 16, 2016].

European Commission, 2015. Energy Union Package: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. COM(2015) 80 final. Brussels: European Commission.

European Commission, 2016. *The EU Emission Trading System (EU ETS)*. Retrieved 01 18, 2016 from European Commission: Climate Action: www.ec.europa.eu/clima/policies/ets/index_en.htm

Eurostat, 2016. Statistics Explained. http://ec.europa.eu/eurostat/statistics-explained/index.php/Main_Page [accessed January 14, 2015]

Global Wind Energy Council (GWEC), 2015. *Global Wind Report. Annual Market Update 2014*. 80pp. February. Available at http://www.gwec.net/publications/global-wind-report-2/ [accessed January 15, 2015].

Gutmann, K., J. Huscher, D. Urbaniak, A. White, C. Schaible and M. Bricke, 2014. *Europe's Dirty 30. How the EU's Coal-Fired Power Plants are Undermining its Climate Efforts*. Brussels, BE: CAN Europe, WWF, HEAL, the EEB and Climate Alliance Germany. 30pp. http://awsassets.panda.org/downloads/dirty_30_report_finale.pdf [accessed January 14, 2016]

Hafner, M, and S. Tagliapietra, 2015. Turkish Stream: What Strategy for Europe. *Energy: Resources and Markets: Nota Di Lavoro* 50.

International Energy Agency (IEA), 2014a. *World Energy Outlook 2014*. 726pp. Paris: OECD/IEA. www.iea.org

International Energy Agency (IEA), 2014b. Key World Energy Statistics 2014. 82pp. Paris: OECD/IEA. http://www.iea.org/publications/freepublications/publication/keyworld2014.pdf [access May 12, 2015].

International Energy Agency (IEA), 2014c. *Energy Policy for IEA Countries: European Union 2014 Report*. Paris: OECD/IEA

Joskow, P.L., 2006. Competitive Electricity Markets and Investment in Generating Capacity. MIT working paper. Retrieved from http://economics.mit.edu/files/1190

Joskow, P.L., 2008. Lessons Learned from Electricity Market Liberalization. *The Energy Journal,* Special Issue. The Future of Electricity: Papers in Honor of David Newbery.

Kaffine, D.T., B.J. McBee and J. Lieskovsky. 2013. Emissions Savings from Wind Power Generation in Texas, *Energy Journal* 34(1): 155-175.

Kaya, Y. and K. Yokobori (eds.), 1997. Environment, Energy and Economy: Strategies for Sustainability. Tokyo, JP: United Nations University Press.

Knill, C. and D. Liefferink, 2007. *Environmental Politics in the European Union.* Manchester, UK: Manchester University Press.

Lacal-Arántegui, R. and J. Serrano-González, 2015. *2014 JRC Wind Status Report*. 87pp. Brussels, BE: Joint Research Centre of the European Commission. ISBN 978-92-79-48380-6. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/2014-jrc-wind-status-report?search [accessed January 16, 2016]

Latvian Presidency of the European Council, 2015. Submission by Latvia and the European Commission on Behalf of the European Union and its Member States: Intended Nationally Determined Contribution of the EU and its Member States. Riga, LV: Mimeograph. 5pp. March 6. http://www4.unfccc.int/submissions/INDC/Published%20Documents/Latvia/1/LV-03-06-EU%20INDC.pdf [accessed January 13, 2016].

Mann, C.C., 2013. What if we never Run out of Oil? *The Atlantic*. May. http://www.theatlantic.com/magazine/archive/2013/05/what-if-we-never-run-out-of-oil/309294/ [accessed January 16, 2016].

Mantau, U., U. Saals, K. Prins, F. Steierer, M. Lindner, H. Verkerk, J. Eggers, N. Leek, J. Oldenburger, A. Asikainen and P. Anttila, 2010. Real Potential for Changes in Growth and Use of EU Forests. Final report. June 30. 160 pp. Hamburg, DE: EUwood. http://www.egger.com/downloads/ bildarchiv/187000/1_187099_DV_Real-potential-changes-growth_EN.pdf [accessed February 7, 2015].

Modi, V, S. McDade, D. Lallement, and J. Saghir, 2005. *Energy Services for the Millennium Development Goals.* The International Bank for Reconstruction and Development/The World Bank and the United Nations Development Programme. http://www.unmillenniumproject.org/documents/MP_Energy_Low_Res.pdf

Newbery, D.M., 2011. Contracting for Wind Generation. EPRG Working Paper 1120. Electricity Policy Research Group, University of Cambridge, Cambridge, UK. http:// www.eprg.group.cam.ac.uk/wpcontent/uploads/2011/07/EPRG1120_Complete.pdf [accessed May 14, 2015].

Newbery, D.M., 2012. Reforming Competitive Electricity Markets to Meet Environmental Targets, *Economics of Energy & Environmental Policy* 1(1): 69-82.

Novan, K., 2015. Valuing the Wind: Renewable Energy Policies and Air Pollution Avoided, *American Economic Journal: Economic Policy* 7(3): 291-326.

Oswald, J., M. Raine and H. Ashraf-Ball, 2008. Will British Weather Provide Reliable Electricity?. *Energy Policy* 36(8): 3212-3225.

Pielke Jr., R. A. 2009. The British Climate Change Act: A Critical Evaluation and Proposed Alternative Approach, *Environmental Research Letters* 4(2): 024010. doi: 10.1088/1748-9326/4/2/024010

Pielke Jr., R. A. 2010. *The Climate Fix*. New York, NY: Basic Books.

Scott, D.S., 2007. *Smelling Land. The Hydrogen Defense against Climate Catastrophe*. 482pp. Vancouver, BC: Canadian Hydrogen Association and Natural Resources Canada.

Smil, V., 2003. *Energy at the Crossroads. Global Perspectives and Uncertainties*. Cambridge, MA: MIT Press.

Stephenson, A.L. and D.J.C. MacKay, 2014. Life Cycle Impacts of Biomass Electricity in 2020. Scenarios for Assessing the Greenhouse Gas Impacts and Energy Input Requirements of Using North American Woody Biomass for Electricity Generation in the UK. Report #URN 14D/243. July. 154pp. London, UK: Department of Energy and Climate Change, Crown Copyright. https://www.gov.uk/government/publications/life-cycle-impacts-of-biomass-electricity-in-2020 [accessed January 14, 2016]

Taylor, P., T. Wiesenthal and A. Mourelatou, 2005. Energy and Envrionment in the European Union: An Indicator-Based Analysis. *Natural Resources Forum* 29(4): 360-376.

van Kooten, G.C., 2010. Wind Power: The Economic Impact of Intermittency, *Letters in Spatial & Resource Sciences* 3(1): 1-17

van Kooten, G.C., 2015a. *All you want to know about the Economics of Wind Power*. Working paper 2015-07. 82pp. REPA Research Group, Department of Economics, University of Victoria. http://web.uvic.ca/~repa/publications.htm

van Kooten, G.C., 2015b. The Economics of Forest Carbon Sequestration Revisited: A Challenge for Emissions Offset Trading. Working paper 2015-04. 60pp. REPA Research Group, Department of Economics, University of Victoria. http://web.uvic.ca/~repa/publications.htm

van Kooten, G.C., 2016. The Economics of Wind Power, *Annual Review of Resource Economics* 8(1): In press.

van Kooten, G.C. and F.P. de Vries, 2013. Carbon Offsets, pp 6-8 in *Encyclopedia of Energy, Natural Resource and Environmental Economics, Volume 1,* edited by J. Shogren. Amsterdam, NL: Elsevier.

Vogler, J., 2013. Changing Concpetions of Climate and Energy Security in Europe. *Environmental Politics* 22(4): 627-645.

World Trade Organization (WTO), 2014. Russia Files Dispute Against EU Over Regulations in the Energy Sector. Retrieved from:

https://www.wto.org/english/news_e/news14_e/ds476rfc_30apr14_e.htm