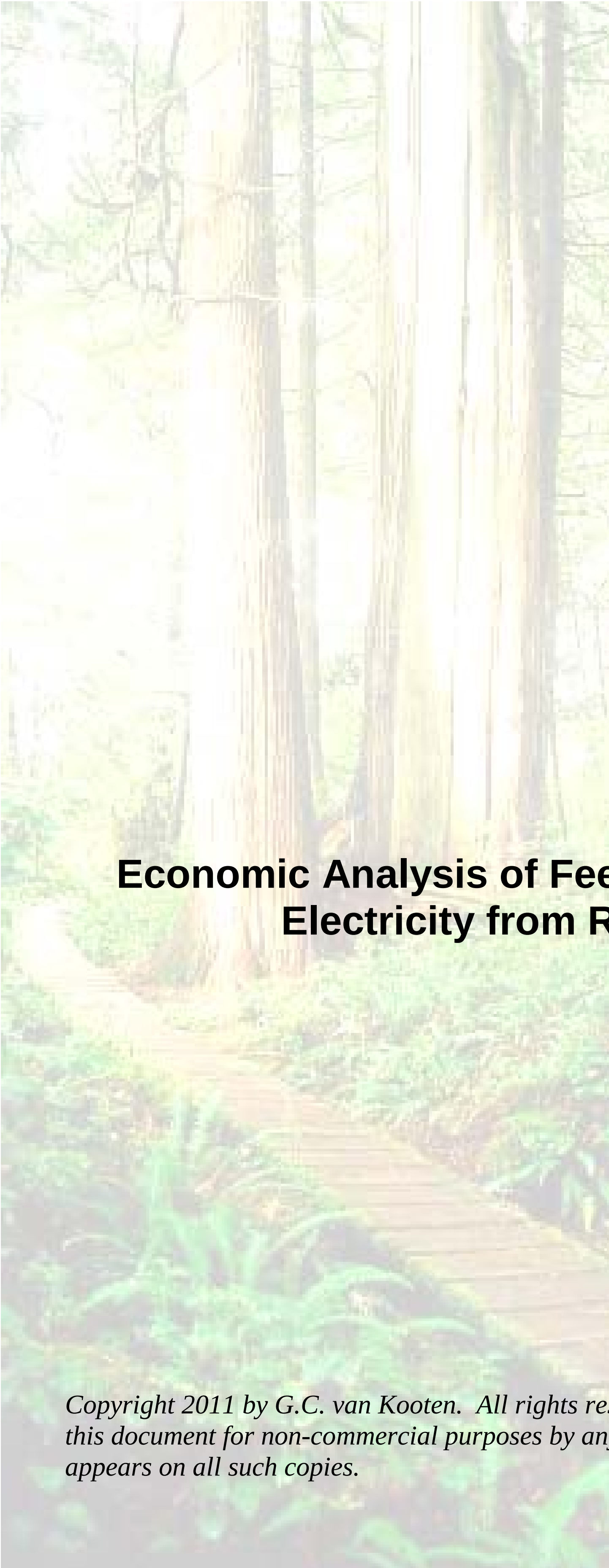

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Economic Analysis of Feed-in Tariffs for Generating Electricity from Renewable Energy Sources

G. Cornelis van Kooten

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Economic Analysis of Feed-in Tariffs for Generating Electricity from Renewable Energy Sources

By

G Cornelis van Kooten

DRAFT: April 25, 2011

INTRODUCTION

The process accompanying the UN's 1992 Framework Convention on Climate Change (FCCC) culminated in an agreement at the Third Conference of the Parties (COP3) held at Kyoto, Japan, in December 1997: Industrialized nations agreed that, by the first commitment period 2008-2012, they would reduce their collective emissions of CO_2 and equivalent greenhouse gases (hereafter just CO_2) to an average of 5.2% below what they were in 1990. Since then, countries have sought to build on Kyoto and reduce CO_2 emissions even further in order to address predicted climate change. Given the perceived urgency of addressing climate change and in an effort to get serious about climate change, the leaders of the G8 countries agreed at a July 2009 meeting in L'Aquila, Italy, to limit the increase in global average temperature to no more than 2°C above pre-industrial levels. They would do this by reducing their own greenhouse gas emissions by 80% or more, and global emissions by 50%, by 2050 relative to 1990 or some more recent year. The European Union already has in place a '20-20-20 target' – a 20% reduction in CO_2 emissions from 1990 levels by 2020, with 20% of energy to be produced from renewable sources.[1] At COP15 in Copenhagen in late 2009, and again at COP16 in Cancun, Mexico in 2010, the EU was prepared to impose a 30% reduction in CO_2 emissions by 2020, if there had been some sort of climate agreement.

The United States also appeared ready to reduce CO_2 emissions by a significant amount: The House of Representatives passed the *American Clean Energy and Security Act* (also known as Waxman-Markey) on June 26, 2009. The Act required large emitters to reduce their aggregate CO_2 emissions by 3% below 2005 levels in 2012, 17% below 2005 levels in 2020, 42% in 2030, and 83% in 2050. The Senate has yet to pass legislation, but had been contemplating major reductions in emissions. The *American Power Act* (2009) proposed by Senators Kerry and Lieberman added to the Waxman-Markey cap-and-trade scheme a carbon tax on large emitters. The tax would have a floor of $12 per ton CO_2 that would rise by the rate of inflation

[1] This target is directed particularly at the countries of Western Europe, or the EU-25, although more recent entrants to the EU are also expected to make significant gains towards its achievement.

plus 3 percent, and a ceiling of $25 indexed to inflation plus 5 percent. This bill was subsequently replaced by a 2010 bill (S.3813) sponsored by Senator Bingham to create a national 'Renewable Electricity Standard' (RES). It required that, by 2021, 15% of the electricity sold by an electric utility be generated from wind or certain 'other' renewable energy sources (presumably solar, etc., and not hydro); up to four of the 15 percent points could, theoretically, be achieved by actions that improve energy efficiency, although these were tightly defined.

To date, no legislation has actually been passed by the Senate and, given Republican gains at the mid-term elections in November 2010 (including a majority of the seats in the House), it will be difficult but perhaps not impossible to pass climate legislation, especially legislation that involves some sort of economic instrument, cap-and-trade or carbon taxes. At the same time, the U.S. Environmental Protection Agency was granted power to regulate CO_2 emissions as a result of a 2007 Supreme Court ruling that CO_2 is a pollutant.

To achieve the kinds of emission reduction targets envisioned, it is necessary to radically transform the fundamental driver of global economies – the energy system. The main obstacle to so doing is the abundance and ubiquity of fossil fuels, which can be expected to power the industrialized nations and the economies of aspiring industrial economies into the foreseeable future. Realistically, global fossil fuel use will continue to grow and remain the primary energy source for much of the next century (Bryce 2010; International Energy Agency 2009; Duderstadt et al. 2009; Smil 2003).

ECONOMIC INSTRUMENTS FOR REDUCING CO_2 EMISSIONS

Several options are available to the authority for reducing reliance on fossil fuels – for reducing emissions of carbon dioxide. These are regulation (also known as mandates) and economic incentives, namely, a carbon tax, a cap-and-trade scheme or subsidies of one form or other. Each is discussed below.

Regulation

The government can choose to regulate emissions of CO_2 from fossil fuels, and other sources, in a variety of different ways. In the transportation sector, fleet fuel economy standards can be mandated: These require that an automobile manufacturer's sales of vehicles in a particular market achieve a specified average fuel economy. Coal-fired power plants may be required to install equipment to capture CO_2 from the smokestack (or new plants must be able to do so). Electric system operators or utilities may be required to derive a specified proportion of their power from renewable generating sources. In some cases, the authority may even specify the extent to which the operator must rely on wind generated power.

Most environmental economics textbooks provide a simple demonstration as to why economic incentives are more efficient than regulation. Hence, it is surprising that policymakers still rely on regulation as a principal means of tackling market failures caused by unwanted emissions.

Aside from transaction costs, which include monitoring compliance, direct intervention leads to economic inefficiencies because economic agents seek only to comply with the regulations, but not lower emissions at least cost. CO_2 emissions are not necessarily reduced by those firms that can do so at the lowest cost. In addition, as new firms enter or new plants are built, emissions can expand even while mandates, such as requirements to adopt the best available technology, are met. Thus, there is no guarantee that regulations will actually reduce CO_2 emissions. Yet, by failing to pass legislation to address climate change, the U.S. Congress has chosen to rely, through the Environmental Protection Agency, on regulation as the vehicle for lowering CO_2 emissions.

Carbon Taxes and Emissions Trading

Carbon taxes target prices, while cap-and-trade targets quantity. A carbon tax raises the cost of emitting carbon dioxide, thereby increasing the price of energy produced by fossil fuels and, if correctly applied, the costs of energy from biomass burning (as it also releases CO_2).[2] With cap and trade, emissions of CO_2 are restricted; this causes them to take on value, thereby raising costs of releasing CO_2 into the atmosphere. By permitting economic agents to trade the limited quantity of emissions (the cap), the cost of a permit falls to its lowest possible value. In principle, the state can choose the tax level (price) or the number of emission permits to auction (quantity), but if all is known the outcome will be the same – the targeted level of CO_2 emissions reduction will be achieved.

Given a choice between carbon taxes and cap-and-trade, economists generally prefer carbon taxes for three reasons. First, the transaction costs associated with emission trading are likely much larger than with a tax.

Second, a carbon tax and cap-and-trade scheme are identical in theory, but when abatement costs and/or benefits are uncertain, picking a carbon tax can lead to the 'wrong' level of emissions reduction while choosing a quantity can result in a mistake about the forecasted price that firms will have to pay for auctioned permits (Weitzman 1974). Such errors have social costs. If the marginal cost of abatement is steep while the marginal benefit (marginal damages avoided) curve is relatively flat, then a small increase in the number of permits that are issued can have a large impact on their price (Pizer 1997; Weitzman 1974, 2002). "Uncertainty about compliance costs causes otherwise equivalent price and quantity controls to behave differently and leads to divergent welfare consequences ... [so] that prices controls are more efficient [than quantity controls]" (Pizer 2002). On economic grounds, a carbon tax is preferred over cap-and-trade.

Finally, large income transfers are involved. With a tax, the authority drives a wedge between the supply and demand curves that causes the price of energy from fossil fuels to rise above the marginal cost of providing that energy by the amount of the tax. The government collects the difference as revenue. With a quantity restriction (a cap), the difference between price and marginal cost of provision constitutes a large rent that is 'up for grabs.' Large industrial emitters

[2] Proponents of biomass energy argue that it is CO_2 neutral, but this is not the case as pointed out below in the discussion pertaining to the use of biomass for power generation.

can capture this rent if all or a significant proportion of the permits are grandfathered rather than auctioned. Rent seeking occurs and, thus, grandfathering of permits is likely to be required for cap-and-trade scheme to be politically acceptable. Likewise, large financial intermediaries will lobby for cap and trade as they gain from trading permits. Further, there is the potential for corruption if permits can be purchased abroad through such devices as the Clean Development Mechanism. If that is the case, we have emissions trading but not a true cap-and-trade scheme, and emission reduction targets are unlikely to be met.

Politicians have generally eschewed carbon taxes as these are seen as just another means to raise overall taxes. Resistance in the U.S. to cap and trade has also come about because it too is increasingly viewed as another form of taxation. This most likely explains the failure of the U.S. Congress to pass climate legislation.

Subsidies

Subsidies are also a form of economic incentive. Governments can subsidize everything from research and development of new technologies that substitute for or reduce reliance on fossil fuels to the construction of energy-efficient buildings and manufacturing plants; states can even subsidize the purchase of end products such as eco-friendly vehicles. Governments have subsidized biofuel production facilities, research into electric, hybrid and hydrogen vehicles, and the construction of biomass power generating plants, wind turbines and solar photovoltaic panels. Needless to say, firms prefer subsidies over taxes and emissions trading (unless they can capture large rents from the grandfathered emission permits); sometimes the public even appears to prefer subsidies, but only as long as they are unaware of the tradeoffs in public spending on other programs and/or assume the funds spent for this purpose will reduce expenditures on things they oppose.

In practice, one finds many of the above economic instruments operating simultaneously. For example, a government might subsidize farmers for growing energy crops and energy companies for building biofuel processing plants, while at the same time regulating ethanol content in gasoline and imposing carbon taxes on gasoline from petroleum. Indeed, they might even at the same time be subsidizing exploration for new sources of petroleum or natural gas.

Feed-in tariffs are a particular type of subsidy to the electricity sector. They guarantee power producers a fixed price for their electricity for a specified period of time. The electricity sector is important because it already accounts for nearly one-fifth of the world's final energy consumption, power can be generated from a great variety of energy sources, and electricity could possibly play a large role in future transportation, whether directly to re-charge electric vehicles or indirectly by producing hydrogen fuel. Hence, we turn our attention to the electricity sector.

ELECTRICAL POWER GENERATION

Fossil fuels are the most important source of energy in the global generation of electricity (Figure 1). Approximately two-thirds of electricity is produced from fossil fuels, while the remainder comes primarily from hydro and nuclear sources. Geothermal, biomass, solar, wind and other sources contribute a meager 2.6% of the energy required to produce electricity.

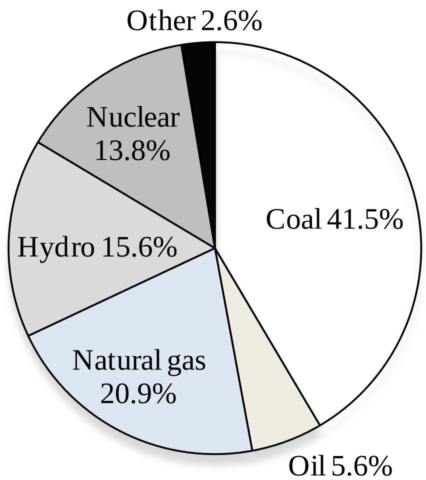

Figure 1: Global Electricity Production by Energy Source, 2007, Percent, Total = 19,771 TWh

To obtain some notion regarding which countries generate the most electricity and the importance of coal in the global electricity generating mix, consider Table 1. Nearly 20,000 terawatt hours (TWh), or 20 petawatt hours (PWh),[3] of electricity were generated in 2007, the latest year for which statistics are available from the International Energy Agency (IEA 2010a, 2010b). Notice that the U.S. and China are the largest producers of electricity and also the largest producers of coal-fired power. Other large industrial nations generate large amounts of electricity, with many relying on coal (Figure 1). Canada is the sixth largest producer, but much of it comes from hydro sources and a significant amount (≈ 25 TWh annually) is exported to the U.S. Clearly, rich countries are rich because they consume large amounts of energy, especially electricity.

Although oil dominates total global consumption of energy because of its use in transportation, very little oil is used to generate electricity. With the exception of a few large, base-load power plants that rely on oil, petroleum is used mainly in diesel generators that power small grids such as those found in remote communities, and in much of sub-Sahara Africa where few alternatives to diesel generation currently exist. While energy security is often cited in the United States as a reason to subsidize wind, solar and other renewable sources of power generation, electricity generation is not reliant on imports of energy from offshore (e.g., the Middle East, Nigeria and elsewhere). As noted, the United States imports (hydro) electricity from Canada but the remainder is generated from domestic sources of energy.

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[3] A watt (W) equals 1 joule (J) per second. A kilowatt (kW) equals 1000 W; megawatt (MW) = 10^6 W; gigawatt (GW) = 10^9 W; terawatt (TW) = 10^{12} W; petawatt (PW) = 10^{15} W. Kilo is abbreviated with k and equals 10^3; Mega (M, 10^6); Giga (G, 10^9); Tera (T, 10^{12}).

Table 1: Largest Electricity Producers, Total and by Selected Fossil Fuel Energy Source, 2007, TWh

TOTAL		Coal/Peat		Gas	
U.S.	4323	China	2656	U.S.	915
China	3279	U.S.	2118	Russia	487
Japan	1123	India	549	Japan	290
Russia	1013	Japan	311	Rest of World	2435
India	803	Germany	311	**Total**	**4127**
Canada	640	South Africa	247		
Germany	630	Australia	194	Oil	
Rest of World	7960	Korea	171	**Total**	**1114**
Total	**19,771**	Russia	170		
		Poland	148		
		Rest of World	1353		
		Total	**8228**		

Source: International Energy Agency (2010b)

An indication of the costs of producing electricity from various sources is provided in Table 2. The costs of producing electricity from wind and solar sources have fallen dramatically, while costs of geothermal, tidal, wave and some other renewable energy technologies are not yet known because they are in various stages of development. Advances in nuclear power generation technology and experience also continue, particularly with regards to performance and safety (Ansolabehere et al. 2003; Deutch et al. 2009). Yet, most renewable energy programs tend, in practice and probably realistically, to ignore geothermal, tidal and wave energy in favor of wind and solar power. But they also exclude from consideration the substitution of natural gas for coal and greater reliance on nuclear energy, two important and proven low-carbon technologies. In essence, therefore, the objective of reducing carbon dioxide emissions is confused with encouraging renewable energy in the generation of electricity (Deutch et al. 2009, p.9).

Consider the future prospects of renewable energy sources in generating electricity, especially their near-term prospects as many developed countries have ambitious greenhouse gas emission targets, some of which are supposed to come into force within a decade. A major problem facing renewable energy relates to its low energy density. As indicated in Table 3, the energy density of renewable energy sources is simply too low compared to that of fossil fuels and nuclear power to make them sufficiently competitive with fossil fuels and nuclear power. Therefore, subsidies are required. Nearly forty countries, and many more jurisdictions if provinces, states and cities are counted separately, provide potential generators of renewable power with feed-in tariffs. The four most common renewable sources of energy that qualify for feed-in tariffs are biomass, small-scale (usually run-of-river) hydro, solar and wind. The prospects of these four energy sources are briefly discussed in order below. With the exception of biomass, these renewable energy sources tend to be intermittent and therefore non-dispatchable.

Table 2: Lifetime Generation Costs by Generating Type, $ per MWh[a]

Generating Type[b]	Midpoint	Low	High
Wind onshore	68.08	36.39	168.71
Wind offshore	78.54	59.09	144.38
Solar thermal	193.64	193.64	315.20
Solar PV	192.21	141.10	2195.39
Run of river/small hydro	108.28	46.45	283.02
Large-scale hydro	53.12	53.12	99.33
Nuclear	30.71	24.34	80.26
Coal (lignite)	39.35	34.40	75.35
Coal (high quality)	31.90	30.30	80.85
Coal (integrated coal gas)	44.73	31.94	69.15
Gas (CCGT)	54.62	44.69	73.24
Gas (open)	54.64	54.64	57.33
Waste incineration	11.39	-4.68	61.19
Biomass	48.74	43.64	117.59

[a] Costs include capital, operating and maintenance, and fuel costs over the lifetime of a power plant, discounted to the present and 'levelized' over the expected output of the generating source over its lifetime. Values are in 2008 US dollars. The midpoint and low values are based on a 5% discount rate, as is the low value; the high value is derived using a 10% discount rate.

[b] Open-cycle gas turbines lose exhaust heat but can respond quickly to changes in demand; closed-cycle gas turbines (CCGT) recycle exhaust heat, which makes them suitable as base-load plants but makes it more difficult for them to ramp up and down.

Source: van Kooten and Timilsina (2009)

Table 3: Energy Densities of Selected Energy Sources

Energy Source	Energy Density (W/m^2)
Corn ethanol	<0.1
Biomass-fuelled power plant	0.4
Wind turbines	1.2
Solar PV	6.7
Small oil well (10 barrels/day)	27.0
Average natural gas well (3300 m^3/day)	287.5
Nuclear power plant[a]	56.0

[a] Based on a 4860 ha location in Texas, although the power plant occupies only a very small area within the property.

Source: Bryce (2010, pp.91-93)

Biomass for generating electricity

Increasing electrical power production from forest biomass, sawmill residue, and 'black liquor' from pulp mills is constrained by high transportation costs and competition for residual fiber, This makes forest biomass an expensive source of energy.

Because of the extent of mountain pine beetle damage to forests in the interior of British Columbia, an obvious use of beetle-killed trees was considered to be power generation. While early studies suggested that this could be done without reliance on large feed-in tariffs (Kumar et al. 2008; Kumar 2009), later studies indicated that this optimistic conclusion was based on average past costs of harvesting and hauling timber from the forest to sawmills.[4] Niquidet et al. (2010) found that, when account is taken of the rising costs of hauling timber as more remote timber damaged sites need to be harvested, marginal costs rise rapidly with truck cycle times (the time required to travel to and from the harvesting site). An electrical generating facility turns out to be only a marginally attractive option for reducing CO_2 emissions when feedstock costs are low; but, as feedstock costs alone rise from an equivalent of 4¢/kWh to 8.5¢/kWh, biomass power is no longer an economically viable option.

Producing char from biomass through a process known as pyrolysis (a form of incineration that chemically decomposes organic matter by heat without oxygen) suffers from similar problems, although high transportation costs might be mitigated somewhat by producing char on site. Nonetheless, the amount of char available for generating electricity will be negligible in comparison to what is needed and there are concerns that the process produces hazardous wastes.

Perhaps the best option for generating electricity from wood biomass is wood pellets. Wood pellet production plants are relatively inexpensive to construct and can, in some instances, be moved quite easily to new locations (although they are not mobile enough to be located at the harvesting site). Wood pellets can be used directly in coal-fired power plants with little or no adjustments to the burners – pellets can be pulverized much like coal and pellets are preferred over wood chips (which are used for pulp).

Because of their flexibility, relatively low production costs and government subsidy programs, demand for pellets has increased sharply. European demand for wood pellets has grown rapidly since about 2005 because of subsidies. As a result, British Columbia's wood pellet production capacity has risen to about one million tons by 2010. But as demand for other energy uses of wood biomass increase, prices will rise.

Using a regional fiber allocation and transportation model, Stennes et al. (2010) demonstrate a

[4] Using average harvest and transportation data, Stennes and MacBeath (2006) found it was more economical to transport wood fiber from the BC interior to coal-fired power plants in Alberta than to construct a biomass power generating facility locally. The reason had to do with the adequacy of wood fiber supply over the life of a power plant, something that could have been addressed with a combined wood-coal fired plant.

major drawback of timber feedstocks. As noted, hauling costs make it costly to employ timber for biomass generation of electricity. Indeed, in British Columbia and other jurisdictions where logging and hauling are important cost components of wood supply, wood residuals and other wood waste are available at a reasonable cost only as a result of timber harvests for sawmilling and production of lumber. Without lumber production, it is often too expensive to access biomass to support a bioenergy sector. In British Columbia, chips from sawmilling operations form the mainstay of the province's pulp industry. Other sawmill residues (bark, sawdust, etc.) are already allocated by mills to on-site space heating and power generation, with some excess chips and residues used in the production of such things as wood pellets, oriented strand board and other products. Competition for sawmill residuals occurs between pulp mills and other wood product manufacturers as well as heating and electricity. While there is some leeway to increase available wood waste by hauling roadside and other waste from harvest operations to power generating facilities, competition for residual fiber raises prices. That is, when account is taken of the supply and demand of wood fiber for all its different purposes, there is little excess fiber available for generating power at reasonable cost. Feed-in tariffs and other subsidies for electricity production would harm existing users of fiber, such as pulp mills or wood pellet producers (Stennes et al. 2010). While pulp producers can out bid energy producers for wood fiber if pulp prices are high, they would have a harder time competing at lower prices for pulp, especially if bioenergy producers are subsidized. Thus, feed-in tariffs for biomass energy in a jurisdiction such as British Columbia might well be politically unacceptable.

In other forest jurisdictions, there might be more leeway for fast-growing tree species to provide power, but similar problems are encountered. Competition for fiber implies that subsidies are required if the fiber is to be used for generating electricity. For example, the EU requires that 20% of total energy come from renewable sources by 2020, although only 7% came from renewable sources in 2009. To meet these targets, many countries will rely primarily on wind and energy from biomass. As a result, a wood deficit of 200 to 260 million m^3 is forecast for the EU by 2020, which is greater than Canada's annual harvest. Globally, an ECE/FAO report estimates that there will be a wood deficit of 320 to 450 million m^3 annually simply to satisfy planned biomass energy needs plus a growing wood-based industry.[5] Global wood fiber prices will certainly increase, resulting in potentially detrimental changes in land use (see below).

What is often neglected in discussions of biofuels and biomass-fired power generation is the fact that bioenergy is not carbon neutral as is often claimed. The combustion of biomass releases carbon dioxide, more than that released from fossils fuels to generate an equivalent amount of energy. It is only when plants and trees grow that CO_2 is removed from the atmosphere, and this can take quite a long time in the case of trees. The timing of CO_2 emissions and sequestration matters; if CO_2 released by burning takes 20 years to be sequestered, for example, there is a penalty associated with the early contribution of CO_2 to global warming (van Kooten 2009).

[5] Results reported by Don Roberts, CIBC, in presentations given in early 2010.

Further, greenhouse gas emissions related to harvests and hauling, and nitrogen fertilizers, may offset any CO_2 benefits of biomass as a fuel (Crutzen et al. 2008). Finally, using biomass for energy can result in land-use changes that largely offset gains from burning biomass in lieu of fossil fuels (Searchinger et al. 2008, 2009). More CO_2 is released in gathering biomass across a large landscape than is the case with coal, for example, as coal deposits are concentrated near a particular location. To mitigate the time that trees take to grow (upwards of 80 years), fast-growing tree species such as hybrid poplar or plants such as switchgrass can be used. While this tilts emissions more favorably towards use of biomass, nitrogen fertilizer is often required to spur growth, and nitrogen oxides are a more potent greenhouse gas than CO_2.

From a policy perspective, energy crops (including trees) are not an efficient means of addressing climate change, although there may be potential to source energy from various biological organisms in the future. However, energy from biological organisms does not appear to be a major component of governments' policy arsenals for combating climate change. Landfill gas generated from solid waste is also a potential source of electricity, but even if it is employed on a large scale, its contribution to the globe's electricity needs would necessarily be extremely small. The same holds for the incineration of municipal wastes.

Hydraulics, Storage and Run-of-River Hydro

A number of countries have developed their hydraulic resources to build large-scale hydropower facilities. With the so-called 'three gorges' dam (affecting the Upper Mekong, Yangtze and Salween Rivers), China now has the greatest hydro capacity in the world (Table 4). In 2007, hydro production only accounted for 14.8% of China's consumption of electricity. This is much less than the proportions accounted for by hydro in Norway (98%), Brazil (84%), Venezuela (72%) and Canada (57%). India relied on hydropower to a greater extent than China, as did Russia despite its relatively abundant fossil fuel resources.

Large-scale hydro remains one of the best options for generating 'clean' electricity, but its main drawbacks relate to inadequate runoff for power generation (especially in regions where water is scarce, intermittent and/or unreliable) and negative environmental externalities (changes in the aquatic ecosystem, impediments to fish migration, land inundation by reservoirs, etc.). Environmentalists oppose large-scale hydro development, particularly in developing countries because of the ecological damage it causes, while even small-scale, run-of-river projects have been opposed in rich countries on environmental grounds. Because of strong environmental opposition against hydropower developments, hydropower's future contribution to increases in overall generating capacity will inevitably remain limited in scope. Expansion of water power is not expected to be a large contributor to the mitigation of climate change.

Table 4: Hydro Electric Power Production and Capacity, 2007

Country	Production (TWh)	Capacity (GW)[a]	% of domestic consumption
China	485	126	14.8
Brazil	374	73	84.0
Canada	369	73	57.6
United States	276	99	6.3
Russia	179	46	17.6
Norway	135	29	98.2
India	124	35	15.4
Japan	84	47	7.4
Venezuela	83	n.a.	72.3
Sweden	66	n.a.	44.5
Rest of World	987	n.a.	n.a.
WORLD	**3162**	**889**	**15.9**

[a] Data for 2006
n.a. not available
Source: International Energy Agency (2010b)

Although unlikely to contribute much in the way of additional clean power, existing large-scale hydro and strategic expansions of reservoir storage capacity (which raise generating capacity) might serve an important purpose when combined with intermittent sources of energy, particularly wind and solar sources. For example, wind-generated power is often available at night, when base-load power plants are able to supply all demand. Wind energy would then need to be curtailed (wasted) or, where possible (and it may not always be possible), base-load plants would need to reduce output, causing them to operate inefficiently. If a base-load plant is coal fired, inefficient operation implies that CO_2 emissions are not reduced one-for-one as wind replaces coal. In some cases, the tradeoff is so poor that CO_2 emissions are hardly reduced whatsoever. This problem can be overcome if adequate transmission capacity exists so that the excess wind-generated power could be stored behind hydro dams by displacing electricity demand met by hydropower. This is the case in northern Europe, where excess wind power generated at night in Denmark is exported to Norway, with hydropower imported from Norway during peak daytime hours.

Similar relationships are found elsewhere. In Canada, for example, the provinces of Quebec and British Columbia rely almost exclusively on hydropower, while the respective neighboring provinces of Ontario and Alberta generate significant base-load power from coal (or nuclear in Ontario's case). Ontario and Alberta are both expanding their installed wind capacity. During nighttime, off-peak hours, excess wind and/or base-load power from Ontario (Alberta) is sold to Quebec (British Columbia), with hydropower sold back during peak periods. Given that the rents from these transactions have accrued to the provinces with hydro assets, Ontario and Alberta have been less than keen to upgrade the transmission interties, preferring to look at other possible solutions to the intermittency and/or storage problems.

In all three cases, there are net economic and climate benefits from the development of higher capacity transmission interties; or, in the case of northern Europe, simply more interties between jurisdictions where wind power is generated (northern Germany, other parts of Denmark) and those with hydro resources (Norway and Sweden). The main obstacle is the lack of incentives for the wind-generating region to 'dump' power into the region with storage, as the latter captures all the rents from such an exchange. This is a game theory problem: If institutions can be developed that facilitate the sharing of both the economic rents and the climate benefits (emission reduction credits), the jurisdictions have the incentive to better integrate the operations of their electricity grids (including construction or upgrading of transmission interties) so that overall CO_2 emissions are minimized.

Wind and Solar Energy: Generating Electricity from Intermittent Energy Sources

There exists a number of promising renewable energy sources that could at some time in the future make a significant contribution to global electrical energy needs. However, the likelihood that these will have a major impact in the short or medium term (five to 50 years) is small. It is evident from Figure 1 that non-conventional sources of energy constitute only about 3% of global electricity production. Raising that to 20% or more constitutes an enormous challenge, especially in a world where energy demand is rapidly increasing as a result of economic development in countries such as India and China. Simply expanding the use of renewable energy and then incorporating renewable energy sources into energy systems will prove difficult, not least because an expansion in the use of renewables will lead to increases in their prices (as we noted with regard to wood biomass).

Among alternative energy sources, solar and wind energy are especially promising. The energy or irradiance from the sun averages some 1.366 kW/m^2, or 174 PW for the entire globe, but it is difficult to convert to usable energy. Other than through plant photosynthesis, there are two ways to harness this solar energy: (1) solar photovoltaic (PV) converts the sun's energy directly into electricity, while (2) solar heaters provide energy to warm a fluid such as water (swimming pools, water tanks, etc.). Solar heaters convert up to 60% of the sun's energy into heat, while PV cells convert only 12% to 15% of the energy into electricity, although PV laboratory prototypes are reaching 30% efficiency. One problem with solar electricity is its prohibitive capital costs, which amount to some $13,000 to $15,000 per kilowatt (kW) of installed capacity (IEA 2005; also see Table 2), although costs have fallen in the past several years. In addition, solar power is intermittent (e.g., output is greatly reduced on cloudy days), unavailable at night, and, in high latitudes, less available in winter when demand is high than in summer (due to shorter days). Nonetheless, for remote locations that receive plenty of sunshine and are not connected to an electrical grid, the costs of constructing transmission lines to bring in outside power might make solar PV and solar heaters a viable option.

Given the current drawbacks of many other renewable sources of energy, wind energy appears to be the renewable alternative of choice when it comes to the generation of electricity. As a result, global wind generating capacity has expanded rapidly from only 10 megawatts (MW) of installed capacity in 1980 to 157,899 MW by the end of 2009, an average annual rate of increase of some 49% (GWEC 2010). Such a high average annual rate of increase is a result of starting from a low base, and is driven largely by feed-in tariffs and other government incentives.

ECONOMICS OF FEED-IN TARIFFS

Because electricity can be produced from any conceivable source of energy, renewable sources of energy can most easily be integrated into an economy through the electricity grid. Consequently, many jurisdictions have set renewable electricity targets, using regulation, feed-in tariffs or other forms of subsidy to encourage the generation of electricity from non fossil fuel, non-nuclear sources. Regulation takes the form of mandates, the best examples of which are renewable electricity standards that require electrical utilities to produce some proportion of their power from renewable sources by certain dates. Such requirements are being adopted in many developed countries, with some even having mandated the elimination of all coal fired power plants.

With the exception of biomass, which has its own demons, wind, solar, run-of-river, wave and tidal energy suffer from intermittency – output is erratic and capacity factors are usually well below 30%.[6] This has serious complications for the way that electricity markets operate. In this section, we consider this complication in more detail as it pertains to feed-in tariffs (FITs). While the focus is on intermittent energy sources, some of the discussion also applies to FITs for biomass or, for that matter, diesel and other forms of power generation.

Electricity Markets

If the prices consumers pay for electricity are fixed, the demand function is essentially a vertical line – demand for electricity is completely inelastic and does not respond to changes in wholesale prices. Time-of-use pricing at the retail level affects demand directly (giving the vertical demand function a downward slope), but to implement time-of-use pricing requires a 'smart grid' – something beyond just smart meters. Smart meters can only detect how much electricity a customer uses at each time of the day; a smart grid enables the customer to adjust electricity use in response of price changes. Thus, smart meters can be used to implement a tiered pricing scheme (such as daytime and nighttime pricing differentials), which can tilt the demand curve slightly; the smart grid enables off-site control of large appliances in response to changing prices.

Even if some degree of real time pricing can be implemented, it is likely that the demand for electricity will remain highly inelastic. Based on cross-section and time series analyses, the short-run elasticity of demand is about –0.3 (U.S. Energy Information Administration 2010,

[6] The capacity factor of a generator refers to the actual power output over a period compared to what it could potentially produce. For example, a 2 MW capacity wind turbine could conceivably produce 17.52 GWh of electricity in one year (= 2 MW × 8760 hours). But this depends on perfect wind conditions. With variable wind, the turbine might only produce 4,200 MWh, and its capacity factor would be 24.0%. The capacity factor of a base-load, coal-fired power plant, on the other hand, might be 85% or more.

p.26), while it is between –1.5 and –0.5 in the long run.[7] This implies that a 1% increase in the price of electricity results in a 0.3% reduction in demand in the short run, and a reduction of 0.5% to 1.5% in the long run.

To examine the supply side, assume an electricity system that is deregulated at the wholesale level. The electricity system operator (ESO) requires owners of generating facilities to commit to produce electricity at a given hour one day (24 hours) ahead of actual delivery. Each generator will offer to produce a certain amount of electricity at a particular price, knowing that the final price received is the market-clearing price for that hour. In essence, a power plant will offer units of electricity at a single price (or variety of prices if costs of producing electricity differ across units) to be produced and delivered on a specified hour the next day. This is known as day ahead, unit commitment. Of course, as the hour approaches for which an owner of a generating facility has committed to supply power more information about the status of generators and the evolution of prices becomes known. Therefore, generators are able to make changes to their offers up to two hours before delivery. The extent of permitted changes is increasingly constrained by penalties as the hour nears.

What do the offers to supply electricity look like? Base load nuclear and coal-fired power plants, and for some grids base-load hydropower dams, will bid in lowest. Indeed, for base-load facilities that cannot readily change their power output, or can do so only at high cost, the optimal strategy is to provide very low (even zero) price bids to ensure that they can deliver power to the grid. Open-cycle, natural gas peaking plants will want to bid in at their true marginal cost of production, which is essentially determined by the price they have to pay for fuel. The facilities that provide the highest bids are those that wish to export electricity to another system, regardless of the energy source used to generate the power; by setting their price high, their output is unlikely to be chosen by the system operator and can thus be exported. (Importers will want to set their prices low to guarantee that the imported power will be chosen.) In between the extreme prices are found a variety of generating facilities, such as biomass plants, combined-cycle gas plants (CCGT), and sub-units of extant plants that are at different levels of readiness, maintenance, et cetera. Once the ESO has all of the information regarding the amounts of electricity that the various components of the generating system are willing to supply, and their associated prices, a *market merit order* is developed to allocate power across the generators depending on demand. An example is provided in Figure 2.

In Figure 2, the supply curve is given by the market order. Base-load nuclear and coal facilities bid in at the lowest price, followed by CCGT and other generating facilities as indicated.[8] The market clearing price is determined by the location of the demand curve at that hour. Assuming

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[7] Price elasticities between 0 and –1 indicate inelastic demand. In a meta-regression analysis of studies of U.S. residential demand for electricty, Espey and Espey (2004) concluded that the best estimates of short-run and long-run elasticities were –0.28 and –0.81, respectively.

[8] CCGT power plants are often base-load facilities but they have a little more wiggle room in ramping production than base-load coal and nuclear power plants. The reason is that available heat from the fuel can be adjusted quicker for gas than coal or nuclear fuel rods. Likewise, biomass fueled plants are often base-load; only their capacity tends to be much smaller than that of coal, nuclear and CCGT plants.

the demand curve on the right, the market price P is given by the marginal open-cycle natural gas plant (NG 2). If the transmission infrastructure somehow impedes NG 2 (or some other plant) from delivering power, then NG 3 determines the market clearing price, which becomes P′. All generators get paid P for the period in question (or P′ if transmission capacity results in NG 3 coming on line instead of some other generator).

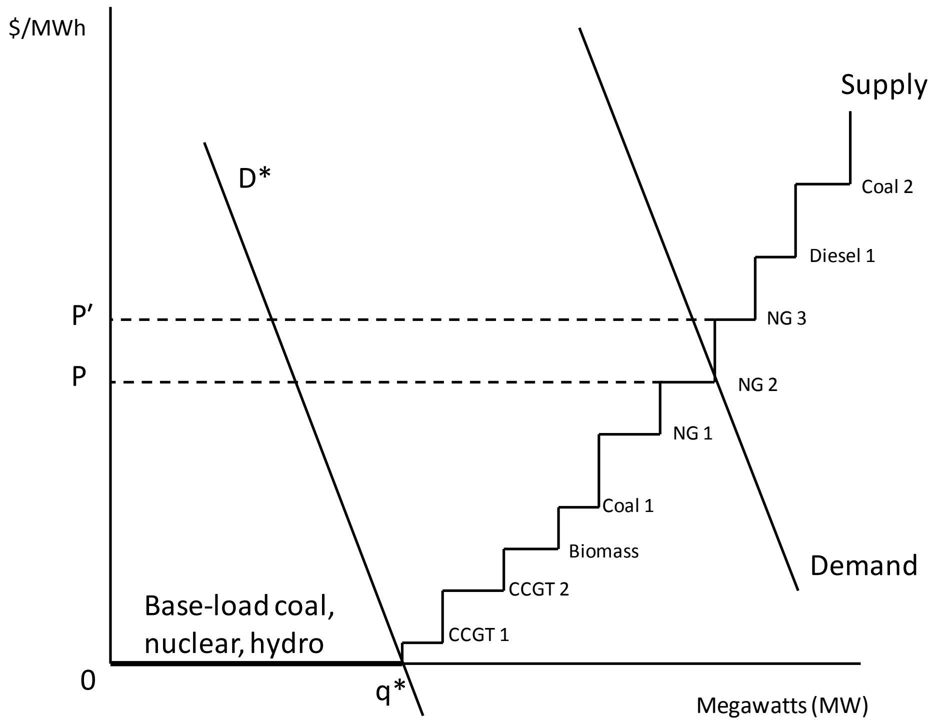

Figure 2: Market Merit Order

Base-load facilities bid in at zero price to avoid incurring the high costs of curtailing output, but also knowing they will receive P or P′. If the demand curve is D* then the wholesale price is zero and only base-load facilities generate electricity. Assuming that investments in base-load capacity were determined from the load duration curve, demand would never be less than D*, with q* representing the system's minimum load. To reiterate, base-load plants would bid in at a zero price despite potentially earning no revenue; this is to avoid high costs of ramping production or, worse, dumping power in an emergency-like situation (i.e., instantaneously reducing pressure in the boiler).

Suppose a feed-in tariff for biomass-generated power increased biomass generating capacity. In terms of Figure 2, biomass would drop in the merit order because of the subsidy and more would be available. This could result in moving CCGT 2 or even CCGT 1 and CCGT 2 'higher up' in the merit order – essentially the bid prices would remain the same but biomass will be chosen before these generating sources. All other generators would be chosen later in the merit order, with NG 1 or even 'coal 1' becoming the marginal power plant. Price of electricity would fall, ceteris paribus. If biomass generation becomes base load, it will be necessary to displace some nuclear and/or coal base-load capacity. This might be desirable except that, as noted earlier, there may be constraints on wood fiber availability.

The picture changes completely when wind, solar, run-of-river or other variable generating capacity is introduced into the electricity system as a result of a feed-in tariff. The situation can be illustrated with the aid of Figure 3. The only difference between Figures 2 and 3 is the addition of q^*q^0 electricity from variable generating sources (hereafter referred to as wind). This shifts the supply curve in Figure 2 to the right by amount q^*q^0. Now, with the original demand curve (the one on the right in Figure 3), it is no longer NG 2 that is the marginal producer of electricity; rather, it is the plant with a lower marginal cost, NG 1. The market clearing price of electricity for that hour falls from P to P^F. The feed-in tariff lowers the price of electricity, which will induce consumers to purchase more of it (as indicated by the arrow).

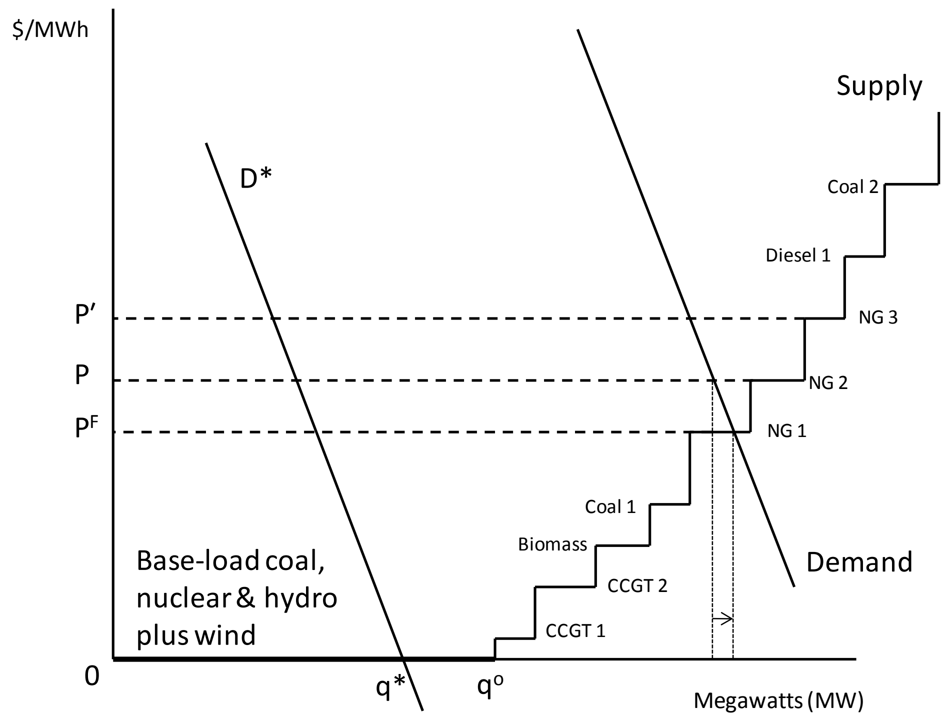

Figure 3: Market Merit Order

What does one do with the wind energy q^*q^0 if the demand in a given hour is D*? Clearly, either the wind must be curtailed (wasted) or base-load output reduced. Base-load hydropower can easily be reduced, as discussed below, so consider only a system with base-load thermal generating capacity. If q^*q^0 could be reliably produced in every period, so it can be considered part of the base load, then some coal or nuclear base-load capacity becomes redundant and can be eliminated – an ideal outcome.[9] However, wind generated power is not reliable and thus cannot replace thermal base-load capacity, except at some cost.

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[9] Of course, with concern about climate change, the optimal solution would be to reduce coal-fired capacity.

Suppose base-load capacity is reduced by the amount q^*q^0. Then, whenever wind power is less than q^*q^0, this is the same as shifting the supply curve in Figure 2 to the left, which would raise the market price for every hour that wind is less than q^*q^0, while lowering price if wind output exceeds q^*q^0. Thus, the effect of a feed-in tariff for wind (or solar, wave, tidal, etc.) is to increase price volatility if thermal base-load capacity is driven from the system;[10] if thermal base-load capacity is not driven from the system, electricity prices will generally be lower, but base-load plants will need to ramp up or down if wind energy is non-dispatchable (i.e., considered to be 'must run'), which will increase their operating costs (van Kooten 2010). Alternatively, if wind is considered dispatchable, wind will need to be curtailed or wasted.

The situation is somewhat different in a system with significant hydropower generating capacity, because hydropower can provide base-load power and serve the peak load and reserve markets. The presence of significant hydro capacity enables a system to absorb wind power that might overwhelm the ability of a system with a high thermal capacity in the generating mix to absorb it, or raise system costs by too much in doing so. That is, the existence of hydro reservoirs enables a system to store wind energy that would be wasted in systems lacking hydro generating capacity in the mix. However, there must be times when this stored wind energy is required to meet load, perhaps at peak load times.

Because demand and supply of electricity must balance at all times, there is one further aspect to electricity markets and that is the need for operating reserves. These consist of regulating reserves that adjust supply continually to meet small changes in demand (load) and supply over a time frame of several seconds to 10-15 minutes. Thermal power plants have the ability to adjust output very quickly over a small range in less than a minute. Some open-cycle gas and diesel generators are operating below capacity or on stand-by and, by adjusting the fuel received (in essence apply more or less pressure to the 'gas pedal'), can readily adjust output. Some generators will simply be idling in standby mode, not delivering electricity to the grid; these are referred to as 'spinning reserve,' as distinguished from units that are operating below capacity. For example, generator NG 1 in Figure 3 is not operating at full capacity and can easily adjust supply (e.g., by the amount indicated by the arrow).

Storage devices, such as batteries and flywheels, might also be used in a regulatory capacity, as might hydropower. Automated generation control, which is also known as regulation, is used to manage small fluctuations in the supply-load balance.

Contingency reserves, on the other hand, are required to meet a situation where power from any given generator is suddenly lost for whatever reason. They are designed to handle emergencies – the contingency that a power plant goes 'off line' and is unable to provide the electricity that it had committed. For example, the Western Electricity Coordinating Council

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[10] Using a grid model, this is precisely what a major European consulting firm found: As installed European wind capacity increased to the levels required to meet 2020 renewable energy targets in electricity, wholesale prices fluctuated wildly, making investments in electrical generating capacity riskier (see Pöyry 2011). This conclusion held even if transmission interties and capacity increased to facilitate wind entering a Europe-wide grid.

(WECC) requires that contingency reserves be sufficient to cover the most severe potential loss (loss of the largest generating unit) plus some proportion of the total production from hydro and thermal sources.[11] The market for contingency reserves is indicated in Figure 4.

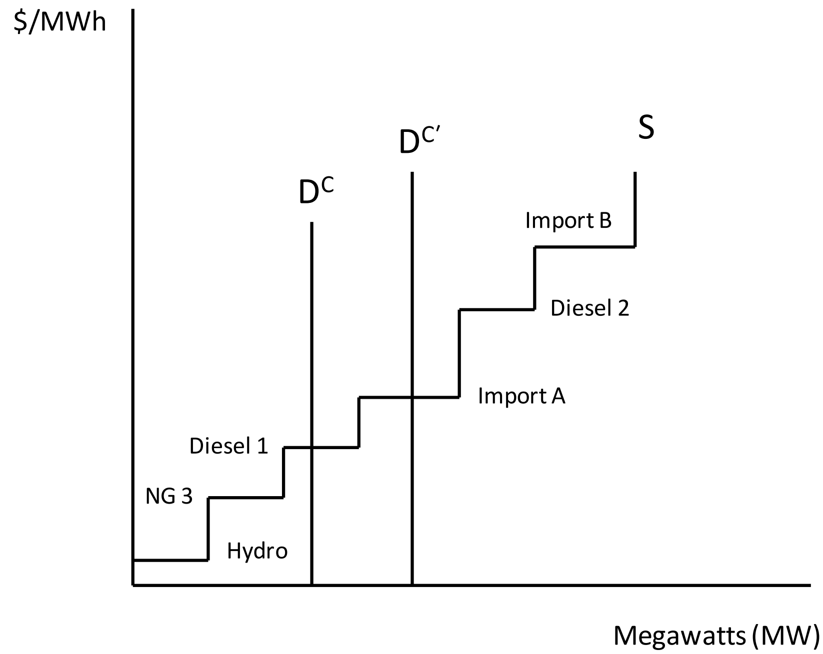

Figure 4: Market for Ancillary Contingent Reserves

Suppose that the merit-order demand for contingency reserves in a given hour is denoted D^C, which is determined by the conditions set out by WECC. The various units bid their reserves much like they do in the establishment of the merit order in Figure 2, although the bid also includes a capacity payment needed to maintain the reserve position. If the offer is accepted, the capacity payment would be made by the ISO regardless of whether any power was dispatched to the grid.

In the ancillary market, the open-cycle and diesel peakers will now want to bid in at a low price because they are the ones that can get off the mark the quickest. Likewise, the bid price of the hydro contingent reserves will be low, perhaps even zero (in which case they obtain the marginal market clearing price P in Figure 2), but the prices bid by peakers NG 3 and Diesel 1 will also be low because they know that, when there is a demand for ancillary services, they will receive at least the price determined by the marginal generator (NG 2 in Figure 2) plus their own bid in the ancillary market. Base-load plants, on the other hand, will bid in very high, if at all, because they can only ramp up output at great expense. The actual bid price will depend on the strategy of the owners of the various units, which would depend on the anticipated state of the units at the time. A market for ancillary contingent reserves is established in a fashion similar to that of the real-time market, except that units will also receive a capacity payment for

[11] Information related to the WECC is available at www.wecc.biz.

their reserve position, while receiving the market clearing price for any electricity they are asked to dispatch.

In the previous discussion of intermittent renewable sources of energy, it was assumed that wind output was predictable. When wind enters an electricity system, however, there is a real risk that output from this source falls (or rises) dramatically and unexpectedly during the course of an hour. This means that the system operator must not only meet its normal reserve requirements (e.g., as set out by the WECC), but must also have additional regulating and contingency reserves that address the variability in wind. In terms of Figure 4, this is seen by the shift of demand for contingent reserves from D^C to $D^{C'}$. When wind capacity is installed, contingency reserves could increase by upwards of 10% and regulating reserves by even more (Gross et al. 2006, 2007). This often requires additional investments in operating reserves of various types.

The additional costs of reserves must be added to the operating costs that intermittent energy imposes on an electricity grid. These are well documented and consist of costs related to more frequent ramping up and down of base-load facilities, operating power plants below their optimal operating range, and more frequent stops and starts of diesel and gas peaking generators (Maddaloni et al. 2008; Prescott and van Kooten 2009; van Kooten 2010; le Pair and de Groot 2010).

THE REAL WORLD OF FEED-IN TARIFFS

Although many jurisdictions provide direct subsidies to the construction of renewable electrical generating facilities, transmission lines and R&D related to generation of electricity from wind, solar and other sources, they have also implemented feed-in tariffs (FITs) as an incentive to increase power generation from various renewable sources. FITs guarantee developers of renewable generating capacity a preferred price for any power they deliver to the grid. For example, if the market price of electricity is $0.10 per kilowatt hour (kWh), the FIT might be $0.15 per kWh, which amounts to a subsidy of $0.05 per kWh. The supplier of renewable power is often guaranteed the higher rate for a period of five or more years. Along with the FIT, the authority might also have to guarantee the renewable generator of power access to the grid through newly-constructed or extant transmission lines.

While subsidies might help in the short run, they are not sustainable in the long run because they distort production decisions resulting in inefficiencies. Suppose only some countries provide FITs that result in greater reliance on wind and solar energy, thereby displacing fossil fuels in power generation. This does not mean that the fossil fuels are no longer burned. After all, the mining of fossil fuels creates economic rents that owners will continue to exploit. Thus, for example, eliminating coal power in the United States does not necessarily prevent the mining of coal and its sale to China, India or elsewhere to be burned for power generation. If the U.S. were to close its coal-fired power plants, owners of coal mines in Appalachia would more than likely sell coal overseas for the production of electricity (*The Economist*, January 29, 2011, pp.64-65). Indeed, curtailing coal use in the U.S. and Europe could reduce global coal prices, at least in the short term. This gives countries that continue to rely on fossil fuels to use coal less efficiently, and lead overseas power producers to invest more in coal-fired capacity than they would otherwise. Once such investments have been made, it could be 40 or more years before such capacity becomes redundant. In this manner, the climate benefits of the original subsidies are offset.

As we will see, FIT programs are primarily but not exclusively a rich country phenomenon. Given that developing countries are increasing electricity output from all sources, feed-in tariffs and other subsidies in some of those countries are used to encourage investments in all forms of power generation, as the desire is for more electrical generating capacity and not for renewable power per se. Thus, it is FIT program benefits in rich countries that are inevitably countered to some extent by rising CO_2 emissions in developing countries, which is due to their improved access to fossil fuels. This is one aspect of the 'rebound effect' – the offsetting increase in emissions that accompany programs designed to reduce emissions in the first place (Jenkins et al. 2011).

Existing Feed-in Tariff Programs: A Comparison[12]

Many countries employ feed-in tariffs as a means of encouraging private development of renewable generating capacity. In Table 5, we summarize the extent of FIT programs for wind projects in various jurisdictions. The Ontario FIT program that is discussed in the next subsection is one of the more lucrative programs, paying the highest tariffs for large on-shore and off-shore projects. The only exceptions are South Africa for off-shore projects and Germany for on-shore projects but then only as a bonus if a wind project is grid compatible (so there is no need for increasing transmission line capacity). As indicated in the Appendix, there are many other jurisdictions that offer FITs for wind power generation, but the scale of projects is limited to at most 10 MW, with 500 kW a more frequent maximum. A 10 MW project constitutes perhaps five large wind turbines or 40 very small turbines. In some countries, FIT payments are of short duration and programs are subject to arbitrary cancelation. An indication of the extent to which small wind projects are subsidized in various places is provided in the lower half of Table 5.

Feed-in tariffs for solar photovoltaic (PV) are much larger than those for wind power as indicated in Table 6. Again Ontario's feed-in tariffs for solar power are the most lucrative. The State of Washington is the only jurisdiction to offer more money to solar power producers, but only if the solar panels are manufactured within the state.

Many other countries offer feed-in tariffs to producers of electricity generated from wind, hydro, solar, biomass, and even geothermal, tidal and wave sources. A list of countries providing FITs for the main renewable energy sources is provided in the Appendix. It should be

[12] All values provided below have been converted to a Canadian dollar basis by Paul Gipe (see http://www.wind-works.org/articles/feed_laws.html); during the first quarter of 2011, the Canadian dollar has been trading at slightly above par against the U.S. dollar. An exchange rate of 1€ = 1.33878 $C is assumed.

noted, however, that power producers employing renewable energy are not the only ones to benefit from FITs. In Tanzania, for example, producers of diesel-generated electricity in rural areas are eligible for a feed-in tariff of $0.253/kWh, while small power producers in general receive between $0.068 and $0.091 per kWh depending on the season, with power provided during the dry season receiving a premium. In all cases, contract lengths for FITs in Tanzania are 15 years.

Table 5: Feed-in Tariffs for On-shore and Off-shore Wind Projects, including Length of Programs, Various Jurisdictions, As of November 2010 (Values in Canadian $)

Jurisdiction	Years	$/kWh
Large-scale Off-shore Wind		
Germany (without bonus)	20	0.174
(with bonus)	20	0.201
France	15	0.174
Ontario	20	0.190
Large-scale On-shore Wind		
Germany	20	0.123
Ontario	20	0.135
France	15	0.110
Spain	25	0.105
South Africa	20	0.179
Vermont	20	0.128
Small On-shore Wind Projects (examples)		
Portugal <3.68 kW (Microgenerator)	15	0.578
Britain 1.5 kW-15 kW	20	0.424
Britain >15 kW<100 kW	20	0.383
Italy <200 kW	15	0.402
Israel <15 kW	20	0.347
Israel <50 kW	20	0.444
Switzerland <10 kW	20	0.204
Vermont <15 kW	20	0.204
Washington State Out of State	6	0.123
Washington State Fully in State	6	0.419
Wisconsin, Xcel Energy	10	0.067
Wisconsin, Madison Gas & Electric	10	0.062
Indianapolis Power & Light >50 kW<100 kW	10	0.143

NOTES:
Source: Calculations made by Paul Gipe, Bakersfield, CA. Available at: http://www.wind-works.org/articles/feed_laws.html
Assumed exchange rate: 1€ = 1.33878 $C

Table 6: Feed-in Tariffs for Solar Photovoltaic, including Length of Programs, Various Jurisdictions, As of November 2010 (Canadian $)

Jurisdiction	Application	Years	$/kWh
Italy[a]	Rooftop small	20	0.524
	Rooftop large	20	0.443
	Ground-mounted small	20	0.465
	Ground-mounted large	20	0.368
South Korea	>3 kW	15	0.758
India	< 1 MW	25	0.435
France	Building Integrated	20	0.562
Germany[b]	Rooftop small (<30 KW)	20	0.576
	Rooftop large (> 1 MW)	30	0.442
	Ground mounted	20	0.428
Czech Republic		15	0.664
Spain (2007 RD)	<100 kW	15	0.455
Austria	<5 kW	12	0.616
Ontario		20	0.802
Washington State[c]	Manufactured in state	8	1.175
California[c]	Commercial	5	0.673
South Australia[c]	Residential	5	0.431

NOTES:
[a] After May 2011, but declining by 6% beginning in 2012
[b] Data for 2009.
[c] Form of net-metering
Source: Calculations made by Paul Gipe, Bakersfield, CA. Available at:
http://www.wind-works.org/articles/feed_laws.html
Assumed exchange rate: 1€ = 1.33878 $C

Some countries are now rethinking their FIT structures. For example, Germany's FITs for rooftop solar PV have fallen in 2011 to $0.385/kWh for units with a capacity less than 30 kW and to $0.290/kWh for units with a capacity greater than 1 MW, while tariffs for freestanding units have been reduced to $0.296/kWh. At the same time, the length of the German FIT program for large-scale rooftop PV has been reduced from 30 to 20 years. The German government is in discussions with solar power producers to reduce FITs even further because

> "consumer energy prices for those not using photovoltaic have risen noticeably to cover the subsidy costs for those using solar energy. ... [The government] is facing growing resistance from non-solar electricity bill payers. Energy providers also have difficulties incorporating any surplus solar power into their networks, as almost half the world's solar panels are mounted on German roofs, and not linked directly to the grid."[13]

[13] Article in *Earth Times* entitled "German solar power producers agree to subsidy cuts" available at:

The Netherlands is reconsidering its feed-in tariffs for wind power because it is finding that the rebound effect offsets too much of the presumed reduction in CO_2 emissions (see Jenkins et al. 2011). In essence, the installation of wind, run-of-river hydro and solar energy capacity does not result in a one-to-one reduction in fossil fuel capacity, nor is there a one-to-one reduction in CO_2 emissions for each kW of wind that replaces a kW of fossil fuel generated power. The reasons are well known. With energy sources that are intermittent or erratic, traditional thermal generating facilities cannot be taken off line; rather, they often produce below their optimal efficient operating range, requiring more fuel and releasing more CO_2 per unit of output. Even if large-scale storage is available (e.g., hydro reservoirs), it cannot always prevent a rebound effect. And, as noted earlier, when it comes to burning biomass for electricity, there may be little in the way of CO_2 savings.

It is not the rebound effect that is the main problem, however. Rather, it is the backlash from electricity consumers that is causing governments to rethink feed-in tariffs. Lucrative feed-in tariffs lead to high electricity rates because someone must eventually pay for the subsidization of higher cost alternatives for generating electricity – pay the costs of reducing CO_2 emissions. The problem with FITs is that the authority chooses the technology to be used for reducing CO_2 emissions, and such choices have a social cost. Alternative technologies might be de-emphasized or overlooked, unanticipated costs related to the existing generating mix and transmission constraints may have been ignored, and externalities may have been disregarded (e.g., transmission lines from a wind site to a load center may need to bypass a wilderness area thereby greatly increasing costs). Often the authority bears these costs because it has done more than simply provide a FIT: It has also guaranteed access to transmission lines. As a result, the costs of generating electricity are higher than the amount of the subsidy, which equals the FIT minus the market price, and reductions in CO_2 emissions are lower than anticipated, sometimes much lower. Further, the FITs lock the authority into long-term payments as contracts average 20 years and tariffs ratchet upwards as a result of inflation clauses.

Feed-in Tariffs: The Case of Ontario

The province of Ontario is committed to reducing its reliance on thermal generation of electricity, especially coal and nuclear. It aims to eliminate coal-fired power generation and, perhaps (especially in light of events in Japan in March 2011), nuclear generation as well. For these reasons and because electricity grids have their own peculiar dynamics, it has chosen to rely on feed-in tariffs over mandated levels of renewable energy use. Therefore, as noted above, the Ontario government launched one of the most ambitious attempts to affect power generation from renewable sources when it passed the *Green Energy and Green Economy Act* on May 14, 2009. The FIT schedule under the Act is provided in Table 7. The important thing to note about the FIT schedule is that feed-in tariffs are indexed to inflation, with the exception of solar power. Solar power is not indexed to inflation because the subsidy is high to begin with and prices of solar panels are expected to fall dramatically in the future.

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http://www.earthtimes.org/articles/news/363164,producers-agree-subsidy-cuts.html (viewed March 15, 2011)

Table 7: Ontario Power Authority's Feed-in Tariff (FIT) Program for Renewable Energy Projects, Base Date: September 30, 2009

Renewable type	Size (capacity of generating plant)[b]	Contract price (¢/kWh)	Percentage escalated[a]
Biomass			
	≤ 10 MW	13.8	20%
	> 10 MW	13.0	20%
Landfill gas			
	≤ 10 MW	11.1	20%
	> 10 MW	10.3	20%
Biogas			
on-farm	≤ 100 kW	19.5	20%
on-farm	> 100 kW, ≤ 250 kW	18.5	20%
biogas	≤ 500 kW	16.0	20%
biogas	> 500 kW, ≤ 10 MW	14.7	20%
biogas	> 10 MW	12.2	20%
Wind			
on-shore	Any size	13.5	20%
off-shore	Any size	19.0	20%
Solar			
roof/ground	≤ 10 kW	80.2	0%
roof top	> 10 kW, ≤ 250 kW	71.3	0%
roof top	> 250 kW, ≤ 500 kW	63.5	0%
roof top	> 500 kW	53.9	0%
ground mount	> 10 kW, ≤ 10 MW	44.3	0%
Water power[a]			
	≤ 10 MW	13.1	20%
	> 10 MW, ≤ 50 MW	12.2	20%

Notes:
[a] Performance factor: 1.35 peak, 0.90 off peak.
[b] Generally a 20-year contract with 2-3 year lead time; for hydro, 40 year contracts
[c] Indexed by the Ontario CPI
Source: (viewed April 21, 2010)
http://fit.powerauthority.on.ca/Storage/99/10863_FIT_Pricing_Schedule_for_website.pdf

There is a significant feed-in tariff for electricity produced from biomass as the government seeks to replace coal-fired power with wood pellets.[14] For biomass generators exceeding 10 MW capacity the FIT is 13.0¢/kWh, while it is 13.8¢/kWh for smaller generators. Contracts are 20 years in length and tariffs are indexed to the Ontario Consumer Price Index. The tariff is also increased by a factor of 1.35 during peak hours (7:00AM to 11:00AM and 5:00PM to 9:00PM), but reduced by 0.90 for all off-peak hours. Already wood producers in British Columbia and Ontario are investing in wood pellet production for domestic use and export (see Stennes et al. 2010).

[14] Wood pellets are easy to transport and can readily be used in lieu of coal in power plants; wood pellet production facilities are also simple to construct, and require relatively little capital investment.

The potential size of the subsidies associated with Ontario's FIT program can be determined from information about electricity rates. Residential customers with smart meters pay 9.9¢ per kWh at peak times, 8.0¢/kWh during mid-peak periods (11:00AM to 5:00PM) and 5.3¢/kWh during off-peak times (9:00PM to 7:00AM). Customers without smart meters pay 6.5¢/kWh for the first 600 kWh (in summer the first 1000 kWh) and 7.5¢/kWh thereafter.

Ontario's average electrical load was some 16,000 MW during 2007, although it has fallen somewhat since then as a result of the financial crisis, which caused some major demanders of power to shut down. Coal and gas generating capacities are both about 4000 MW; nuclear generating capacity amounts to some 10,000 MW, while hydro capacity is nearly 6000 MW. To provide some indication of the costs and benefits of Ontario's FIT program, assume that only 30% of the load is satisfied by fossil fuels, or 4800 MW per hour, and the objective is to eliminate that production. Further, assume that, despite the capacities of coal and natural gas generation, coal-generated power accounts for half or more of fossil fuel generated power. Finally, assume that biomass and wind generated power substitute for fossil fuel power – biomass accounts for either half or one-quarter of the required substitute power with on-shore and off-shore wind accounting for two-thirds and one-third, respectively, of the remainder.

For every metric ton (t) of coal that is burned, 7506 kWh of energy are generated and 2.735 tonnes of CO_2 are released.[15] Thus, it takes 320 tons of coal to burn half of the 4800 MWh of electricity supplied by coal-fired generation, releasing 874.6 tCO_2 hourly or 7.660 Gt CO_2 per year. At the same time, natural gas plants will release 495.8 tCO_2 each hour or 4.343 Gt of CO_2 annually if they generate 2400 MW of electricity each hour.

The costs to the government of the FIT program depend on the extent to which various renewables substitute for fossil fuel generation and the average amount that final consumers pay for electricity. In Table 8, it is assumed that consumers pay an average of 8.5¢/kWh. Using various biomass and wind combinations and fossil fuel displacement scenarios, and FIT data from Table 7, it is possible to calculate carbon fluxes and costs to the public treasury of reducing CO_2 emissions. Results provided in Table 8 suggest that costs to the treasury could amount to $2.4-$2.6 billion annually, which will put a severe strain on the provincial treasury. In essence, by substituting fossil fuel energy with renewable sources in the generation of electricity, Ontario will pay a subsidy ranging from some $45 per t$CO_2$ to well over $1000 depending primarily on the extent of biomass generation. Greater reliance on biomass compared to wind leads to higher costs.

Several points are worth mentioning. First, there exist much cheaper ways to reduce CO_2 emissions, including purchase of certified emission reduction credits on carbon markets. Second, the analysis in Table 8 is crude, focuses only on the costs to the public treasury and excludes any other costs, some of which can be quite high. For example, it is assumed that wind energy can substitute directly, one-for-one for fossil fuels, which is certainly not the case (van Kooten 2010). Third, as noted above, Ontario is not the only jurisdiction to employ feed-in

[15] From http://bioenergy.ornl.gov/papers/misc/energy_conv.html (viewed March16, 2011), coal releases 25.4 metric tons of carbon per terajoule (TJ) compared to 14.4 for natural gas.

tariffs. Germany subsidies to wind, solar and hydro generation amounted to $7.3 billion in 2009 and were forecast to rise to $11.3 billion by the end of 2010.[16]

Finally, it is important to consider how FIT subsidies are paid. Currently, Ontario has not raised electricity rates to reflect the cost of its FIT program partly because it fears this will make Ontario firms less competitive and partly to avoid any political fallout. By not allowing rates to rise, however, there is also no incentive for consumers to reduce their electricity consumption; indeed, unless the cost of the FITs are passed along to consumers, rates may fall, as indicated in the next section, resulting in an offsetting increase in CO2 emissions (a rebound effect). Yet, in all likelihood, the Ontario government will eventually need to shift program costs onto ratepayers because the budgetary burden of large subsidies (Table 8) cannot be sustained in an era of fiscal restraint. At that point, political opposition to renewable energy subsidies is likely to increase as in Germany.

Table 8: Costs and Benefits of Ontario's Feed-In Tariff Program: Hourly CO_2 Flux and Cost of Reducing CO_2 Emissions, Various Scenarios

	Biomass 50%; Wind 50%			Biomass 25%; Wind 75%		
Coal to NG →	1 : 0	¾ : ¼	½ : ½	1 : 0	¾ : ¼	½ : ½
CO_2 flux			tCO_2			
Coal saving	1749.2	1311.9	874.6	1749.2	1311.9	874.6
NG saving	0	247.9	495.8	0	247.9	495.8
Sequestered[a]	665.8	665.8	665.8	332.9	332.9	332.9
Biomass emission	2058.2	2058.2	2058.2	1029.1	1029.1	1029.1
Net flux	*356.9*	*167.5*	*-21.9*	*1053*	*863.7*	*674.3*
			US dollars			
Subsidy	$272,000	$272,000	$272,000	$300,000	$300,000	$300,000
Subsidy per tCO_2	$762	$1624	n.a.	$285	$347	$45

Notes:

[a] Carbon sequestered in tree growth over 25 years using growth function (9.1), including all above ground biomass with carbon discounted at 2%.

n.a. indicates not applicable because eliminating fossil fuel generation results in a net release of CO_2 – there is no climate change benefit whatsoever in this scenario.

DISCUSSION

Unlike carbon taxes or emissions trading, feed-in tariffs distort the playing field towards the authority's preferred electrical generating option(s). In effect, the politicians or a regulator such as the U.S. EPA (i.e., the authority) selects those technologies that they feel will best accomplish their objectives. One objective might be to reduce carbon dioxide emissions, but clearly, given the questionable nature of intermittent sources of energy and the high costs of wood fiber, there exist other objectives that FIT programs seek to address. These objectives might include a

[16] See http://www.upi.com/Science_News/Resource-Wars/2010/10/05/Solar-boom-drives-up-German-power-price/UPI-74351286299555/ (viewed October 11, 2010).

desire to create jobs, develop a wind turbine and/or solar panel production sector, eliminate coal burning for non-climate related reasons (replacing coal with biomass), dramatically increase harvests from domestic forests, diversify sources of energy, appease environmental lobby groups, and so on. However, these are anything but climate related objectives.

As seen in this study, most FIT programs provide subsidies that last for a decade or more, with many programs also providing inflation protection to those investing in electrical generating capacity based on alternative energy sources that are eligible for FIT payouts. As a result, an electrical grid might be locked into generating assets that are not compatible with existing generating assets, while reducing incentives to invest in generating assets that might lower overall CO_2 emissions in the future.

At the same time, FIT programs can lock a government into the subsidization of power from alternative energy sources for an extended period. This can impose a long-term burden on the treasury and taxpayers. If costs can be passed along to consumers of electricity in the form of higher rates, then consumers are forced to pay for politically-motivated programs, ones that may not directly target CO_2 emission reduction or do so in an inefficient fashion. Higher electricity rates disadvantage industry relative to industry in other jurisdictions where rates are lower, transfer income from general ratepayers to recipients of FIT subsidies, and harm those least able to pay higher rates for heating or cooling their homes.

If the government is unable to transfer the costs of FIT subsidies to ratepayers (or simply desires not to), the burden on the treasury could be unsustainable. For Ontario, which has an average load of 16 GW, the annual cost was calculated to be some $2.5 billion or more than $32 billion over a 20-year project life (discounted at 7.5%), a not insignificant sum. Meanwhile, as demonstrated in this study, the feed-in tariff leads to a reduction in electricity prices at the wholesale level, while the deployment of intermittent generating capacity causes prices to fluctuate to such an extent that it reduces incentives to invest in new capacity. Assuming that part or all of the reduction in wholesale prices gets passed along to (at least some) consumers, there is a rebound effect that could offset any reduction in CO_2 emissions by 60% or more (Jenkins et al. 2011).

Given a desire to promote development of alternative energy sources for generating electricity, what policies might a government employ? If the sole objective is to reduce carbon dioxide emissions, the economist would favor a carbon tax as such a tax would address the issue at hand. The tax would tilt the playing field against fossil fuels, particularly coal but also biomass, and give non-CO_2 emitting renewable energy sources a leg up. However, the required carbon tax may need to be quite high to encourage investment in, for example, wind and solar energy, while it adversely affects extant generators but perhaps not enough to close them down. The authority might simply reject a tax in favor of feed-in tariffs because it has in mind objectives over and above that of reducing greenhouse gas emissions. The analysis in this paper suggests that, if this is the case, the authority needs to consider alternative policies (e.g., construction subsidies to wind, solar, etc., tax holidays, capital cost allowances) that lead to investments in desired renewable energy alternatives. These might be more effective and less costly.

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Appendix: Countries with Feed-in or Other Price Subsidies for Renewable Energy

Country	Wind	Hydro	Solar	Biomass
Algeria	✓	✓	✓	
Argentina	✓			
Australia			✓	
Austria	✓		✓	
Bosnia Herzegovina	?	?	?	?
Brazil	✓	✓		✓
Bulgaria	✓	✓	✓	✓
Canada	✓	✓	✓	✓
China	✓		✓	✓
Croatia	✓	✓	✓	✓
Czech Republic	✓	✓	✓	✓
Denmark	✓			✓
Dominican Republic	?	?	?	?
Finland	✓			✓
France	✓	✓	✓	✓
Germany	✓	✓	✓	✓
Greece	✓		✓	
Hungary	?	?	?	?
India			✓	
Iran	?	?	?	?
Ireland	✓	✓		✓
Israel	✓		✓	
Italy	✓		✓	✓
Japan	✓			
Luxembourg			✓	
Malaysia	✓	✓	✓	✓
Malta	?	?	?	?
Mongolia	✓	✓	✓	
Portugal	✓	✓	✓	
Serbia	✓	✓	✓	✓
Slovakia	✓		✓	✓
Slovenia	?	?	?	?
South Africa	✓	✓	✓	
South Korea	✓	✓	✓	
Spain	✓	✓	✓	✓
Switzerland	✓	✓	✓	✓
Taiwan	✓	✓	✓	✓
Thailand	✓	✓	✓	✓
The Netherlands	✓	✓	✓	✓
Turkey	✓	✓	✓	✓
Ukraine	✓	✓	✓	✓
United Kingdom	✓	✓	✓	✓
United States	✓	✓	✓	✓
Vietnam	?	?	?	?

NOTES:
Some countries such as Canada and the U.S. have separate jurisdictions that have implemented their own FITs. A ? indicates that a country has a renewable subsidy but little is known about it.
Source: Derived from http://www.wind-works.org/articles/feed_laws.html (Paul Gipe, Bakersfield, CA)