Renewables Forecasts in a Low Carbon World: A Brief Overview[*]

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I. Introduction

This chapter examines how concerns for climate—coupled with policy-makers' and voters' other preferences—are expected to affect the growth of renewables, particularly in the United States and the European Union. The chapter begins with a review of the recent growth in renewables and a discussion of current carbon policies. Then I review predictions of levels of investment in renewables in a low carbon world. Within the next twenty years, some authors predict that 20 to 40 percent of electricity will come from renewable resources, in an attempt to mitigate the impacts of climate change. Given the wide range of assumptions regarding carbon policies, economic growth, the responsiveness of the economy to carbon policy, innovation in renewables, and other

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modeling approaches, it is hard to generalize among these "black box" models. The complexity and continuous updating of these models makes a detailed peer review process necessary though beyond the scope of this paper.

Under continued dependence on fossil fuels in a "business as usual" scenario, climate scientists predict significant increases in average temperature and sea level, as well as many other climatic responses. Climate change is expected to adversely affect many economic sectors including agriculture, forestry, insurance, health, tourism, and energy. Furthermore, there are many notable nonmarket effects, such as the loss of flora and fauna and the increase in human morbidity and mortality. The Intergovernmental Panel on Climate Change (IPCC 2007) and Stern (2006) review the science and economic consequences of climate change.

These concerns may be addressed through several mechanisms for mitigating climate change. Broadly, we may change how we produce and use electricity, space heating, transportation and other energy uses; we may sequester greenhouse gases (for example, by reducing deforestation or increasing reforestation); or we may even consider climate geo-engineering.[1] Within the electricity sector, methods for reducing greenhouse gases—like carbon dioxide (CO_2)—include both demand-side (conservation and energy efficiency) and supply-side options. Supply options include switching from coal to less carbon-intensive conventional technologies like natural gas, large hydroelectric, and nuclear power; continuing to use coal but reducing the carbon emissions by using abatement technologies like carbon capture and sequestration (CCS); or, the focus of this

[1] Geo-engineering includes methods like stratospheric sulfur aerosols that manage solar radiation. These methods do not reduce greenhouse gases but rather limit their effect on global warming. Some also use this term to include carbon sequestration.

book, turning to alternative renewable sources of electricity, including wind, solar, geothermal, and small hydropower.

From an economic perspective, greenhouse gases are global, stock externalities. Chapter 4 of this book covers this topic in more depth. However, in brief, an externality is a cost (or benefit) incurred by others not involved in a market transaction. Global externalities are those where the location of the source of the pollutant is irrelevant to the damages. For example, a coal-fired power plant in China may be the source of released carbon dioxide emissions, but the effects of these emissions will be felt all over the world. Furthermore, their effects will be the same as had the carbon dioxide emissions come from natural gas power plants in England. Stock pollutants are long-lived pollutants whose damages from current emissions may be felt for years to come. For example, carbon dioxide emitted today will remain in the upper atmosphere for 100 years or more (IPCC 2007).[2] For stock pollutants, the optimal policy is clear in theory: each ton of emissions released is charged the net present value of all future damages that it causes.[3] Namely, a pollution tax can achieve the efficient outcome. Note a cap-and-trade regulation can also be efficient if the permit price equals this tax.

A pollution tax on greenhouse gases would give firms and consumers incentive to change behavior in many ways: switching to less carbon-intensive technologies, conserving electricity, driving less, *etc*. Firms investing in renewables would be just one of many responses. Are renewables the best option for addressing climate change? In

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[2] Not all greenhouse gases are as long lived. Methane, for example, has a chemical lifetime in the atmosphere of approximately 12 years. Technically, a stock pollutant never expires: for example, lead is a true stock pollutant. However, the economic insights of stock pollutants help in thinking about regulating greenhouse gases.

[3] More precisely, the optimal level of pollution at a point in time will be where present value marginal benefits of pollution (the avoided compliance costs) are equal to the present value marginal costs of pollution (the marginal damages). For further discussion, see Tietenberg (2006).

order to answer this question, one would need to know the relative marginal costs, both private and external, incurred by each option that reduces greenhouse gas emissions.

Whether or not producing electricity from renewable resources is the cheapest way to reduce greenhouse gas emissions, many government agencies and other authors predict that renewables will be a major contributor to a low carbon future. Investing in renewables is a popular response to climate concerns in part, perhaps, because of the other externalities that it addresses. First, other energy sources have additional negative externalities like conventional air pollution, water pollution, and nuclear waste. Note that if regulation results in marginal social costs equaling marginal social benefits of these other energy sources, these externalities will be internalized and no further regulation is required. Second, there may be positive technological spillovers from investing in renewables from which other industries, or firms in the same industry, benefit.[4] Learning benefits within a firm, which may account for the largest gains, are not positive externalities. Finally, subsidizing technology is seemingly more politically palatable than taxing firms and consumers for polluting.

The remainder of this chapter is organized as follows. Section II provides an overview of current electricity sources and energy and climate policies affecting the recent growth in investment in renewables. The section also discusses the direction of future carbon policies. In Section III, I review the literature on predictions of investment in renewables under various low carbon scenarios. Section IV concludes the chapter.

[4] Fischer and Newell (2008) show that a policy promoting renewables may be more efficient than a carbon tax if these positive technology spillovers are large relative to the climate externalities. However, they find for a range of parameter values, a price on carbon is preferred even when there are knowledge spillovers.

II. Current Energy Sources and Renewables Policies

A. *Current Energy Sources*

Electricity production is dominated by fossil fuels. In the US, coal accounts for over 50 percent of electricity production, while natural gas accounts for another 20 percent (EIA 2009b). Conventional, carbon-free technologies include nuclear power, which produces 20 percent of the US electricity, and hydroelectric power, which provides six percent. The EU is less dependent on fossil fuels: only 54 percent of power comes from coal, oil or natural gas (Eurostat 2009). Nuclear (28 percent) and hydropower (10 percent) are larger in the EU than in the US.

Non-hydropower renewables—such as wind, solar, geothermal, tidal, and biomass—account for less than seven percent of electricity produced in either the US or the EU. In 2008, the US produced 4111 Terawatt-hours (TWh) of electricity.[5] Of that, only 3.0 percent of was from non-hydropower renewables, including wind (52 TWh), wood (39 TWh), and other renewable sources (33 TWh) (EIA 2009b). In 2007, the European Union (EU-27) produced 6.5 percent of its electricity from wind (104 TWh), wood (52 TWh), and other renewables (55 TWh) (Eurostat 2009). Despite the fact that the United States produces over 20 percent more total electricity than the EU, the European Union produced more power from renewable sources than did the US.

While still a small share of total electricity production, the past two decades have seen enormous growth in renewables. In 1990, the Organization for Economic Cooperation and Development (OECD) countries had a total capacity of 2.4 gigawatts

[5] One TWh is one million megawatt-hours (MWh) or a billion kilowatt-hours (kWh). One TWh approximately equals the annual consumption of about 89 thousand US residential customers.

(GW) for wind power and 0.5 GW of solar, including both solar photovoltaics, PV, and solar thermal (IEA 2004).[6] By 2008, however, wind capacity had reached 17 GW in Spain alone (WWEA 2009). Table 1 reports installed wind capacity in the largest ten countries and worldwide for 2007 and 2008. Worldwide, wind capacity has reached 121 GW in 2008, an increase of 29 percent over the previous year (WWEA 2009). This annual growth rate is typical of this industry over the past decade. From 1997 to 2008, Figure 1 plots annual worldwide capacity and the annual growth rate.

This impressive growth rate has also been exhibited in other renewables, as well. As of 2008, worldwide capacity in solar PV has reached 13 GW (REN21 2009). As recently as 2003, there were only 1.3 GW (REN21 2009). This ten-fold increase can be attributed primarily to Germany and Spain, which account for two thirds of the world's solar PV capacity (REN21 2009). Overall, total renewables (excluding large hydropower) is now at 280 GW (REN21 2009). Table 2 reports capacity of various renewable resources by country.

Historically, the two major impediments to renewables have been costs and intermittency. The cost of wind power has dropped substantially over the past decade (IEA 2004). Now, with the production tax credit (which is discussed below), wind power costs less than five cents a kWh in the US and can compete with the cost of building new fossil fuel fired power plants (Wiser and Bolinger 2008). Photovoltaic solar power is an order of magnitude more expensive: the average installed cost (excluding direct financial incentives or tax credits) in 2007 was $7.6 per Watt in the US (Wiser, Barbose, and Peterman 2009), or about 30-50 cents per kWh, depending on the interest rate and

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[6] Electricity generation capacity is measured in Watts (W), kilowatts (kW, one thousand W), megawatts (MW, one million W), or gigawatts (GW, one billion W).

capacity factor. These costs have fallen substantially over the past few decades. Even from summer 2008 to summer 2009, they fell another 40 percent with the entry of China into the market (Galbraith 2009). While dramatically cheaper than in the past, solar PV remains an expensive option for addressing climate change (Borenstein 2008). In comparison, in 2007, the average installed cost of wind was $1.7 per Watt in the US (Wiser and Bolinger 2008). The IPCC (2007) projects that the costs of renewables will continue to fall and that, by 2030, renewables (including wind, solar PV, and biomass) will see capital costs under $1.2 per Watt. Chapter 2 of this book further discusses renewable technologies and their costs.

B. Recent Renewable and Climate Policy

The United States has been setting policies to promote investment in renewables for over three decades. In 1978, the Public Utility Regulatory Policies Act first provided subsidies for investing in renewables. In some states, like California, this led to substantial investments. For a review the history of US renewables policies, see chapter 10 of this book as well as Martinot, Wiser, and Hamrin (2005).

The growth in US renewables has been driven mainly by federal tax credit incentives. With the passage of the American Recovery and Reinvestment Act of 2009 (ARRA), wind, small hydropower, geothermal, biomass, municipal solid waste, and marine energy sources may be eligible to earn a subsidy of $21/MWh under the Production Tax Credit (PTC).[7] Many of these renewable resources can forego the PTC

[7] See http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h1enr.pdf (accessed August 25, 2009).

and become eligible for the 30 percent Investment Tax Credit (ITC).[8] As a third option, a Department of Treasury cash grant can be selected in place of the PTC and the ITC. Metcalf (2009a) provides greater detail on the tax incentives for renewables. US wind investment is quite elastic to changes in the user cost of capital (Metcalf 2009b): the federal PTC has been a substantial driver of wind investment over the past two decades. In the next section, I discuss how these incentives are expected to affect renewable investment.

A second major driver of renewable investment in the United States is the set of state level renewable portfolio standards (RPS), which are discussed in Chapter 9 of this book. To date, 28 states and the District of Columbia have implemented mandatory programs that require utilities to purchase a certain percentage of their power from renewable sources, where the definition of the technologies that comply with the regulation differs from state to state.[9] Markets for renewable energy credits, RECs or green tags, have arisen within some states. These RECs allow firms to comply with the regulations by either directly investing in renewables or by buying credits from other compliant sources.

In Europe, some countries have chosen renewable standards as a policy instrument to achieve the targets in the Renewable Electricity Directive (2001/77/EC). Like in many US REC markets, several European countries have implemented tradeable certificates in order to reach these goals (Nielsen and Jeppesen 2003, European Commission 2009). Figure 2 reports the share of renewable electricity by country for

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[8] Some renewables, including solar, wind and geothermal energy, first became eligible for tax credits with passage of the 1978 Energy Tax Act.

[9] See the Database of State Incentives for Renewables and Efficiency, http://www.dsireusa.org/, which is a project of the North Carolina Solar Center and the Interstate Renewable Energy Council that is funded by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

large hydropower and other renewables in 2007. Notably, over half the electricity generated in Sweden is from large-scale hydropower or other renewables and more than a quarter of Denmark's power is from non-hydro renewables. The figure also reports the 2010 objectives. While these targets are greater than what was the share of electricity generation from renewable resources in 2007 for many countries, some have just reached the target (for example, Denmark) while other countries have even exceeded it (namely, Germany and Hungary).

In order to comply with these standards, many countries have used feed-in tariffs that have spurred investment in renewables. Many of these subsidies are on the order of hundreds of Euros per MWh. For example, some solar power producers in Spain receive €340/MWh under *Real Decreto* 1578/2008. In 2008, Germany's solar feed-in tariff was even greater: some solar producers received €574/MWh under the *Erneuerbare-Energien-Gesetz*.[10] As a result, Spain and Germany have seen dramatic growth in renewable investments (see Tables 1 and 2). Chapters 10, 11, and 12 of this book discuss the EU experience, focusing on the UK, Germany, and Spain, respectively.

In addition to renewable standards and feed-in tariffs, the EU has implemented a multinational, multi-industry cap-and-trade policy for greenhouse gases. The EU Emission Trading System (EU ETS) began in 2005 and regulates about two billion metric tonnes of CO_2 each year. With permit prices fluctuating between €10-30 a tonne, this market is valued at around $50 billion per year.[11] Chapter 5 further discusses emissions trading.

[10] The EEG was further amended: as of January 2009, PV solar subsidies have been reduced to €330-430/MWh.
[11] The price on August 24, 2009 was €15.34 (Point Carbon, http://www.pointcarbon.com/).

The second major issue that renewable sources face is intermittency. Namely, some renewable resources, like wind and solar power, only produce some of the time and cannot be depended on to produce reliably. Intermittency will not be completely solved until a cheap, reliable mechanism of storing power is developed (NREL 2008). However, at a level of investment that is predicted over the next few decades (between 20 and 30 percent of electricity generation), geographic averaging and natural gas capacity that serves as backup reserve are likely to dampen the issue of intermittency. This may require new investment in natural gas power, especially in areas where renewables primarily produce offpeak (Campbell, 2009). Complete dependence on current non-hydroelectric renewable technologies seems questionable however, because of intermittency issues.[12]

A related issue concerns the development of the grid: in the US, many of the locations that have the most potential for renewables are far from population centers where electricity demand is greatest. Vajjhala *et al*. (2008) discuss how state RPS would provide significantly different incentives in for improving the transmission network than would a federal standard. A federal standard would allow for greater cost savings but would require more of a transmission build out. State polices would be less cost effective, as renewables would be built in many states that have high costs, but would require less investment in new transmission. Chapters 6, 8, and 9 of this book further discuss the important issues of intermittency and designing the transmission grid.

[12] Some express concern that predictions of substantial levels of investment in the future are not feasible given the issue of intermittency. In a recent paper, Heal (2009) reviews the literature on the economics of renewables. He shares these concerns and concludes that nuclear and CCS are likely to be important sources of electricity in a low carbon future.

This chapter's focus is on what investment in renewables may look like in a low carbon future. Given this brief overview of current renewable policies and investment, I turn to discussing the direction of future carbon policy.

C. Direction of Future Policy

Recently, carbon policy has become a central topic in both the U.S. and the E.U. In the U.S, while regional policies have been implemented, like the Regional Greenhouse Gas Initiative (RGGI) in the Northeast, or discussed in the West, like California Assembly Bill 32 (AB 32), the focus has turned to a national cap-and-trade policy. In particular, Congress is considering the American Clean Energy and Security Act of 2009, which is also known as the Waxman-Markey bill. If it were to pass, this bill would be the first US national climate policy and would regulate multiple industries.[13] Its goal is to reduce greenhouse gas emissions by 17 percent of 2005 levels by 2020 and over 80 percent of 2005 levels by 2050 (111th Congress, 1st Session H.R. 2454), mainly through a national cap-and-trade system.[14]

In addition to the tradable permit system, the Waxman-Markey bill contains a Renewable Electricity Standard (RES). The RES would require that 15 percent of electricity purchased in the United States come from renewable resources (including solar, wind, biomass, landfill gas, and geothermal) by 2020.[15] This is in line with the White House agenda of ten percent renewables by 2012 and 25 percent by 2025 (Heal

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[13] It is unlikely that the Waxman-Markey bill will pass into law as it was written when the House passed in the summer of 2009. As of this writing, Congress has not passed any Climate bill.
[14] The bill is available at: http://energycommerce.house.gov/Press_111/20090515/hr2454.pdf (accessed August 20, 2009).
[15] The requirement is that 20 percent be from renewables or energy efficiency but that at least 75 percent of that amount must be through renewables. This constraint is expected not to be binding.

2009). Finally, the US has recently passed a short term stimulus bill to help with the economic recovery, the American Recovery and Reinvestment Act of 2009.

In Europe, both carbon policies and goals of renewable shares are expected to continue. The EU ETS is currently in its second phase, from 2008-2012. In June 2009, the new EU ETS Directive commits the EU to reducing greenhouse gas emissions by 20 percent of 1990 levels by 2020 (Directive 2009/29/EC).[16] Furthermore, Directive 2009/28/EC states that 20 percent of the EU's total energy consumption be from renewable resources by 2020. Note that this is a much larger commitment than in the US, which seeks to have 20 percent of electricity production from renewables by 2020. In the US, and in the rest of the world, about 40 percent of total energy consumption is used to generate electricity. So a commitment to 20 percent of electricity generation in the US is a commitment to only eight percent of total energy consumption.

These policies focus on the near future. However, in order to attain a low carbon world, some believe that we will need an even greater investment in renewables. The next section of the paper examines the level of investment in renewables that is expected if we have carbon policies, either like those described above or policies that call for even more dramatically reduced emissions. The focus remains on the US and EU but some models examine worldwide levels of investment in renewables.

[16] See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0063:0087:EN:PDF for greater detail.

III. Forecasts of Renewables in a Low Carbon World

In examining the policies outlined in the previous section, as well as other possible policies, many authors have attempted to forecast what level of investment in renewables would be required in order to obtain a low carbon world. This section outlines the findings of some of the major studies in this area, including those by the International Energy Agency, the European Commission, the Department of Energy, the Environmental Protection Agency, the Forres 2020 Project, and a few others. For each model, I report (when possible) both the expected capacity of and generation from renewables excluding large-scale hydropower, as well as for total renewables. Each model has thousands of assumptions regarding economic growth, resource availability, technology, prices, *etc*. A careful comparison of the models requires an in-depth examination of each assumption and the modeling approach taken. However, the intent of this chapter is to provide a brief overview of the findings so the reader can gain an appreciation of the range of estimates in the literature, rather than to provide a meta-analysis or pick a preferred model. The range of models that I discuss provides perspectives of worldwide, US, and EU investment over the next 20 to 40 years.

A. A Global Perspective

The International Energy Agency's annual report is the *World Energy Outlook*. The IEA (2007) uses its World Energy Model (WEM) to examine long run forecasts of emissions, energy supply and demand, and energy sources under various scenarios. IEA reports three scenarios: a reference or business-as-usual scenario; an alternative policy scenario that would include reducing greenhouse gas emissions by 19 percent *relative to* *the reference case* by 2030; and a 450 stabilization scenario that would result in carbon dioxide equivalent (CO2e) emissions peaking in 2015 and falling by up to 85 percent of 2000 levels by 2050.[17] This last scenario is a low carbon world in which carbon dioxide equivalents concentrations would be stabilized at 445 to 490 parts per million (ppm) (IPCC 2007). For the year 2030, the reference scenario implies 42 gigatonnes (Gt, or billion metric tonnes) of CO_2 emissions, the alternative policy scenario implies 34 Gt, and the stabilization scenario implies 23 Gt.

In a low carbon world, non-hydropower renewable resources would double their expected generation in 2030 relative to a business-as-usual scenario (see Table 3). This would include adding over 1400 TWh per year from wind and solar power. Even in the reference case, the amount of wind power is expected to increase five-fold from current levels.[18] Overall, the IEA predicts that 40 percent of electricity could be produced from renewable resources, about half of which is from non-hydropower resources.

The Department of Energy also publishes a global perspective of renewable investments in their *International Energy Outlook*. In the business-as-usual scenario, they predict that by 2030 there could be 6,724 TWh of renewables (21 percent of total generation) including 1,951 TWh of non-hydroelectric generation (6.1 percent of total generation). Of this, most of the non-hydropower will be in the OECD countries (1,417 TWh).

[17] CO2e is a measure for greenhouse gases whereby all gases are normalized by their global warming potential.
[18] In 2008, wind power produced 260 TWh (WWEA 2009); while, in the reference case, the IEA (2007) predicts that there could be 1287 TWh by 2030.

B. A European Perspective

The European Commission's (2007) *World Energy Technology Outlook-2050* (WETO) forecasts three cases of world energy out to 2050: reference case; the carbon constraint case; and the hydrogen case. The report uses the POLES model, a worldwide simulation model of various energy sectors, to look at both EU and global energy issues. The model accounts for world population and GDP growth, as well as technological advancement lowering the costs of energy.[19] Table 4 reports the WETO's predicted electricity generation by fuel type for each scenario in 2030 and 2050.

In the reference model, the EC (2007) forecasts that total renewables will account for 21 percent of electricity production by 2030 and 25 percent by 2050. By 2050, solar and wind are expected to produce over half of the electricity generated from renewables, with wind (6433 TWh per year), particularly offshore, becoming even larger than hydropower (4853 TWh per year) worldwide. This represents a 25-fold increase in wind power from 2008 levels! The increase to 1493 TWh from solar is even larger in magnitude (the US and EU produced about 4.5 TWh last year). Nuclear power is also predicted to increase rapidly. The reference case includes modest carbon policy akin to what is currently in place in those countries with carbon policy. For this case, the WETO reports substantial investment in renewables for the world as a whole. Nonetheless, carbon dioxide emissions are projected to be more than double today's levels by 2050 in this scenario.

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[19] The Prospective Outlook on Long-term Energy Systems (POLES) model was developed by the Centre National de la Recherche Scientifique (CNRS). It is maintained by CNRS, UPMF University, Enerdata, and the Institute for Prospective Technological Studies. See http://www.eie.gov.tr/turkce/en_tasarrufu/uetm/twinning/sunular/hafta_02/5_POLES_description.pdf (accessed August 29, 2009).

The reference case is also reported by region. In Europe, the WETO predicts even greater renewable penetration: 26 percent of electricity production could be from renewables in both 2030 and 2050. Solar, biomass, and wind power will account for approximately two thirds of that generation. North America is similar with an expected 20 percent of all electricity coming from solar, wind or biomass.

The carbon constraint case seeks to stabilize carbon dioxide concentrations, though at levels greater than the IEA study: the WETO case aims to stabilize CO2e at 650 ppm. In 2030, the WETO predicts 8823 TWh of renewable production, about half from hydropower and a quarter each from wind and biomass. In 2050, wind is predicted to be the dominant, accounting for 7336 TWh of the 17,439 TWh that are renewable. This implies that renewables will account for 30 percent of total electricity production, with wind (12.7 percent), solar (4.0 percent), and biomass (4.6 percent) all playing important roles. North America and Europe are expected to have similar levels of non-hydro renewable penetration: 14.2 and 9.8 percent wind, 6.3 and 6.7 percent solar, and 7.2 and 4.1 percent biomass for North America and for Europe, respectively.

The hydrogen case continues with carbon policies to stabilize greenhouse gas concentrations but also assumes substantial breakthroughs in hydrogen technology. In particular, breakthroughs in the performance and cost of the distribution and consumption sectors of the hydrogen economy are identified as being of greatest importance. This scenario changes the mix of fossil fuels to nuclear power and changes transportation fuels: hydrogen provides 13 percent of final energy consumption (primarily for transport) in this case, compared to the two percent share in the reference case. However, with respect to renewables, the hydrogen scenario is qualitatively similar to the carbon constraint case.

C. A United States Perspective

The Department of Energy's Energy Information Administration publishes the *Annual Energy Outlook*, which reports long run projections of US energy supply and demand. The EIA (2009a) uses the National Energy Modeling System (NEMS) to forecast scenarios relevant to investments in renewables. The reference case for 2030 forecasts an increase in renewables capacity of 57 GW in the US (+/- 10 GW, depending on scenarios assumptions regarding costs). This accounts for about 22 percent of all new capacity constructed over the next 22 years. Regardless of the cost scenario, the EIA expects 730 TWh of renewable generation in 2030. Non-hydropower resources are predicted to account for about 14 percent of US total electricity generation (or 430 TWh). Costs do not change predictions much because the state renewable portfolio standards are assumed to bind. However, the mix of renewables does change: the EIA forecasts greater use of wind power relative to biomass if capital costs fall.

The EIA compares their reference case with some other studies. Namely, they note that IHS Global Insight (IHSGI 2008) predicts similar levels of growth in renewables, with slightly more conservative estimates from Energy Ventures Analysis, Inc. (EVA 2008). In the reference case, by 2015, the EIA (2009a) predicts generation from hydroelectric and other renewables, including net imports, to be 555 TWh while IHSGI predicts 537 TWh and EVA predicts 420 TWh, just slightly more than the 374 TWh generated in 2007. By 2030, the predictions increase to 758 TWh (EIA), 864 TWh (IHSGI), and 535 (EVA). These correspond to 15, 17, and 11 percent of total generation for each model, respectively. EIA's projections of capacity are also in line with alternative models. In addition to IHSGI and EVA, the Institute of Energy Economics and the Rational Use of Energy (IER 2008) also forecasts renewables capacity for 2015 and 2030. The total capacity for hydroelectric and other renewables was 131 GW in 2007. In 2015, it is expected to increase to 157 GW (EIA), 160 GW (IHSGI), 115 GW (EVA), and 208 (IER). By 2030, the capacity is predicted to be 191, 232, 128, and 312 GW, respectively. In summary, the EIA reference case seems consistent with several other predictions by industry and academia.

The EIA (2009a) predicts several counterfactuals relevant to a low carbon future relative to a reference case that pre-dated the recent stimulus bill—American Recovery and Reinvestment Act of 2009 (ARRA). The first counterfactual is to look at the effect of the ARRA, which extends two important subsidies: the PTC and the ITC. Figure 3 compares annual investment in non-hydropower renewables from 2006 to 2030 with and without ARRA. In 2012, the policy is expected to increase non-hydropower renewables from 195 TWh to 310 TWh, a 59 percent increase. By 2030, total renewables are expected to account for 15 percent of electricity generation in the US (two thirds of which are from non-hydroelectric resources).

The increase in renewable capacity from the ARRA is even more substantial. By 2015, an additional 40 GW of renewable capacity is expected, mostly from wind (35 GW). The EIA (2009a) predicts that, by 2030, wind power capacity (68 GW) will nearly rival that of conventional hydropower (78 GW) in the US. Only some of the increase in renewables that is attributed to the ARRA is the result of simply extending the PTC.

In a simulation that extends the PTC through 2019, the EIA (2009a) predicts that wind power would increase by 19 GW (while biomass, municipal solid waste, and geothermal power would be unchanged) by 2020 relative to the reference scenario. While an increase of 19 GW may seem large, especially given that the US only had 25 GW wind power capacity in 2008 (WWEA 2009), the EIA (2009a) predicts that the ARRA will increase renewable power by over 33 GW in 2020, with wind accounting for all of the gain. The ARRA allows developers to convert the PTC into federal grants, thereby avoiding a major hurdle of the PTC: namely, only those with significant tax liability can benefit from the tax credit.

In a third scenario, the EIA examines a low carbon case: the Lieberman-Warner bill, S. 2191 (LW110). The EIA expected that the bill would result in the electric power sector's emissions falling by over 50 percent relative to 2007 levels. Furthermore, the bill would have increased renewable generation in 2030 from 730 TWh to 1063 TWh (or 22 percent of total electric generation). Renewable capacity would nearly double from the reference case (57 to 103 GW). Nuclear power and advanced coal with carbon capture and sequestration (CCS) would also increase substantially: from 13/1 GW of nuclear/CCS capacity in the reference case to 47/99 GW in the LW110 case.

D. A Forecast of Proposed US Carbon Policy

In a recent report, the EPA (2009) analyzed the Waxman-Markey bill. While a federal carbon policy will almost surely differ from this exact bill, it is useful to examine it nonetheless, as it is the most recent proposal as of this writing. This bill's cap-and-trade policy would result in greater costs for fossil fuel electricity generation, making renewables more competitive. The EPA (2009) estimated the initial cost of polluting to be around $13 per metric tonne of CO2e. From the cap-and-trade policy alone, the EPA (2009) finds that investment in primary energy that has either no or low carbon emissions—namely renewables, nuclear power, and advanced coal with carbon capture and sequestration—would rise for the business-as-usual scenario of 14 percent of primary energy to 18 percent by 2020, 26 percent by 2030, and 38 percent by 2050.

Using a detailed, Integrated Planning Model, the EPA (2009) accounts for both the cap-and-trade program as well as the RES. Table 5 reports the expected investment in various sources of electric power under the reference case as well as under the Waxman-Markey bill. The reference case is based on the EIA's *Annual Energy Outlook* (EIA 2009a). Relative to the reference case, the climate bill would increase electricity generated by renewables (excluding hydropower) by only three to five percent. Including hydropower, the EPA model predicts approximately zero change in generation from renewables in 2025. This status quo is due to a reduction in total electricity consumption, in part because of higher electricity prices but also because of economic incentives to conserve. One way utilities can comply with the Renewable Electricity Standard is through energy efficiency programs.

Even though the EPA does not predict that the bill will result in substantial *incremental* investment in renewables, the reference case includes 364 TWh produced by renewables in 2025. In contrast, current production from renewables is 124 TWh (EIA 2009b). In other words, based on current policies, the EPA expects renewables to triple over the next 17 years. In the reference case, non-hydroelectric renewables would account for eight percent of total electricity generation (or nine percent under the Waxman-Markey bill). Including hydropower, this increases to 14 percent (16 percent with the bill). A final note regarding the Waxman-Markey bill: according to the EPA's model, the bill is expected to cause substantial growth in "clean" coal (advanced coal with carbon capture and sequestration), on the order of 400 to 1200 percent, relative to the reference case.

In addition to the EPA's study, the MIT Joint Program on the Science and Policy of Global Change has analyzed the bill (Paltsev *et al.* 2009). This study finds that annualized costs of the bill would be on the order of $400 per household with a permit price starting just over $20 per ton of CO_2 in 2015 and reaching $38 by 2030. The bill is expected to increase renewables only slightly: the share of power from non-hydroelectric renewables increases from 10 to 11 percent.

E. A Forecast of EU Renewables Policy

In a report financed by the European Commission's Directorate-General of Energy and Transport, Ragwitz *et al*. (2005) examined how investment in renewables might proceed in the European Union through 2020. The authors use the Green-X model from the FORRES 2020 project, which assumes learning-by-doing and scale economies.

For the year 2020, their model suggests that in the reference case there could be 385 TWh from wind, 8.8 TWh from PV solar, and 607 TWh of total renewables (excluding large-scale hydropower). For comparison, the EU produced only 104 TWh from wind, 3.8 TWh from solar PV, and 212 TWh from non-hydropower renewables in 2007 (Eurostat 2009). As a share of overall gross electricity consumption in the EU countries, this is an increase from 6.5 percent in 2007 (16 percent if hydropower is included) to 15 percent (22 percent) in 2020.

The authors also examine a policy scenario whereby "best practices" of currently available strategies are applied across all 27 EU countries.[20] In this policy case, wind power is expected to produce 461 TWh, another 17.9 TWh from solar PV, and 928 TWh from total renewables (excluding large-scale hydropower), or 26 percent of expected total electricity generation. With hydropower, this increases to 1234 TWh (34 percent). The authors conclude that, following currently available best practices, renewables could account for a third of all electricity generation in the EU.

F. Other Models

This final subsection briefly summarizes the research of some academics, trade groups, and non-profit organizations who have examined the question of what could be the long run level of investment in renewables. Palmer and Burtraw (2005) use the RFF Haiku model of the US electricity industry to analyze the effects of renewable portfolio standards (RPS) and renewable energy production tax credits. In the reference case, the authors predict that in 2020 there could be 151 TWh of non-hydropower generated, or only 3.1 percent of total generation (9.5 percent if hydropower is included). Under a general renewable production tax credit, which is set at current levels but applies to a much broader set of renewables, Palmer and Burtraw find that 729 TWh would be produced. This would result in 15 percent of electricity coming from non-hydropower renewables (with 43 percent of it from wind power). Total renewables, including hydropower, are predicted to account for 21 percent of electricity supply. Palmer and Burtraw look at several possible RPS for 2020: five, ten, fifteen, and twenty percent. In

[20] Best practices are defined as those "strategies that have proven to be most effective in the past in implementing a maximum share of RES have been assumed for all countries" (Ragwitz *et al*. 2005).

each case, the standard is binding for non-hydropower renewables and hydropower accounts for an additional 6.5 percent of total electricity generation. For the low-level RPS, non-hydropower renewables are dominated by geothermal. However, a 20 percent RPS would require substantial investment in wind power, accounting for about half of all non-hydropower renewable generation (468 TWh of 948 TWh).

Many other studies have examined this question. For example, the IPCC (2007) note that renewable electricity, including hydropower, was 18 percent of world electricity supply in 2005 and that, with a carbon price of $50 per tonne of CO2e, it could reach a 30 to 35 percent market share by 2030. The Union of Concerned Scientists (2009) suggest a blueprint to reduce US carbon dioxide emissions by 84 percent below 2005 levels by 2030. Through energy efficiency policies, the study suggests that electricity consumption could be reduced by 35 percent relative to the reference case. A RPS would result in wind, solar, geothermal, and biomass providing 40 percent of the total electricity, or about 21 percent of overall energy supply. The WWEA (2009) expects there to be 1500 GW of installed wind capacity producing 12 percent of electricity generation by 2020. The Energy Watch Group (Rechsteiner 2008) predicts that by 2025, the investment could be even greater; with 7500 GW installed wind capacity producing 16,400 TWh a year. Furthermore, the study suggests that total renewables could account for over 50 percent of new power installations worldwide by 2019 and all of it by 2022. By 2037, Rechsteiner (2008) suggests that non-renewable generation could be *completely* phased out.

IV. Conclusion

Within 20 years, some authors predict that 20 to 40 percent of electricity could be produced from renewable resources. Some even predict higher levels. Table 6 draws together the medley of forecasts outlined in the previous section to show the range of model's predictions as well as some important regional and policy differences.

Returning to an economist's perspective, one would need to know the relative net marginal social benefits for each type of renewable resource, at each location and point in time in order to determine whether a 20, 30, 40, or even 50 percent market share for renewable electricity is optimal. However, this chapter focuses not on what *should be* the level of investment in renewables but rather on what modelers predict *could be* the level of investment, either based on policies that are currently being discussed—such as the third phase of the EU Emission Trading System, EU Directive 2009/28/EC on renewables, or the US Waxman-Markey bill—or future policy objectives, like stabilizing carbon dioxide equivalent concentrations at 450 or 650 ppm.

By reviewing major studies on this topic, this chapter provides a range of estimates of levels of investment in wind power, solar PV, non-hydropower renewables and total renewables for the world overall, the EU, and the US. The range of levels of investment reflects many differences regarding the assumptions in the models, the policies being analyzed, and the methodologies used by the researchers. This chapter has shown that although there is a diversity of opinions on what might happen over the next twenty to forty years, studies employing a variety of models and a range of assumptions regarding carbon policy forecast that we are likely to see a significant increase in the role of renewables in meeting electricity demand.

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Figures and Tables

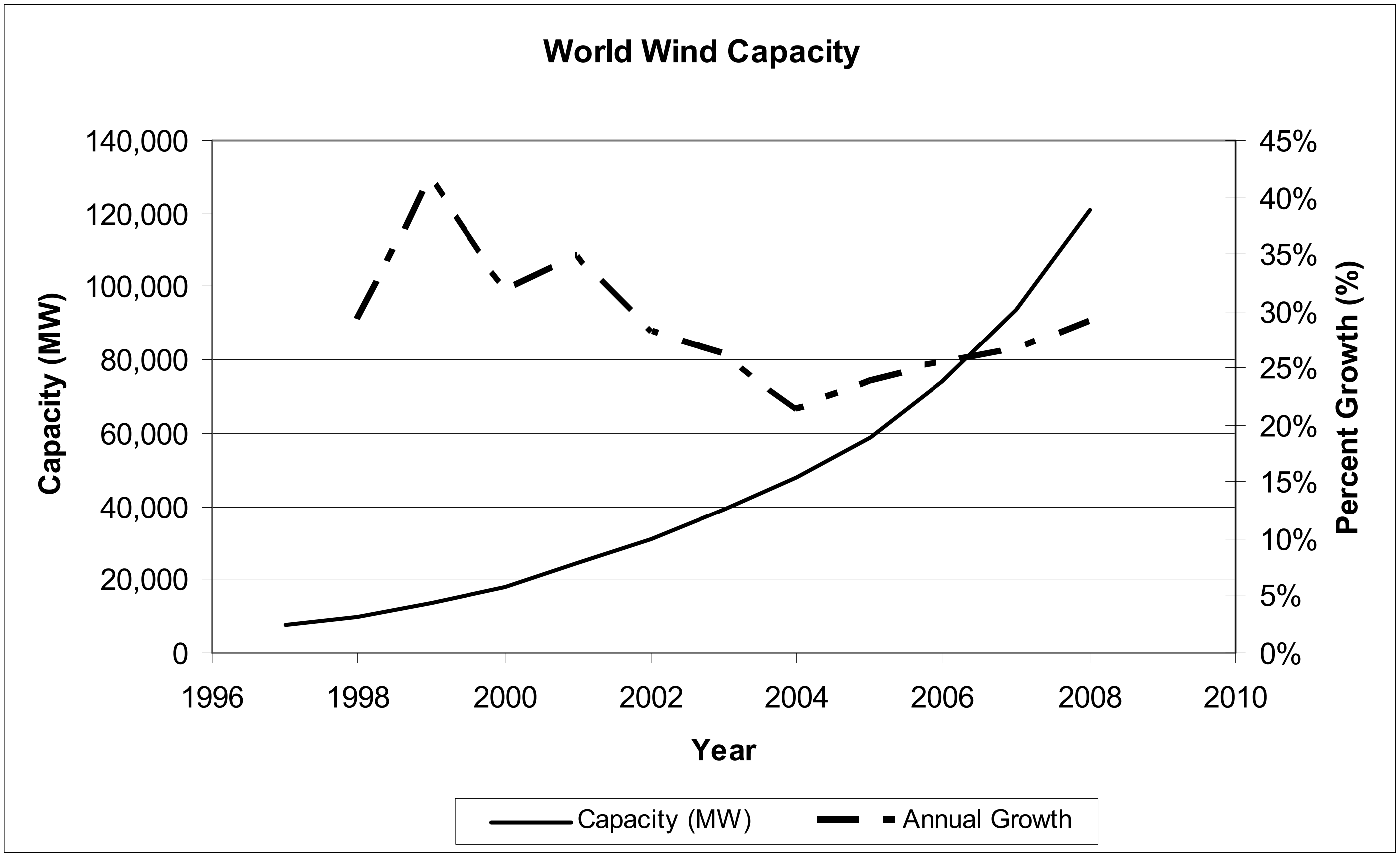

Figure 1: Wind Power Worldwide Capacity (MW) and Annual Growth Rate. (Source: WWEA 2009).

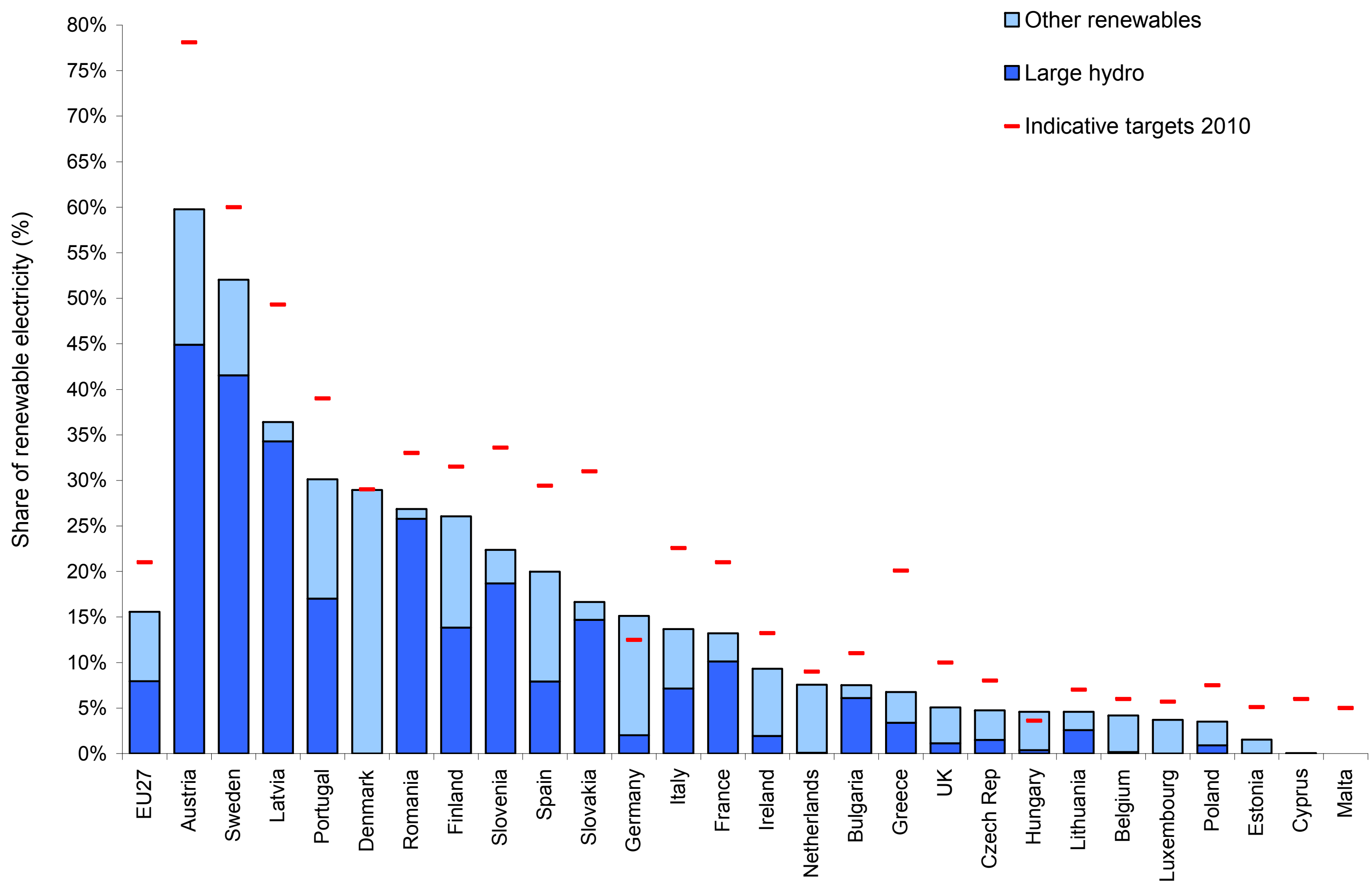

Figure 2: Share of Renewable Electricity by EU Country in 2007 (Source: Author's calculations based on the Commission of the European Communities (2009) and Eurostat (2009)).

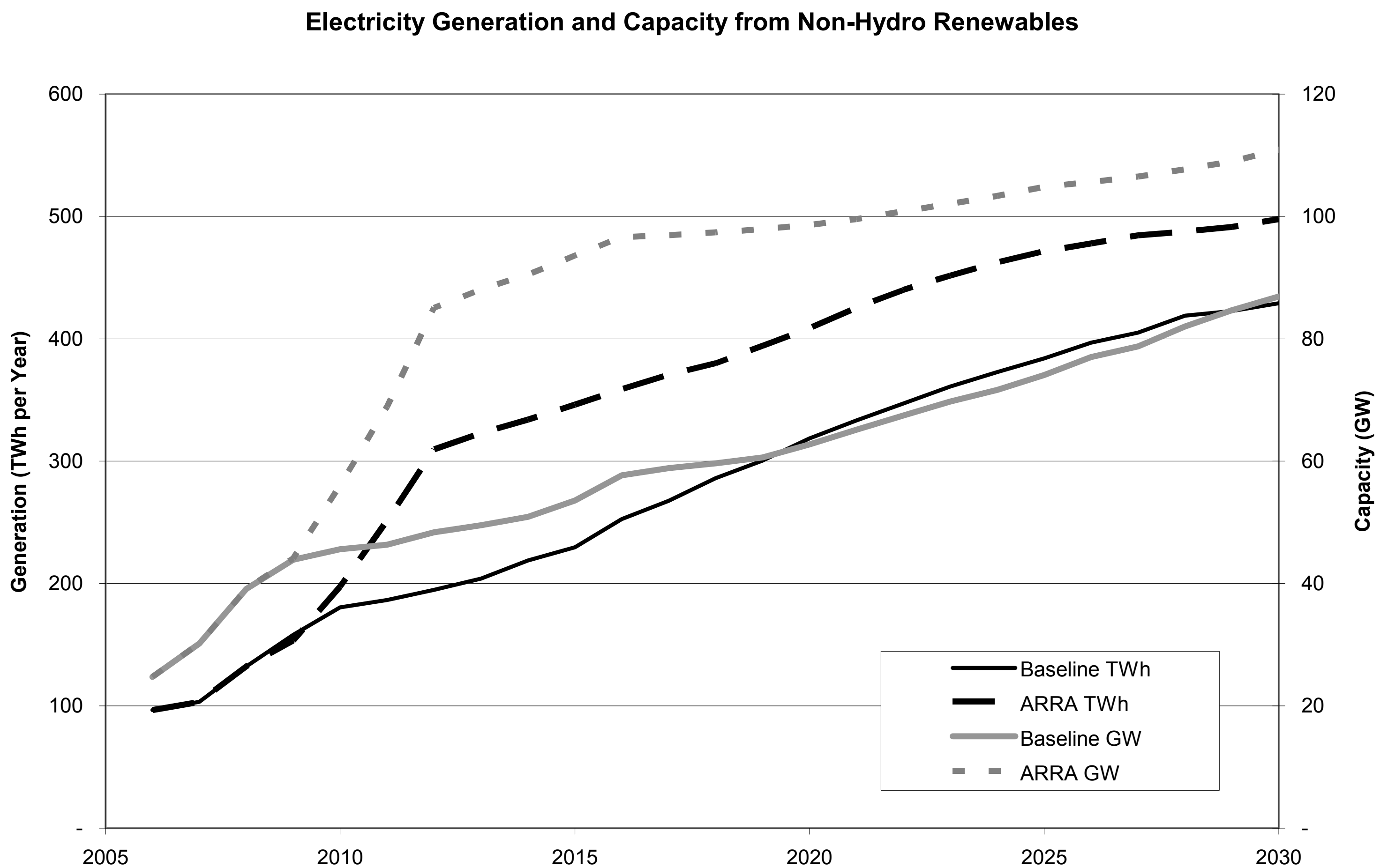

Figure 3: Expected Electricity Generation and Capacity from Renewable Sources (excluding Hydropower) under the Baseline Reference Case and under the American Recovery and Reinvestment Act of 2009 (ARRA) (Source: EIA 2009a).

Table 1: Total Installed Capacity of Wind Energy in 2008 (Capacity in GW)

Country	2007	2008	Change	Growth Rate
US	16.8	25.2	8.4	50%
Germany	22.2	23.9	1.7	7%
Spain	15.1	16.7	1.6	11%
China	5.9	12.2	6.3	107%
India	7.9	9.6	1.7	22%
Italy	2.7	3.7	1.0	37%
France	2.5	3.4	0.9	39%
UK	2.4	3.3	0.9	38%
Denmark	3.1	3.2	0.0	1%
Portugal	2.1	2.9	0.7	34%
Rest of World	13.1	17.1	4.0	30%
Total	93.9	121.2	27.3	29%

Source: World Wind Energy Association (2009).

Table 2: Capacity of Renewable Resources by Type and Country in 2008 (Capacity in GW)

	World	Developing Countries	EU-27	China	United States	Germany	Spain	India	Japan
Wind	121	24	65	12.2	25.2	23.9	16.8	9.6	1.9
Small Hydropower	85	65	12	60	3	1.7	1.8	2	3.5
Biomass	52	25	15	3.6	8	3	0.4	1.5	0.1
Solar PV	13	0.1	9.5	0.1	0.7	5.4	3.3	0	2
Geothermal	10	4.8	0.8	0	3	0	0	0	0.5
Solar Thermal	0.5	0	0.1	0	0.4	0	0.1	0	0
Ocean (Tidal)	0.3	0	0.3	0	0	0	0	0	0
Total Renewable	280	119	96	76	40	34	22	13	8

Notes: Total renewables excludes large hydropower. The source is the Renewable Energy Policy Network for the 21st Century (2009)

Table 3: IEA World Energy Outlook Predictions

Generation by Energy Source in Terawatt-hours (TWh)

Source	2005	2030 Reference Case	2030 Stabilization Case	Change	Growth Rate
Hydro	2922	4842	6608	1766	36%
Biomass	231	840	2056	1216	145%
Wind	111	1287	2464	1177	91%
Geothermal	52	173	219	46	27%
Solar	3	161	406	245	152%
Tidal (Wave)	1	12	28	16	133%
Non-hydro Renewables	398	2473	5173	2700	109%
Total Renewables	3321	7315	11,781	4466	61%
Total Generation	18,197	35,384	29,300	-6084	-17%
Percent Renewable	18%	21%	40%		

Source: Table 5.6 of IEA (2007).

Table 4: European Commission's WETO (2006) Report on Electricity Generation (TWh) by Fuel Type for Three Scenarios

Panel A: Year 2030

	World			Europe			North America		
Energy Source	Reference	Carbon	Hydrogen	Reference	Carbon	Hydrogen	Reference	Carbon	Hydrogen
Coal	12,689	9,114	8,205	1,551	969	794	2,944	1,208	1,491
Gas	8,760	9,438	8,851	1,319	1,545	1,540	1,836	2,281	2,186
Biomass	1,372	1,684	1,644	258	315	311	417	469	474
Nuclear	6,328	6,449	8,834	1,447	1,432	1,597	1,088	967	981
Hydro and Geothermal	4,148	4,284	4,226	697	706	702	711	732	730
Solar	91	213	183	17	29	28	13	68	55
Wind	1,880	2,642	2,417	545	608	604	428	728	727
Hydrogen	39	56	44	9	15	12	4	9	7
Total Electricity	36,295	34,587	35,039	5,932	5,673	5,642	7,560	6,548	6,714
Percent Renewable	21%	26%	24%	26%	29%	29%	21%	30%	30%

Panel B: Year 2050

	World			Europe			North America		
Energy Source	Reference	Carbon	Hydrogen	Reference	Carbon	Hydrogen	Reference	Carbon	Hydrogen
Coal	19,066	9,016	9,371	1,860	781	633	3,976	1,415	1,525
Gas	9,072	9,640	8,959	1,337	1,492	1,465	1,408	1,841	1,738
Biomass	2,246	2,649	2,584	328	361	360	598	680	685
Nuclear	14,866	19,862	21,426	2,931	3,612	3,942	2,014	2,509	2,474
Hydro and Geothermal	4,853	5,128	4,998	738	746	743	764	784	782
Solar	1,493	2,326	2,058	344	593	591	308	590	523
Wind	6,433	7,336	6,799	817	859	838	1,115	1,337	1,352
Hydrogen	811	1,477	898	190	321	243	73	196	120
Total Electricity	60,040	57,812	57,377	8,608	8,803	8,845	10,337	9,407	9,233
Percent Renewable	25%	30%	29%	26%	29%	29%	27%	36%	36%

Table 5: EPA Analysis of the Waxman-Markey Bill (H.R. 2454)

Generation by Energy Source in Terawatt-hours (TWh)

Panel A: Year 2020

Energy Source	Reference Case	H.R. 2454	Change	Growth Rate
Coal	2222	1940	-282	-13%
Advanced Coal (w/ CCS)	14	71	57	407%
Natural Gas/Oil	703	486	-217	-31%
Nuclear	816	816	0	0%
Hydropower	290	285	-5	-2%
Other Renewables	334	351	17	5%
Total Renewables	624	636	12	2%
Total Electricity	4379	3949	-430	-10%
Percent Renewable	14%	16%		

Panel B: Year 2025

Energy Source	Reference Case	H.R. 2454	Change	Growth Rate
Coal	2312	1851	-461	-20%
Advanced Coal (w/ CCS)	14	184	170	1214%
Natural Gas/Oil	788	544	-244	-31%
Nuclear	837	820	-17	-2%
Hydropower	292	282	-10	-3%
Other Renewables	364	375	11	3%
Total Renewables	656	657	1	0%
Total Electricity	4607	4056	-551	-12%
Percent Renewable	14%	16%		

Source: EPA (2009).

Table 6: A Summary of Model Predictions for 2030

			Generation Percentage	
Geographic Scope	Modeling Organization	Carbon Policy	Non-Hydro Renewables	All Renewables
Worldwide	IEA	Business As Usual	7%	21%
		450 Stabilization	18%	40%
Worldwide	EC	Business As Usual	11%	21%
		Carbon constraint	14%	26%
		Hydrogen	12%	24%
Worldwide	IPCC	$50/ton price	-	30-35%
Europe	EC	Business As Usual	15%	26%
		Carbon Constraint	17%	29%
		Hydrogen	17%	29%
U.S.A.	EIA	ARRA	9%	15%
		Lieberman-Warner	-	22%
	EPA	Waxman-Markey	16%	26%

Sources: IEA from http://www.worldenergyoutlook.org/docs/weo2009/fact_sheets_WEO_2009.pdf, EC from http://ec.europa.eu/research/energy/pdf/weto-h2_en.pdf and figure 38 of http://ec.europa.eu/research/energy/pdf/weto-h2_en.pdf, and EPA from Page 27 of http://www.epa.gov/climatechange/economics/pdfs/WM-Analysis.pdf.