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The Economics of Renewable Electricity Policy in Ontario

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Abstract

Economic evaluation of green or renewable power should compare the cost of renewable power with the cost savings from displaced fossil generation plus the avoided harm from reduced emissions of air pollution and greenhouse gases. We use existing estimates of the values of the harm and we calculate cost savings from renewable power based on wholesale spot prices of power in Ontario and steady-state estimates of the cost of new gas generation to estimate the value or affordability of various forms of renewable power in Ontario. We find that timing matters in evaluating intermittent renewable sources.

Considering air pollution and greenhouse gases we find that coal generation is dominated by natural gas, supporting Ontario's policy of ending coal generation by 2014. Renewable power thus displaces gas. Dispatchable renewable generation sources, such as many biogas, biomass and some hydroelectric sites cause savings and reduced harm that can justify some of the Ontario Feed-in-Tariff prices up to $130/MWh; other FIT prices are too high. Wind and solar power are variable, so the value of their power depends on system marginal costs when they generate. Wind's displacement of gas capacity costs is low because it cannot be depended upon when demand is high and generation is needed, so it justifies prices of only $60 to $95/MWh, less than the FIT price of $115. Solar power justifies higher prices than wind, up to $152/MWh because solar generates in the daytime when prices are higher and when solar can fairly reliably displace gas capacity. Still, solar power falls far short of justifying the 2012 Ontario FIT prices of $347 to $549/MWh. Ontario's Feed-in-Tariff program costs more than necessary to achieve its environmental goals.

Keywords: renewable energy, green energy, wind power, solar power, air pollution harm, greenhouse gases, feed-in-tariff, electricity generation externalities.

JEL Classification: L94, Q42, Q51, Q52, Q53, Q54, Q58.

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1. Introduction

If we were not concerned about pollution and the environment, energy policy in Canada would be simple: use the lowest cost power source, which would be hydropower in some locations and coal elsewhere except when and where natural gas is inexpensive. This would minimize the financial cost of meeting our electricity needs. Actual policies are now quite different, especially in Ontario, where we are spending large amounts of money to reduce or eliminate coal-burning and to subsidize renewable power. The motives are several:

- The air pollution discharged from burning coal harms human health and the environment.
- Burning coal and to a lesser extent natural gas discharges CO2 which contributes to global warming.
- The world is moving toward renewable power and if we promote renewable power at home we may improve our future industrial prospects.
- Promoting renewable power will create jobs in the province, employing workers who have been displaced from other manufacturing jobs.

Policies to encourage "green" or renewable power have now been around long enough to stimulate extensive analysis of their costs, benefits, and general effectiveness.[2] A traditional method for comparing the costs of generating technologies is to calculate the average cost per MWh generated over the lifetime of the generation plant, the 'levelized cost." That method fails to quantify the environmental factors that lead to a preference for renewable power. Furthermore, as Joskow (2011) demonstrates, it is not an appropriate method for comparing dispatchable power and intermittent renewable power projects. This paper will propose a more complete economic framework for evaluating renewable energy, review the arguments for promoting renewable energy, and assess Ontario's *Green Energy and Green Economy Act*.

2. Evaluating Green Energy

Renewable power, except for some hydroelectric projects, generally costs more than power from fossil fuels. In many parts of Canada the low-cost hydroelectric projects that are reasonably close to electricity demands have already been developed, so future hydroelectric projects are likely to have higher costs, either for generation infrastructure or for transmission lines. Some hydroelectric projects raise significant environmental issues. So, renewable power projects generally compete with power plants fuelled by coal or natural gas or with nuclear plants. Most renewable power projects will generate electricity that is more costly than if a coal plant or gas plant were built. But looking at only the financial costs for fossil generation ignores the environmental harm that they cause.

Most economists would agree with environmentalists that when we compare power sources we should compare not just financial costs but full social costs including the value of environmental harm caused by burning fossil fuels.[3] Considering full social costs implies a definition of affordable green power: green power is affordable if its total social cost is less than the total social cost of the conventional power source that it displaces including the value of all environmental harm caused by the conventional power. The value of the environmental harm is

[2] See Green and Yatchew (2012) for a recent review of policies supporting renewable energy.
[3] See, e.g., Pindyck and Rubinfeld (2013, pp. 662-63, 668-70), Cropper and Oates (2000, p. 55).

some measure of the damage caused or of our collective willingness to pay to avoid that damage. Using this definition, determining affordability involves the following steps:

- Determine the value of the reduced environmental harm from reduced generation by the displaced conventional sources;
- Determine the financial cost savings from reduced generation by the displaced conventional sources;
- Determine the cost of generation by the renewable/green sources.
- The renewable/green source is affordable if its cost is less than the sum of the financial cost saved by displacing the conventional source, including operating cost and any relevant portion of capacity costs, plus the value of the harm avoided by displacing the conventional source.

In practice, we have a fleet of existing conventional generators so in the short run most renewable power will displace some output from these generators. In the longer run, renewable power may allow us to avoid investing in additional conventional generation or in the refurbishment of existing generation. We can therefore calculate the cost savings from reduced operation (and less construction) of the conventional sources, add the value of the harm avoided by not burning fossil fuel and then choose the renewable if its cost does not exceed the sum of these two. The cost savings from displacing power from conventional generators will depend on the timing of the displacement. We will present a methodology for recognizing that intermittent technologies may generate when system marginal costs are either higher or lower than average and crediting them with the actual costs saved.

We will also discuss the promotion of green power to create jobs or create a sustainable green industry.

3. Environmental Harm from Burning Fossil Fuels

Burning coal or oil leads to the discharge of sulphur dioxide, nitrogen oxides and particulates which may include toxic materials including mercury in the case of coal. Burning natural gas leads to the discharge of nitrogen oxides. Environmental regulation over the last half century has led to technological developments that can remove the vast majority of these pollutants from the exhaust stream, but some pollution is still discharged, the amount depending on the fuel and the technology used. Burning any of the fossil fuels releases carbon dioxide, and while carbon sequestration is under active investigation, at the present time no large-scale carbon sequestration has been demonstrated at an Ontario power plant. This study focuses on emissions from burning fossil fuels rather than on life-cycle emissions that would include emissions from fuel production, emissions associated with capital equipment and other associated emissions. For a recent survey of life-cycle emissions from electricity generation see Synapse (2012).

For any specific power plant the emission rate of each of these pollutants is known. Extensive studies have explored the relationship between emission rates or ambient pollution concentrations and environmental harm or harm to human health. If we can attach a dollar value to those harms we will have an estimate of the value of the harm caused by each MWh of electricity generated at a power plant. In general, such studies find that the largest portion of the damages arise from effects on human health. A landmark study in Ontario estimated that each MWh of electricity generated from coal burned in Ontario caused health damages worth $113, environmental harm worth $3 and greenhouse gas harm worth $10 (valuing CO2 damage at $10/tonne), for total damage equal to $126/MWh, in 2005 $CDN. (DSS/RWDI, 2005, pp. 29, 32.) Expressed in 2012 $CDN, this would be $127 for health alone and $132 when environmental harm (excluding CO2) is added. The health damage estimates in this study are several times those in previous studies because DSS/RWDI use an exposure-response relationship much greater than other studies. Subsequent analysis has questioned the conclusions and methodology of the exposure-response relationship used in DSS/RWDI, finding little evidence for any health effects at current pollution levels in Canadian cities. (Koop, McKitrick and Tole, 2010.) However the methods used by Koop *et al*. have in turn been criticized in the epidemiological literature (Thomas *et al.*, 2007) and have not been widely adopted in health effects studies. This leaves significant uncertainty regarding the Canadian estimates of the health damages from burning coal.

The health and environmental effects of air pollution from stationary sources have been extensively studied in the United States, with studies subjected to public comment and peer review over a period of many years. Most of Ontario's population and fossil fuel generation is located southern Ontario which is in the same airshed as the Great Lakes states. Southern Ontario's pollution concentrations and population densities are similar to those in the neighbouring states so we can use the US damage estimates relating to these states to estimate harm caused by air pollution in southern Ontario.[4] A comprehensive 2009 study by the US National Research Council of the National Academy of Sciences examined the health and environmental harm caused by all forms of energy. (US NRC, 2009.) They used standard exposure-response models, air dispersion models for each power plant and values of morbidity and mortality to derive the health and environmental effects arising from the operation of fossil fuelled power plants. (US NRC, 2009, p. 84.) They go on to estimate dollar values for those harmful effects using values that have become standard in the environmental effects literature. (US NRC, 2009, p. 85.) The majority of the value of harm comes from human health effects. For coal-fired plants, about 85% of the harm is attributable to sulphur dioxide emissions. (US NRC, 2009, p. 92.) Most of the variation in this harm among power plants arises from the variation in emission rates rather than from the location of the emission. (US NRC, 2009, p. 91.) This tends to support the use of these US data to estimate harm caused in southern Ontario. As a first approximation, if we assume that the median (weighted by generation) coal-fired power plant in the US is comparable to Ontario's coal plants, we can use their 50th percentile plant to estimate effects in Ontario, and similarly for gas-fired power plants. Their results are in 2007 US dollars. We adjust for exchange and inflation by using US inflation from 2007 to 2012 (1.1084) and the 2012 Canada/US exchange rate (0.98). With respect to burning coal, the median US plant is estimated to cause harm valued at 1.8 cents/kWh (US NRC, 2009, p. 92) or $20.36/MWh in 2012 $ CDN. This is less than one-sixth the damages found by DSS/RWDI (2005).

Because the individual plant emission rate is an important determinant of the magnitude of harm, we can improve on this estimate by using actual emission rates from Ontario coal plants. We have actual emission rates for the Nanticoke generating station from 2007, to which we can

[4] Ontario south of a line from Pembroke to Orillia contains over 90% of Ontario's population in about 15% of its area. Its population density, at about 250/sq. mi. is similar to that of seven Great Lakes states: New York, Pennsylvania, Ohio, Indiana, Illinois, Michigan and Wisconsin, which have a collective average population density of 234/sq. mi. (Data spreadsheet)

apply the US estimates of the harm caused per kilogram of pollution discharged. The 2007 data and the corresponding NRC damage estimates are presented in Table 1. This yields values 50 percent greater than those based on the median US plant. We prefer the Table 1 estimate because it relies on actual recent emission rates from the Nanticoke generating station, the primary coal-fired plant in southern Ontario. We round this up to **$30/MWh** of harm caused by coal emissions. We use this value, along with **$130/MWh** representing the DSS/RWDI damage estimates, to provide a range of estimates of the health and environmental effects.

Table 1 Nanticoke Traditional Emissions and Harm

Pollutant	Emission Rate kg/MWh	Damage Rate $US/ton	Damage $CDN/MWh
Sulphur dioxide	3.73	5,800	26.90
Nitrogen oxides	1.24	1,300	2.00
PM Total Partic	0.381		0.00
PM10	0.120	340	0.05
PM2.5	0.038	7,100	0.34
Total			**29.29**

Sources: US NRC (2009, Table 2-8, p. 90), OPG (2008, Appendix A, p. 41); OCAA (2005). 2012 $CDN = 2007 $US*1.131.

With respect to burning natural gas, the median (weighted by generation) US plant is estimated to cause harm valued at 0.036 cents/kWh (p. 118) or $0.407/MWh in 2012 $CDN. This is one-fiftieth of the harm per MWh caused by the median coal plant because the gas plant emits much less of all pollutants, especially sulphur dioxide, than the coal-fired power plant.

As with coal, we can improve on this estimate by using data on actual emission rates from Ontario gas plants. We have actual emission rates for the five major combined cycle gas turbine (CCGT) generating stations in southern Ontario in 2010, to which we can apply the US estimates of the harm caused per kg of pollution discharged. The 2010 emissions data and the corresponding NRC damage estimates are presented in Table 2. Sulphur dioxide is not included because the National Pollution Release Inventory for the gas plants does not report it because the quantities emitted are negligible.[5] This method produces damages five times greater than the US calculation because of surprisingly high reported PM emissions from one Ontario gas plant that employs SCR to reduce its NOx emissions. We will use **$1.56/MWh** to represent the harm caused by conventional emissions from gas-fired power plants in Ontario. DSS/RWDI do not provide an estimate of the harm caused by emission from gas-fired power plants and their study does not provide a basis for separately estimating the effects of the individual air pollutants. In order to try to reflect the higher risks estimated by DSS/RWDI, we will also present the EPA CCGT damage estimates increased by the ratio of the DSS/RWDI coal harm to the EPA coal harm: (130/30)*1.56 = $**6.76/MWh**.

[5] US EPA, "Clean Energy/Air Emissions/Natural Gas" http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html , accessed 22 February, 2013.

Table 2 Average Southern Ontario CCGT Traditional Emissions and Harm			
Pollutant	Emission Rate kg/MWh	Damage Rate $US/ton	Damage $CDN/MWh
Nitrogen oxides	0.099	1,300	0.16
PM10	0.151	340	0.08
PM2.5	0.151	7,100	1.33
Total			**1.56**

Sources: Emission rates calculated by author from NPRI "2010 Facility & Substance Information" for each plant: http://www.ec.gc.ca/pdb/websol/querysite/query_e.cfm . Damages from NRC (2009, Table 2-18 p. 90), 50^{th} percentile plant. 2012 $CDN = 2007 $US * 1.131.

Estimating the value of the harm caused by CO2 emissions is, if anything, more difficult than estimating the harm caused by traditional air pollutants, in part because the long-term effects of global climate change are still quite uncertain. Economist William Nordhaus (2007, p. 31) used a macroeconomic and climate model to analyze the carbon prices that could be justified by anticipated harms and proposed a tax on CO2 of $4.63 starting in 2010, rising to $19 in 2050, all in 2005 US prices.[6] Other analysts have come to highly varied conclusions. Rather than analyzing this extensive literature here, we rely primarily on the well-regarded Stern review, published in 2007. Stern said that the harm caused by emissions of CO2 might be $29/tonne (2000 USD) if GHG control started soon (after the review was published) or as high as $85/tonne if we carried on with business as usual for a while before imposing controls. (Stern, 2007, p. 287.) These high values arise in part from using a low discount rate that is a matter of some debate. (Weitzman, 2007.) This would equal $38 to $111 in 2012 $CDN. In fact, apart from emission reductions caused by the economic slowdown, little progress has been made in reducing worldwide CO2 emission since the Stern review was published, so his high estimate is more relevant. We use $100/tonne as a high estimate of the value of CO2 reduction based on science that directly connects human activities to global climate change.

For comparison we can look at the cost, in dollars per tonne, of policies that reduce greenhouse gas (GHG) emissions sufficiently to reduce the risk of disastrous global climate change. A report by MK Jaccard and Associates (2009, pp. 19-21) found that achieving a 20% carbon reduction from 2006 GHG emission rates in Canada by 2020 would require a carbon tax starting at $40/tonne CO2 in 2011 and rising to $100/tonne in 2020. More recently, the Canadian National Roundtable on Environment and the Economy found that as of 2012, **existing** federal and provincial policies to reduce GHG would impose costs under $50/tonne for about half of the reductions, but over one-third would cost more than $100/tonne. (NRTEE, 2012, pp. 95-97.) Achieving the federal government's 2020 GHG target, set at the signing of the Copenhagen Accord in 2010[7], would require the use of all proposed policies including those costing as much as $150/tonne. (NRTEE, 2012, pp. 97-98.) The government's 2030 targets still require policies costing more than $100/tonne. (NRTEE, 2012, p. 108.) These are costs comparable to the high end of the Stern estimates of marginal benefits of CO2 control.

None of the federal or provincial policies mention such high costs per tonne explicitly. In the United States, the Environmental Protection Agency analyzed the more promising of the

[6] Nordhaus proposed a tax on carbon of $17 in 2010 and $70 in 2050. 1 tonne of carbon is 3.67 tonnes of CO2.
[7] For a summary of Canadian greenhouse gas policy for the last quarter century, see NRTEE (2012, pp. 28-30).

GHG control bills introduced in Congress, the Waxman-Markey bill, and estimated that it might give rise to CO2 prices around $17/tonne in 2015 increasing to $28/tonne in 2025. (US EPA 2009, pp. 3, 22.) In Canada, the BC carbon tax rose to $30/tonne in July of 2012.[8] Alberta's climate control legislation requires emission reductions or payment into a technology fund at $15/tonne.[9] The Federal 'Turning the Corner' policy allowed industry to avoid installing controls by paying into a technology fund at a maximum cost of $15/tonne. (Canada, 2008.) This may be an indication of the price that governments think that the public is willing to pay for GHG control, perhaps reflecting some balance between global warming believers and sceptics. We use $25/tonne to represent a price that some governments are prepared to impose explicitly on polluters in 2012 (and the low end of damage estimates) and $100 to represent the upper estimates of the value of the benefits of controlling emissions to avoid terrible global harm in the future.

Burning coal releases approximately one tonne of CO2 for every MWh of electricity generated. (OPG, 2008, p. 15.) Burning natural gas in the Ontario CCGT plants releases on average 0.395 tonnes of CO2 for every MWh of electricity generated.[10] Multiplying these emission rates by $25 and $100/tonne yields the value of greenhouse gas harm displayed in Table 3.

Table 3 summarizes the results thus far, showing the calculation using Ontario emission rates. These calculations imply that we should be prepared to pay a premium of $55 to $230/MWh over the cost of displaced power for renewable power that displaces coal power in southern Ontario, depending on the value of CO2 and whether one prefers the EPA or DSS estimates of health effects. We should be prepared to pay a premium of $11 to $46/MWh over the cost of displaced power for renewable power that displaces natural gas power in southern Ontario. Note that the natural gas harm is mostly related to carbon dioxide; conventional air emissions cause little harm. Most important, no matter what value is placed on air pollution or GHG damage, natural gas generation causes a small fraction of the harm caused by coal.

Table 3 Summary of Environmental Harm Reduction ($CDN/MWh)

	Displace Coal	**Displace Gas**
Air Pollution (EPA/DSS)	30 to 130	1.56 to 6.76
Greenhouse Gases ($25/$100)	25 to 100	9.88 to 39.52
Total harm	55 to 230	11.44 to 46.28

Source: Author's calculations using Ontario emission rates, harm from Tables 1 and 2 and from DSS/RWDI (2005).

Intermittent generators require that the system maintain spinning reserve that is ready to generate when the wind diminishes or a cloud hides the sun, and the spinning reserve will involve burning coal or gas, thus causing some emissions not counted in Table 3. In addition, variations in the output of intermittent wind generators requires that fossil plants increase and decrease their output, called ramping, and these changes in output consume more fuel than is

[8] British Columbia Ministry of Finance, "How the Carbon Tax Works" http://www.fin.gov.bc.ca/tbs/tp/climate/A4.htm , accessed 12 September 2012.
[9] Alberta, 2008, "Climate Change," http://www.environment.alberta.ca/01855.html , viewed 17 September 2012.
[10] Author's calculation of an average emission rate in 2010 based on the NPRI report of CO2 emissions for five large gas plants in Ontario and net generation amounts from Tom Hilbig of Sygration, 23 July, 2012.

consumed in steady operation.[11] To this extent Table 3 overstates the benefits of displacing these fuels with intermittent generation. On the other hand, emissions from the production of natural gas would increase the harm associated with gas generation that would be captured if we did a life-cycle analysis. We do not make adjustments in our analysis for these offsetting factors.

4. Cost Savings for Displaced Power

Joskow (2011) argues that the cost saving from displacing conventional power with intermittent power must take into account the system marginal cost or spot price when the intermittent power is actually generated. In principle the cost savings arising from displacing conventional power with renewable power could be calculated by simulating system operation over the planning period without the renewable power then repeating the simulation with the addition of some renewable power and reduced investment in and operation of conventional capacity to achieve the same level of system reliability. This is a complex exercise requiring sophisticated modeling capability and detailed data about the generation portfolio and about hourly demand. The cost and complexity of such analysis rules it out for the routine evaluation of new renewable projects.

An alternative is to analyze a recent historical period, using Ontario's spot price (the Hourly Ontario Electricity Price, HOEP) as an estimate of system marginal cost. A marginal increase in renewable power output would save operating costs equal to the spot price at any hour of the year. New renewable capacity would allow a reduction in conventional capacity that would leave system reliability unchanged; the resulting capital cost saving represents the capacity credit attributable to the renewable resource. This approach can produce an ex-post measure of cost savings arising from displaced conventional power caused by renewable power in Ontario. We use this approach to explore the timing of wind and solar power relative to variations of HOEP.

We note that Ontario's spot price is so variable from one year to the next that recent history is not a reliable guide to marginal costs for the next decade or two. We therefore use a steady-state estimate of the capital and operating costs of natural gas generation to produce steady-state quantitative estimates of future cost savings from new generation in Ontario. We use our historical analysis to adjust those steady-state estimates for the time varying output of wind and solar power. We focus on wind and solar power, both of which are intermittent, but we also estimate the savings from dispatchable renewable power such as biogas or biomass.

We do not analyze nuclear power. Davis (2012) says that nuclear is not a viable option in the US because it is too expensive even if one ignores safety and operating risks. The US Energy Information Administration (2012, Table 1) forecasts that advanced nuclear power plants will cost about 70% more per MWh of electricity produced than CCGT plants. While the OPA (2007, p. 10) presented an example in which nuclear power appears competitive with gas at the high gas prices of that time, Ontario's experience with nuclear projects involves numerous cost

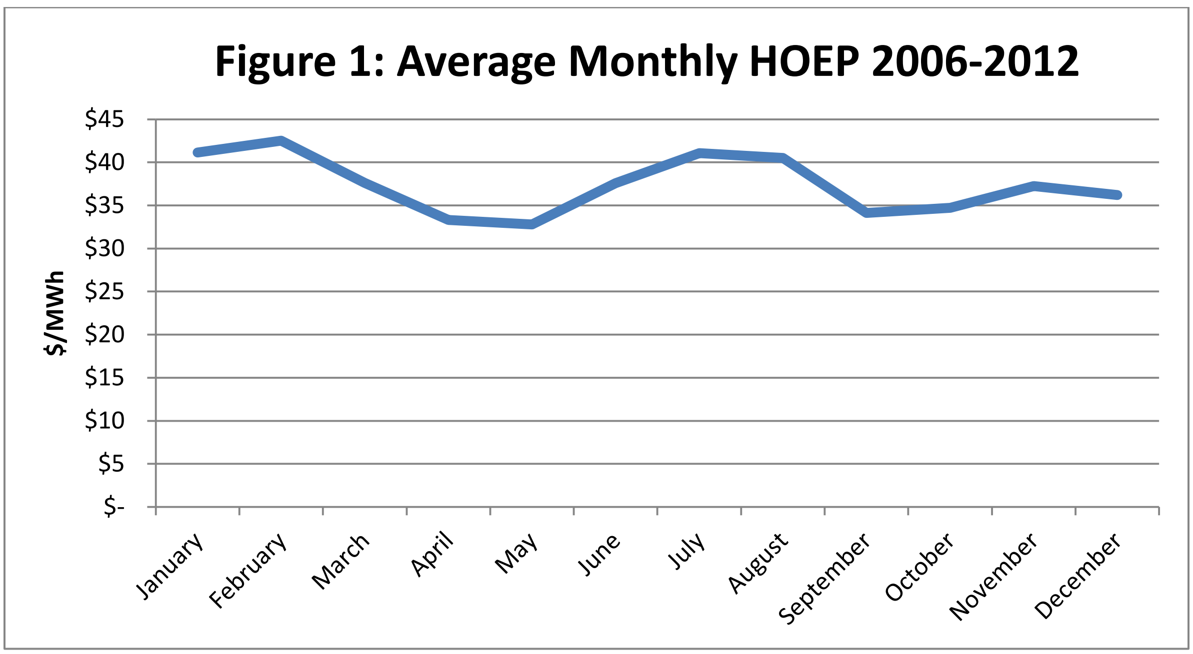
[11] The OPA standard contract for clean power specifies additional payments for startup and ramping. See: Exhibit J to OPA CHPSOP Contract of 2011 at: https://cms.powerauthority.on.ca/sites/default/files/page/Blackline%20-%20CHPSOP%20Contract_0.pdf , p. 89.

over runs and long delivery times.[12] I do not see a way to quantify either the costs or risks of the nuclear option in Ontario with confidence. This analysis sets aside the nuclear option on the grounds that it is dominated by natural gas. Moreover the renewables of greatest interest today are intermittent wind and solar which are not good substitutes for the base load generation inherent in nuclear power.

4.1. Recent Renewable Cost Savings

We will examine variable (marginal) costs and capacity (fixed) costs separately. In Ontario the HOEP is the result of generators submitting bids to the system operator, IESO, which dispatches generators starting with the lowest bid and increasing in price until the demand is satisfied. The optimal bidding strategy for any generator is to bid its marginal generation cost. So, the HOEP is the best available estimate of the variable or marginal cost of generation at every hour of the day in Ontario.[13] This means that the annual cost avoided for power displaced is the sum over the year of renewable output in each hour multiplied by the HOEP in that hour.

HOEP varies widely owing to variations in both supply and demand. From 2006 through 2012 the prices range from less than -$10/MWh[14] to over $200/MWh, with the majority between $25 and $55/MWh. Prices are lowest in spring and fall when we are not heating or cooling much with further depression when the spring freshet provides ample hydroelectric power. Prices are high in February when heating and lighting loads peak and again in July and August when air conditioning loads peak and hydroelectric power is less abundant. See Figure 1.



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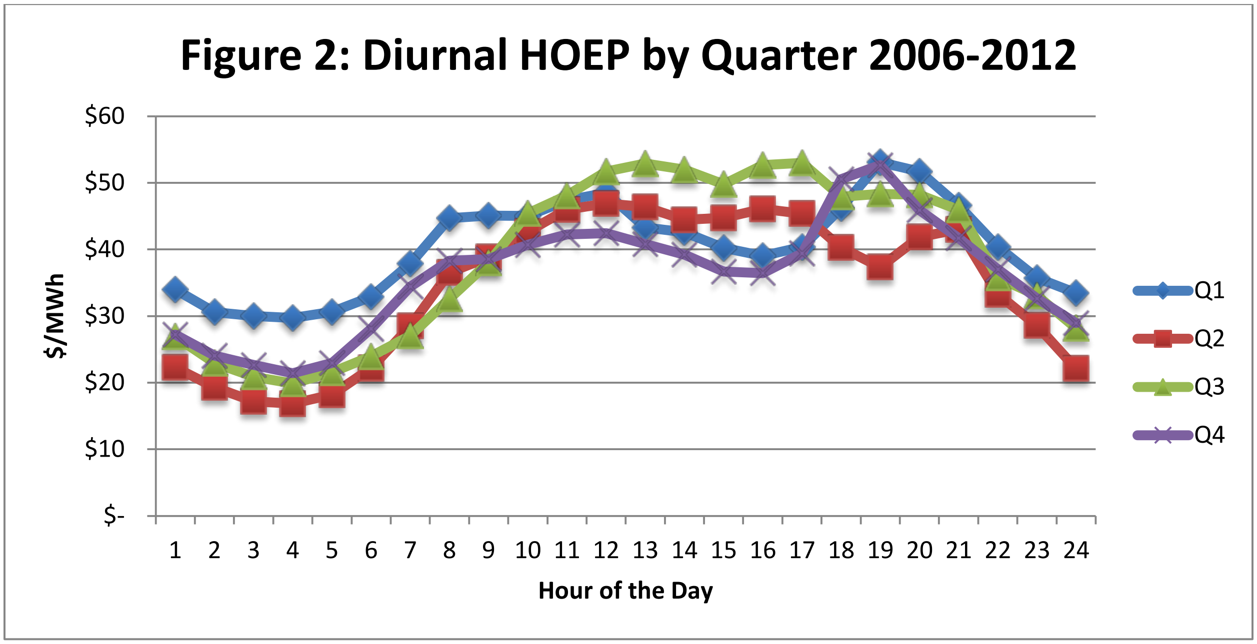
[12] For a critical summary of Ontario's nuclear experience see, Ontario Clean Air Alliance Research, 2010, "The Darlington Re-Build Consumer Protection Plan," http://www.cleanairalliance.org/files/active/0/darlington.pdf .
[13] (2011) uses the spot price in as the measure of operating cost saving for intermittent generators.
[14] In the last few years the spot price has gone negative on occasion, particularly at night, when baseload generation exceeds the Ontario demand plus exports. See Dachis and Dewees (2011).

HOEP also varies consistently with the hours of the day and the days of the week and that variation depends on the season. The marginal cost of generation is higher during the day than at night as more expensive marginal resources are called upon in daytime. The price peak in the first and fourth quarters occurs between 6PM and 9PM when home and work demands overlap, with a lesser peak in the morning. In the second and third quarter there is a broad price plateau from mid-day to evening. See Figure 2.



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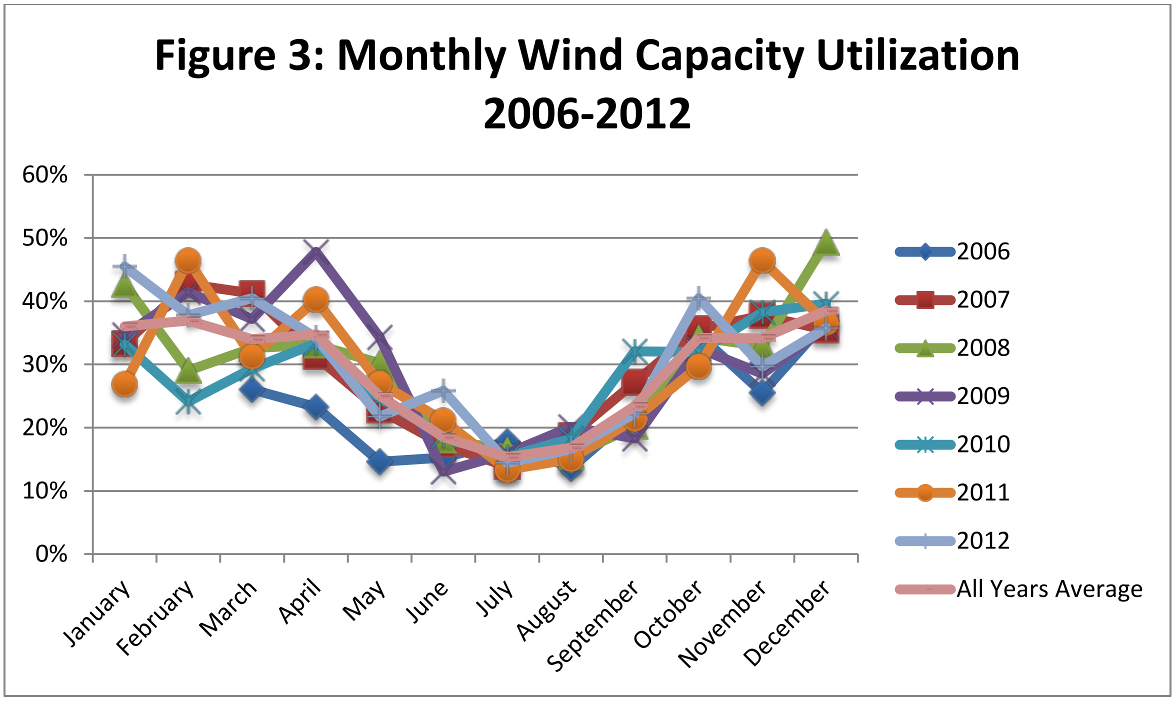
These variations in HOEP are sufficiently large and predictable that they may affect the cost of displaced power from intermittent generation sources. For example, if wind generation is weak in the summer when prices are high, wind might be credited with saving less than the annual average HOEP. Solar power might be credited with displacing power worth more than the average HOEP since its generation occurs only during daytime when the price is higher.

4.1.1. Value of Wind Output

We have analyzed hourly generation data for Ontario wind farms from 2006 through 2012. Figure 3 shows the average capacity utilization (output/(capacity*hours)) in each month for those wind farms. Capacity utilization is low in summer and higher but quite variable in October through April. Capacity utilization in June through September is less than half that in winter, averaging just 15% in July. Figure 4 shows the capacity utilization for each hour of the day, averaged for each year from 2006 through 2012. In each year there is only a small diurnal pattern to the wind. The average daily maximum capacity utilization occurs in mid-afternoon when HOEP is high and again at midnight when HOEP is low.



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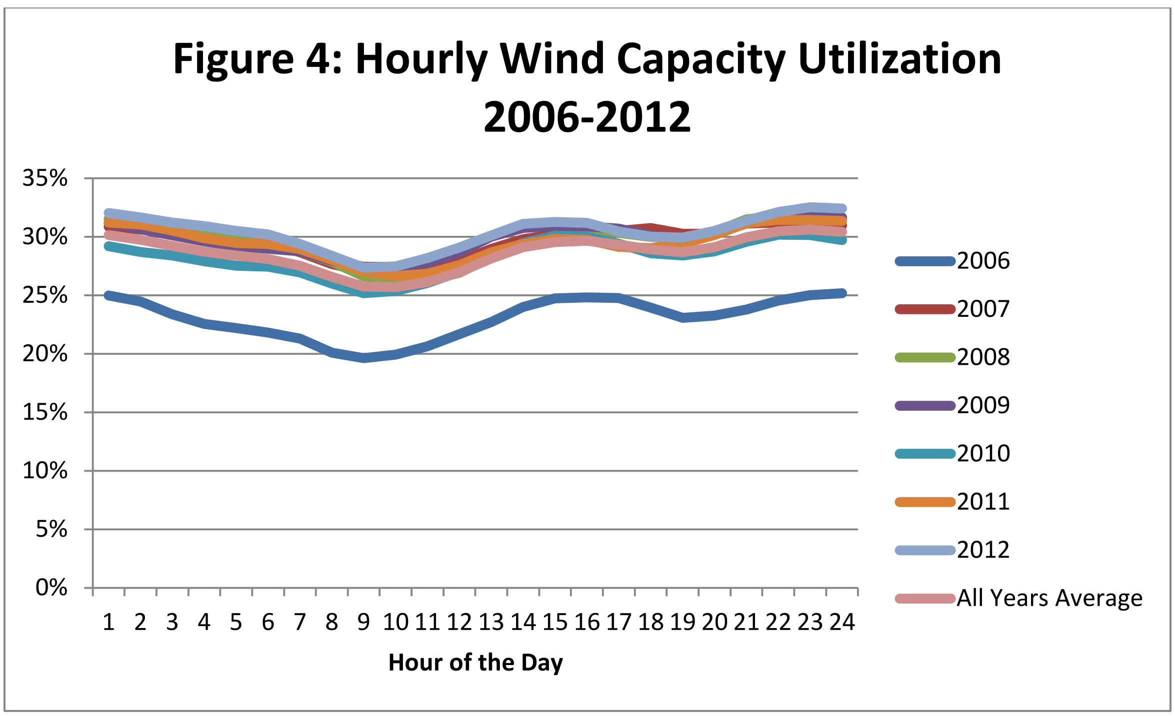

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We can determine the economic significance of this variation in wind output by comparing the average value of wind output with average HOEP. The unweighted average HOEP for a year represents the average price that would be earned by a baseload generator that was paid the spot price in each hour. The product of wind output in each hour multiplied by HOEP in that hour is the value of wind output. Table 4 presents the unweighted average HOEP for each year and the average price of the power displaced by all wind farms weighted by the power output in each hour over each of the seven years in this period. The third line shows the ratio of the value of wind-generated power divided by HOEP for each year.

Table 4 Relative Value of Power Displaced by Wind 2006-2012							
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
HOEP ($/MWh)	45.30	47.81	48.83	29.52	36.25	30.15	22.80
Wind value ($/MWh)	43.78	48.02	47.26	29.02	33.53	27.05	20.17
Wind $/HOEP $ (%)	96.7	100.4	96.8	98.5	92.5	89.7	88.4

Source: Capacity Credits Linear v2 2013feb4, 'statistics'.

HOEP plunged from 2006-8 to 2009-12 as the Ontario economy slowed and industrial activity dropped, reducing electricity demand. The value of power displaced by wind declined as well.[15] But the ratio of the value of wind power to average HOEP ranges from 100.4% in 2007 down to 88.4% in 2012 with an average of 94.7%. We cannot tell from our data whether the decline in the ratio represents a trend or a random variation. The ratios suggest that on average the generation cost savings from wind power are worth 5% less than the average HOEP.

We also analyzed the relative value of individual wind farms. In a given year the individual wind farms might vary by 5% in relative value, with only a 3-point spread in 2007 and a 10-point spread in 2009. There were not major differences in relative value when the farms were averaged over their operating years.

To what extent does wind power reduce the need for conventional generation capacity? While wind and solar power are variable, there is some probability that they will operate when capacity is required to meet peak system needs. The credit for reducing natural gas capacity depends on the timing of demand, wind patterns, and the other generators operating in the system so it will differ from one electricity system to another. Milligan (2002) found a capacity credit of 25% to 35% of nameplate capacity for wind in an unspecified Great Plains location. Fripp and Wiser (2006, p. xii) found peak-period wind capacity factors 15% less than the average wind capacity factor for certain California locations, while certain Northwest sites have peak capacity factors 20% greater than their average capacity factor. Our analysis finds that during hours of peak system prices Ontario wind farms in aggregate operated at a median capacity factors ranging from 14.5% in 2010 to 25% in 2007. The capacity factors of individual farms were somewhat more varied with lower minima. The Ontario IESO reports the median wind contribution during the peak five hours in summer, winter, and each shoulder month ranges from 13.4% in summer to 33.6% in winter. The Ontario Power Authority (OPA, 2011a, p. 22) reports that Ontario's wind farms operated at 12-16% of capacity during peak demand hours, which now occur in summer in Ontario, in the afternoon. We use the mid-point of the OPA peak factors, 14%, as the wind Capacity Credit factor RCC_w meaning that 1 MW of wind capacity reduces the need for baseload gas generation by 0.14 MW.

[15] Indeed on a number of occasions during 2010-2012, usually at night, Ontario had surplus baseload generation that drove the spot price negative when wind was generating and being paid its FIT price. (Dachis and Dewees, 2011).

Our analysis of Ontario wind farms finds an average capacity factor for 2007 through 2012 of 29.5%. We will use our estimate of 0.295 for RCF_w, the Ontario wind farm capacity factor in our model.

4.1.2. Value of Solar Output

We do not have sufficient data from Ontario solar farms to perform an analysis similar to our wind farm analysis. One Ontario study simulated solar generation in suburban Toronto relative to hourly demand in years 2000-2006 and found a strong correlation between solar generation and system electricity demand. (Pelland and Abboud, 2007.) Borenstein (2008) studied solar power in California, looking at actual wholesale power prices in 2000-2003 in relation to the output of simulated solar installations. Solar installations produce their maximum power from mid-day to mid-afternoon and wholesale power prices in California peak at the same time because of high demand for air conditioning. He found that if solar power was valued by the hourly wholesale price rather than by the long-run average wholesale price its value increased by around 10%, with the amount of the increase varying from zero to 20% depending on assumptions. (Borenstein, 2008, Table 1.) The orientation of the solar panels affected the extent of the premium; west-facing panels generated power worth 10% more than the flat price while south-facing panels generated more power but the that power was worth only 5% more than the flat price because the power peak occurred in mid-day while the price peak occurred in the late afternoon. In an Ontario study, Aegent (2009, p. 24, Table 1) assumes that solar power in Ontario will earn a 10% premium, that is, 110% of the average HOEP. In the absence of other Ontario data, we will assume a 10% premium over HOEP for solar power in Ontario.

The Auditor General (2012, p. 111) reports that solar generators operated at an annual average of 13% to 14% of capacity, but at 40% of capacity during peak times. We will use 0.14 as the solar capacity utilization factor RCF_s. Pelland and Abboud (2007) found that if solar is a small fraction of Ontario generation, e.g. 2%, its capacity contribution ranges from 30% to 44%. The capacity contribution is high because solar production is higher in summer afternoons than at any other time and Ontario's peak system demand is now in the summer. The OPA (2011, p. 22) reports a solar capacity contribution during the summer peak of 35% to 55%. We assume a solar capacity credit factor RCC_s of 40%, meaning that 1 MW of solar capacity could displace 0.4 MW of gas capacity.

4.2. Future Marginal Power Cost

We conclude that wind should be credited with a 5% discount from HOEP for displaced power and solar should be credited with a 10% bonus. But what is the baseline HOEP from which these deviations are calculated over the 20 years of assumed project life for a renewable investment today? The average HOEP from 2006 through 2012 was just under $40/MWh with a decline from $49 in 2007 to $23 in 2012 because of declining demand and declining natural gas prices. Aegent (2012, p. 8) assumed that HOEP would range from $21.25 in 2012 to $33.00 in 2016 in as-spent dollars. For the next 20 years there are great uncertainties about both supply and demand for electricity in Ontario. Major decisions must be made about retiring or refurbishing aging nuclear plants and the extent to which natural gas will substitute for nuclear. The future of industrial electricity demand is highly uncertain, depending on many factors including the future value of the Canadian dollar. Uncertain demand and supply mean that the future spot price of electricity is highly uncertain. While the price is now below $30, it could hit

$40 or even $50 (in 2012 $CDN) over a 20-year time horizon if gas prices increase or we fail to replace retiring generation plants. This means that the historic data provide modest guidance as to marginal costs for the next decade or two. We will therefore look at a steady-state estimate of capital and operating costs for fossil generation in the next section. This will provide a constant average of both marginal and total costs. We will use our historic analysis as a basis for applying a 5% discount for power displaced by wind and a 10% premium for power displaced by solar.

4.3. Steady-state Analysis

The financial cost savings from displacing fossil power can be calculated by assuming steady-state operation throughout the year and using standard generation plant parameters for capital and operating costs. We assume that renewable power in Ontario will displace new investment in natural gas generation and the operation of new or existing gas generation, since, as we demonstrate below, gas dominates coal when environmental and health harms are considered. The standard calculation of the cost savings from this displaced power divides costs between fixed and variable costs and assumes steady state operation, ignoring variations in output during the year.[16] The fixed annual costs include the cost of capital investment amortized over the life of the facility plus any costs that do not vary with power production. These are gas fixed costs for a year, GFY. The variable annual costs are the cost of fuel and output-related maintenance, GOY which are equal to gas operating costs per MWh, GO, multiplied by the MWh produced. We will represent the output of a gas generation plant with capacity GMW by a capacity factor, GCF which equals annual output divided by maximum theoretical annual output of GMW*8760 hours/year. We base our calculations on a mid-merit Combined Cycle Gas Turbine (CCGT) plant that is expected to run 4,380 hours/year or 50% of the time.[17]

If we install 1 MW of renewable capacity of type j with a capacity utilization or capacity factor of RCF_{j} , over the course of a year it will displace gas output in the amount of RCF_{j} *8760 MWh. This will save variable costs equal to RCF_{j} *8760*GO per year. In addition, we can postpone investment in gas capacity in the amount of the contribution of this renewable plant to the system capacity needed for reliability, the Renewable Capacity Credit, RCC_{j}. We divide the RCC_{j} by the gas availability factor GAF to reflect the fact that the gas plant is assumed not to be available a small part of the year for reliability purposes. In the case of base load renewable generation, the RCC may approach 1, while solar or wind power will make a much smaller

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[16] See OPA (2007, section 3) for an explanation of this methodology. The resulting price per MWh of electricity which, if paid over the life of the plant would fully cover all capital and operating costs, is called the 'Levelized Unit Electricity Cost', LUEC. See, also, US EIA (2012).

[17] Some argue that because of their minute-to-minute variability, wind and solar power displace not CCGT but simple cycle gas turbine generation which has higher emissions and operating costs and lower utilization leading to higher capital cost per MWh generated. They say that wind and solar should be credited with saving more generation cost and more emissions than are attributed to the CCGT plant. The counter-argument is that adding highly variable wind or solar facilities to a system increases the need for highly variable reserve power such as simple cycle gas turbines and that without the wind or solar facility the system would need less of the flexible simple cycle capacity and would operate it less. I believe that any reduction in gas capacity and consumption that arises from adding wind or solar to a system will take place with mid-merit CCGT plant, and that the effect on highly flexible simple-cycle gas turbines will, if anything, be to increase the required capacity and use of such facilities. If there is error in basing our analysis on CCGT, it is to overstate the cost savings and overstate the pollution and GHG reduction associated with adding wind and solar generation to the system.

contribution to system capacity because they cannot be relied on to generate at times of peak demand. Total annual savings from a 1 MW renewable installation of type j will be:

(1) $TAS_j = RCF_j *8760*GO + GFY*RCCj/GAF$.

For ease of comparison, we want to determine the savings from displaced power in terms of the cost per MWh of renewable power generated. We can do this by dividing the total annual savings in equation 1 by the MWh of renewable power generated, which will be the product of the renewable capacity factor multiplied by 8760 hours/year. Savings per MWh of renewable power will thus be:

(2) $SRMj = RCF_j *8760*GO/(RCF_j *8760) + GFY*RCCj/(GAF*RCF_j *8760)$

This simplifies to:

(3) $SRMj = GO + GFY*RCCj/(GAF*RCF_j *8760)$

To estimate the value of power displaced we use our historical analysis which showed that wind displaces power worth somewhat less than the average marginal cost while solar displaces power worth somewhat more. We therefore multiply GO by RVF_j, the renewable value factor derived above:

(4) $SRMj = GO*RVF_j + GFY*RCCj/(GAF*RCF_j *8760)$

We can use this cost model to evaluate the cost savings from displaced power from both base load renewable generation, such as biogas, biomass or some water power, which is available at all times and can be dispatched by the system operator, and intermittent renewable generation, which depends on the wind blowing or the sun shining and cannot be dispatched.

In 2007, the Ontario Power Authority estimated annual fixed costs for CCGT generating plant at about $100,000//MW/year in year 2007 $CDN (OPA, 2007, p. 10) or $109,000 in 2012 $CDN. Aegent Advisors (2012, Table 7, p. 30) estimated fixed annual costs for new CCGT plant at $153,000/MW/year in 2012 $CDN. The Ontario Power Authority (2011b, p. 7) reported that the Oakville Generating Station was to have a fixed cost, also called a Net Revenue Requirement of $17,277/month or $207,324/year. The Ministry of Energy reported that the average net revenue requirement for Ontario CCGT plants is $13,187/MW/ month or $158,244/MW/year.[18] We will use $180,000/MW/year for our fixed annual CCGT plant costs, GFY. See Table 5 for data and parameter values.

The financial costs of generating an additional MWh from an existing gas plant, GO, are the avoided variable costs, fuel and maintenance. Most of this cost depends on the price of natural gas. In 2007, the OPA (2007, p. 9) assumed a total variable cost of $58.75/MWh

[18] Email from Jennifer Kent to Press Gallery, 16 July, 2012 subject: “Gas plant background information.”

assuming a gas cost of $8/MMBTU.[19] However gas prices have dropped considerably since 2007 to less than $4/MMBTU[20] in 2012 and with shale gas coming on stream gas prices in Ontario are expected to remain at these levels for the foreseeable future. Assuming a heat rate of 7,000 BTU/kWh, a gas price of $4/MMBTU and an OM&A cost of $4/MWh, we have a marginal cost of (7*4+4=) $32/MWh. A worse case assumption of a heat rate of 7,500 and a gas price of $5/MWh yields (7.5*5+4=) $41.50/MWh. We use **$40/MWh** as the variable cost savings of gas power generation displaced by intermittent renewables, GO. If the price of gas rose to $8/MMBTU, our variable cost savings would reach $60/MWh.

Table 5 Cost Model Parameters, Values, Definitions

Parameter	Value	Definition
GFY	180,000	gas fixed cost: $/year per MW capacity
GO	40.00	gas operation cost: $/MWh
RCCs	0.40	solar capacity credit MW per MW
RCCw	0.14	wind capacity credit MW per MW
RCCb	0.85	biogas, biomass capacity credit MW per MW
RCFs	0.14	solar capacity factor
RCFw	0.295	wind capacity factor
RVFs	1.10	solar value factor
RVFw	0.95	wind value factor
RCFb	0.85	biomass capacity factor
GCF	0.5	gas capacity factor for 4380 hrs/yr
GAF	0.95	gas availability factor

Source: see text. AffordRenew Research Data 2012 'GasCostReplace Model'. 25 Feb 2013 calc.

We are now in a position to estimate the cost savings from displaced generation for both baseload and intermittent generation using the steady-state model.

Dispatchable renewables such as biogas, biomass or some hydroelectric facilities would displace new gas generation plants. We follow industry assumptions that a biomass plant would have a capacity utilization rate around 85%, so RCF_b would be 0.85. (Aegent, 2012, Table 1, p. 23.) We assume that its capacity credit would be higher than average annual availability at 90% of nameplate capacity, so $RCC_b = 0.9$. This yields savings for displaced power shown in Table 6. A new dispatchable renewable generation plant with an 85% capacity utilization and a 90% capacity credit would save $83 for each MWh generated.

Intermittent renewables would save operating costs and displace a smaller fraction of new gas generation plants but because they have low capacity factors, every MWh generated would save proportionally more capacity cost. See equation 4. Table 6 shows that every MWh generated from a wind farm would save $38 in gas operating costs (adjusted for the 5% debit)

[19] The OPA assumed a heat rate of 7000BTU/kWh and a fuel price of $8/MMBTU to calculate a fuel cost of $56/MWh for a combined cycle generation plant. Variable OM&A costs were assumed to be $2.75/MWh, for a total of $58.85/MWh.

[20] In June, 2012, the Union-Dawn gas price was $2.41/MMBTU, while in January, 2012 it was $3.09. During 2011, this price ranged from $4.87 in January down to $3.63 in December. NGX Union-Dawn Day-ahead Index http://www.ngx.com/marketdata/UDSPOT.html .

and $10.26 in capacity costs (because of the low 0.14 wind capacity credit) for a total of $48. In contrast, every MWh generated from a solar farm would save $44 in operating cost (adjusted for the 10% bonus) and $61.80 in gas capacity costs. This large capacity cost saving arises because solar does not generate much electricity but it tends to be on-peak, so each MWh gets a lot of credit for gas capacity displacement. Total solar costs savings are $106/MWh.

Table 6 Cost Saving from Displaced Generation					
($/MWh Generated)					
Generator Type	**Variable**	**Op Cost**	**Cap Cost**	**Total**	**Operation**
Biogas	SRMb	40.00	43.26	83.26	Dispatchable
Solar	SRMs	44.00	61.80	105.80	Intermittent
Wind	SRMw	38.00	10.26	48.26	Intermittent
Gas plant		40.00	41.10	81.10	Baseload, at 50% CF

25 Feb 2013 calculations, AffordRenew Data Calc 2013 ‘GasCostReplace Model’

5. Conclusions Regarding Affordability

All reasonable valuations of the harm caused by air emissions and greenhouse gas emissions from coal and gas-fired generating stations suggest that coal is dominated by gas which emits very little air pollution and only 40% of the greenhouse gases of coal generation. Using the DSS rather than the EPA health valuation increases the impetus to replace coal with gas. Ontario should therefore continue to move quickly to phase out coal and replace it with gas generation. Assuming that we phase out coal by 2014, renewable generation will displace gas generation. Table 7 shows the air pollution harm, the savings from displaced power and the total value of renewable generation assuming $25 and $100/tonne values for GHG. We estimate that we should be prepared to pay from $95Wh to $130 for dispatchable renewable power depending on the pollution and GHG values. We should be prepared to pay $60 to $95/MWh for wind power. We should be prepared to pay $117 to $152/MWh for solar power. If future gas operating costs were $60/MWh rather than $40 in 2012 $CDN, the subtotals and totals in Table 7 would all increase by $20/MWh.

Table 7 Value of Renewable Generation for Displacing Gas Generation ($/MWh generated)			
	Biogas	**Wind**	**Solar**
Air pollution harm (Table 3) (EPA or DSS)	1.56 to 6.76	1.56 to 6.76	1.56 to 6.76
Savings from displaced generation (Table 6)	83	48	106
Subtotal	85 to 90	50 to 55	107 to 113
Total with GHG at $25 or $100 /tonne	95 to 130	60 to 95	117 to 152

25 Feb 2013 calculations, AffordRenew Data Calc 2013 ‘GasCostReplace Model’

These prices are well below the prices that Ontario has paid for some baseload renewables and wind power and a small fraction of the prices paid for solar power. We provide a more detailed analysis of the implications of greenhouse gas values in the next section where we discuss the Feed-in Tariff provisions of the *Green Energy and Green Economy Act, 2009.*

6. *Assessment of Ontario's Green Energy and Green Economy Act, 2009*

On May 14, 2009, Ontario enacted the *Green Energy and Green Economy Act*.[21] That *Act* provides for a Feed-in-Tariff (FIT) that would offer fixed prices per kWh of electricity for green or renewable energy. The Ontario Power Authority was empowered to contract to purchase electricity from FIT projects at the specified prices for a 20-year period with some inflation adjustment.[22] The price depended on the technology, with prices as low as 10.3 cents/kWh for large landfill gas generation, 12.2 cents for large waterpower generation and 13.5 cents for onshore wind generation, and as high as 44.3 cents for large ground-mounted solar and 80.2 cents for small rooftop solar. (Ontario Ministry of Energy, 2012, Appendix 4.) The FIT program was designed to encourage the rapid deployment of a large amount of renewable power relying on various technologies, so the prices were set to be profitable for developers. In 2012 some prices were reduced. (Ontario Ministry of Energy, 2012, Appendix 4, p. 27.) See Table 8 for 2009 and 2012 prices converted from cents/kWh to $/MWh. Biomass and biogas projects receive the FIT price plus an annual escalation equal to 50% of the increase in the CPI. Wind and water power receive 20% escalation and solar receives no escalation. The FIT program attracted many projects during the first three years after the *GEA* came into force. By the spring of 2012, it was expected that FIT contracts would lead to increased capacity amounting to 2850 MW of wind, 2396 MW of solar and 50 MW of biomass.[23]

Table 8 Feed-In Tariff Prices and Implications

Renewable Fuel Source and Size	2009 Prices	Implied CO2 Value	2012 Prices	Implied CO2 Value
	$/MWh	$/tonne	$/MWh	$/tonne
Biomass <10 MW	138	104	138	104
Landfill gas >10MW	103	23	103	23
Biogas farm < 100 kW	195	235	195	235
Biogas > 10 MW	104	25	104	25
Water 10 to 50 MW	122	52	122	52
Onshore Wind	135	169	115	125
Rooftop Solar < 10 kW	802	1421	549	887
Rooftop Solar > 500 kW	539	866	487	756
Ground Solar <10 kW	642	1084	445	668
Ground Solar 10 to 500 kW	443	663	388	547
Ground Solar 0.5 to 5 MW	443	663	347	461
CO2 value calculated as (FIT price*escalation adjustment – displaced generation savings (Table 6) – air pollution harm (Table 7))/0.395 .				

FIT rates from the Ontario Ministry of Energy (2012, Appendix 4: Price Schedule) converted to $/MWh. CO2 value from AffordRenew Data Calc 2013, 25 February, 2013.

[21] See: http://www.e-laws.gov.on.ca/html/source/statutes/english/2009/elaws_src_s09012_e.htm .
[22] FIT Rules Version 1.5.1, October, 2011, sections 6.3, 7.1, 7.2.
http://fit.powerauthority.on.ca/sites/default/files/FIT%20Rules%20Version%201%205%201_Program%20Review.pdf .
[23] Bruce Sharpe, Aegent Energy Advisors, 2012, "Ontario Electricity Price Increase Forecast December 2011 to December 2016," submission to the Ontario Energy Board, 21 March, 2012, OEB files EB-2010-0377, 0378, 0379; EB-2011-0043 and 0004, Table 1, p. 23, annual capacity additions 2012-2016.

We argued above that the health and environmental effects of coal power were sufficiently great that Ontario is justified in moving ahead to eliminate coal-fired generation, at least in Southern Ontario, by 2014 and replacing it with gas-fired generation. What does our analysis say about the merits of purchasing renewable power at prices set out in the FIT tariffs? The bottom line in Table 7 above shows the prices that we can justify by the cost of power saved plus the environmental and health harm avoided. Many of the prices in Table 8 are above even the highest values in Table 7. We regard those prices as unaffordable, particularly the solar prices and farm biogas prices which are far more than the affordable prices.

Another way to analyze the FIT is to accept the FIT prices and to determine what value we would have to place on reducing CO2 emissions in order to justify those prices, given our cost of baseload gas generation in Table 6 and our value of health harm caused by air pollution emissions, summarized in Table 7. If we subtract the displaced gas generation cost and health harm from the FIT price adjusted for inflation we get the premium paid per MWh for CO2 reduction.[24] Dividing that premium by 0.395 gives us the premium paid per tonne of CO2 reduced when we displace baseload gas by baseload renewables. The results are shown in the two columns of Table 8 labelled CO2 value. Small biomass projects are affordable if we believe that we should spend \$104/tonne to reduce CO2 emissions. Farm biogas projects imply a CO2 value of \$235/tonne which is far greater than even the Stern values of CO2 and greater than any politician or government has seriously discussed for GHG policy in Canada. The only FIT prices that imply a CO2 value less than \$100/tonne are for landfill gas, non-farm biogas and water projects. These comparisons use the EPA pollution values. Using the DSS values would reduce the implied cost/tonne by \$13/tonne of CO2. Only large landfill and biogas prices are justifiable if we value CO2 at \$25/tonne.

To analyze intermittent solar and wind generation, we compare the FIT prices to the cost savings from displaced gas generation from Table 6, and the health harm from gas emissions, \$1.56/MWh. In both cases we allow for the gas capacity reduction that would be enabled by the intermittent capacity. Rooftop solar projects are affordable if we believe that we should spend over \$800/tonne to reduce CO2 emissions (2009 prices) or \$700/tonne (2012 prices). All of the solar prices imply CO2 values more than ten times greater than any politician or government has seriously discussed for GHG policy in Canada. The solar component of the FIT program cannot be justified by the highest reasonable environmental, health or global warming argument. Even wind power implies a CO2 value of \$169 in 2009 and \$125 in 2012, well above any plausible value. If we use the DSS health damages from intermittent gas, we would subtract about \$13 from the implied value of CO2 throughout Table 8. If we add \$20/MWh to the anticipated cost of gas generation we would subtract about \$50/tonne from all the values in Table 8. Both adjustments together still leave the implied cost/tonne of CO2 at unreasonably high levels for solar, while wind becomes affordable. So, wind is affordable only under worst-case gas cost assumptions, worst case health assumptions and CO2 values over \$50/tonne.

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[24] We assume future CPI inflation at 2%/year for 20 years. For solar projects, which receive no inflation adjustment, the real price becomes 1/1.02 as great each year. The average price over 20 years is the FIT price multiplied by $(1/20)*\sum 1/1.02^t = 0.834$. Wind receives a 20% escalation yielding an adjustment of 0.864, while biogas and hydro receive 50% escalation for an adjustment of 0.94.

In 2012, large solar projects are paid three to five times as much as wind projects. This is wildly disproportionate to the value bonus and capacity credit that solar's daytime generation implies for the value of its power, shown in Table 6.[25] For a given expenditure on intermittent renewable energy we could achieve three times the CO_2 reduction by investing in wind as by investing in solar electricity projects. Solar projects are absolutely dominated by wind projects.

There was a federal subsidy of one cent/kWh for renewable power projects approved between 2007 and 2011 that applied to many wind power projects.[26] This increased the implied value of CO_2 necessary to justify qualifying projects by $10/MWh of power generated, or $25/tonne of CO_2. In addition, businesses may take advantage of accelerated depreciation on qualifying renewable energy generation equipment, again increasing the implicit subsidy.[27]
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The finding that solar power is hopelessly uneconomical today is not unique to Ontario. Borenstein (2012 p. 85) shows that photovoltaic solar power is uneconomic in Sacramento, California, costing from 32 cents to 47 cents/kWh. After adjusting for solar's daytime advantage and savings in line losses from local generation, he finds that rooftop solar would only make economic sense for displacing gas in California, where electricity prices are higher than in Ontario, if CO_2 was worth $316/ton, (p. 86). Sacramento is sunnier than Toronto so solar power is inherently worse here. He concludes that a large commercial installation would be more economical, but would still require an imputed CO_2 price greater than $100/ton.

Bullfrog Power sells green (wind and hydro) electricity in Ontario for a premium of 3 cents/kWh over the standard price of electricity. Since the electricity portion of a residential consumer's bill is about 8 cents/kWh in 2012, the total cost of power (not transmission, distribution or other charges) for a residential Ontario customer of Bullfrog Power is about 11 cents/kWh or $110/MWh, slightly below the 2012 FIT price for large onshore wind. Assuming that Bullfrog Power's share of the residential market is less than 10%, this means that less than 10% of the population is prepared to pay the current FIT price individually to substitute wind power for Ontario's current mix of nuclear, hydro, gas and coal. The percentage of the population prepared to pay the current FIT price for solar power, 34.7 cents/KWh for large ground installations, must be far smaller.

6.1. What about Job Creation?

Like many government programs, the *Green Energy Act* has been touted as creating thousands of jobs in Ontario. Most government announcements about the *GEA* and the FIT have mentioned job creation.[28] This claim is exaggerated.[29] The basic economics of government 'job

[25] Some argue that rooftop solar saves transmission and distribution lossses and capacity costs. But T&D losses represent only a few % of the cost of power and the network capacity saving from micro solar is unproven.
[26] NRCan, 2008, "EcoACTION Terms and Conditions," http://www.nrcan.gc.ca/ecoaction/power/conditions/6539 .
[27] Canada Revenue Agency, 2012, "Accelerated Capital Cost Allowance for Efficient and Renewable Energy Generation Equipment (Class 43.1)," http://oee.nrcan.gc.ca/industrial/financial-assistance/details.cfm?max=10&pageId=1&categoryID=1&regionalDeliveryId=all&programTypes=4&keywords=&ID=977&attr=24 .
[28] The Ministry of Energy's home page for the *GEA* in August, 2012, mentions job creation in the first sentence: http://www.energy.gov.on.ca/en/green-energy-act/ . The headlines in the Ministry's news site are replete with claims of job creation. See: http://www.energy.gov.on.ca/en/news/ .
[29] See Barrow and Serletis (2010, ch. 12, p. 342).

creation' can be seen in the following simple example. Suppose that the government spends $1 million on a green energy project subsidized by the *GEA*. The Minister can attend a ground-breaking for a factory that hires workers to produce inputs to the green energy project. Workers in that factory know that their jobs would not exist without the government's expenditure of $1 million. However the $1 million must be recouped by the government through taxes or, in the case of the *GEA*, higher electricity prices. When the government collects $1 million from electricity consumers to repay the investment, electricity consumers will have $1 million less to spend or save. They will reduce their discretionary spending on food, clothing, retail, and their savings or whatever they cut back when they have less money. The reduction in spending on these items must destroy jobs as surely as spending $1 million creates them. Waitstaff, clerks, production workers will be laid off. Businesses that use large amounts of electricity will respond to their higher electricity costs by cutting other costs, laying off workers, retrenching and/or raising prices. Indeed, the government has explicitly recognized the job destruction effect of higher electricity prices with its announcement on June 12, 2012 of an electricity price break for Ontario companies that create new jobs and invest in Ontario.[30] To a first approximation, the job losses from collecting $1 million in higher taxes or higher electricity prices will cancel out the job creation from spending that $1 million in the first place.[31] The *GEA* may create jobs in the first few years but it will destroy a similar number of jobs over the 20 years when we pay the higher electricity prices.

The fact is that government spending does not generally create jobs; it moves them around in time and space. If the government spends $1 million now and repays it over the next 20 years using higher taxes or higher electricity prices, it has moved jobs from the future to the present. It moves jobs from restaurants, stores and producers of many goods to the green energy sector. If the spending occurs during a recession and the taxing or higher prices occurs during boom times, this can increase employment during the recession and reduce it during the boom, a good thing. But there is nothing in the *GEA* to ensure that the spending occurs during recession or that the higher prices occur only during economic prosperity. Similar arguments are made by Trebilcock and Wilson (2010, p. 10), citing Danish and German studies that document the economic negatives of subsidizing expensive renewable power.

A study by the Brookings Institution reviews the 'jobs' benefits of US clean energy programs and reaches similar conclusions. (Brookings, 2012, pp. 10-12.) "The essential reality of international trade is that it changes the *composition* of jobs, not the total number, at least in the long run. . . . [A] net gain in employment from subsidizing clean-energy exporters may well prove elusive." (p. 11.) "Programs designed to promote the sustained commercialization of new technologies are seldom effectively counter-cyclical, either." (p. 12.) This result is confirmed by a recent empirical study of Ontario's *GEA* which finds that while the *GEA* can stimulate employment in green sectors of the economy, there is a reduction in employment in other sectors leading to a net reduction in employment overall. (Bohringer et al., 2012.)

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[30] Ontario Ministry of Energy and Infrastructure, 12 June, 2012, Press Release "Industrial Electricity Incentive Program," at: http://news.ontario.ca/mei/en/2012/06/industrial-electricity-incentive-program.html . Qualifying companies can sign long term contracts with the Ontario Power Authority for reduced electricity prices.

[31] To the extent that consumers would save a portion of their income, the tax reduces consumption by less than 100% of the tax amount because savings are reduced as well. In these cases, the job destruction from the taxes in the short run will be less than 1 for 1.

In short, *GEA* 'job creation' is little different from any fiscal stimulus now that will be paid back through taxes over the next 20 years. Both economic theory and decades of experience suggest that any accounting of 'job creation' must look at both creation and destruction to determine the net effect of the program. A useful starting assumption is that government spending does not affect long run employment. If green energy 'creates more jobs' than fossil energy generation, that is because it is more costly per MWh than fossil energy generation and thus we are getting less value for our money. We may create more jobs but we reduce overall output, destroy more jobs later and thus reduce our standard of living. (Borenstein, 2012, p. 84.) This does not seem like an attractive goal.

6.2. What about creating Green Industry?

Government publicity regarding the *GEA* has emphasized green jobs and the development of a green economy.[32] It has been suggested that an important goal of the *GEA* is to make Ontario a leader in green electricity and to create an industry that will make Ontario prosper in the future. The Feed-in-Tariff pays far more for some green power technologies (solar) than for others, indicating a clear desire to encourage those specific technologies. (See Table 8.) Is sustainable industry a realistic outcome of the *GEA* subsidies for green power and of the other government subsidies for this industry?

Borenstein (2012, p. 84) is sceptical: "[I]t seems hard to argue the general case that government policymakers are better at identifying emerging business opportunities than the private sector." There are few examples of government support of an industry that was uneconomic on its own that grew up to be profitable without ongoing government support. An alternative argument is that there are 'network externalities' to the green energy industry and that government support will allow the industry to grow to the point where one Ontario firm feeds advantage to another Ontario firm, providing intellectual property, experience or even trained workers such that the industry as a whole is more prosperous. This assumes that there are substantial externalities among firms in this industry, as there arguably are for tech firms in Silicon Valley or Waterloo or Kanata, and that those externalities will be captured more by Ontario firms than by out-of-province firms. While this is a popular argument in favour of industry subsidies, Borenstein (2012, p. 84) says that "evidence supporting it is scarce." He notes that Spain subsidized enormous investments in solar power; that in 2008 Spain was the largest market for solar products in the world, but that when Spain reduced subsidies in 2009 new installations disappeared along with the domestic industry. Germany has continued to invest in solar generation, but while 77 percent of installed solar panels were made in Germany in 2008, that share dropped to 27 percent in 2010 as China and Japan expanded their manufacturing activity.[33]

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[32] The Ontario Ministry of Energy website in the summer of 2012 states: "Ontario's Green Energy Act (*GEA*) was created to expand renewable energy generation, encourage energy conservation and promote the creation of clean energy jobs." The 'Backgounder' issued by the Ministry of Energy and Infrastructure (as it then was) on February 23, 2009, carried the headline: "Green Energy Act: A Bold Plan for a Green Economy," and claims that the *Act* would create 50,000 jobs in its first three years. The Two-Year Review of the *GEA* asserts that the *Act* has "helped launch a clean energy manufacturing base, creating new jobs and cleaner air." Ministry of Energy, 2012, p. 1.

[33] Data from Roney (2011).

Morris et al. (2012, p. 4) note that the US developed a technology policy in the 1970s in response to a decline in US manufacturing and the rise of Japanese manufacturing accompanied by industrial policies of the Japanese Ministry of International Trade and Industry. Alternate fuel programs developed in the 1970s in response to the OPEC oil shock spent nearly $100 billion on synthetic fuels and on the breeder reactor without ever producing any commercial output. (Morris et al., 2012, p. 5, 12.) A study by the National Academy of Sciences of fossil fuel programs found that the benefits were approximately equal to their costs, while investments in coal liquefaction ran into high costs and low net benefits. (Morris et al., 2012, p. 5, National Academy of Sciences, 2001, Chapter 4.)

In addition, the desire to identify technological winners may begin with unbiased decision-making in mind, but governments are invariably political. The prospect of subsidies for green energy will bring out lobbyists demanding a share for their firm/industry/sector. Elected members will want a project in their riding. The program that emerges will usually include many projects that have nothing to do with the initial lofty goals and much more to do with buying votes. Morris et al. (2012, p. 13) report on the US Congress' deliberation on ways to moderate the use of oil in the 1970s, observing that ". . .the prospect of federal subsidies and dispensations had clearly invited a feeding frenzy by interest groups, many of whom would keep circling Washington for decades." They conclude that the US Congress "seldom sticks to sponsoring and sheltering only genuine industrial winners, green or otherwise." The same forces must operate in Canada with similar results.

Morris et al. (2012, p. 9) also reject the notion that trying to become a leader in a particular technology will necessarily improve national welfare. Companies may gain from becoming leaders in their field. Countries do not, because an increase in the success of one export sector generally leads to reduced success in other export sectors, a dynamic that is currently visible in the tension between Alberta energy exports and Ontario manufacturing exports. Subsidizing an industry to be a 'first mover' does not necessarily confer the advantage that is often claimed. Private firms already have incentives to develop profitable technologies and pursue growth opportunities. Moreover it is not obvious that being first is always an advantage. Sony introduced the Betamax video cassette recorder in 1975, JVC quickly followed with an incompatible VHS cassett recorder and ultimately the VHS format drove Sony's Betamax from the market. (Besen and Farrell, 1994.) The Blackberry was good and first but is struggling to survive an onslaught by more nimble successors.[34]

Another problem with Ontario's green energy subsidies creating a leading manufacturing industry in Ontario is that other jurisdictions have the same job-creation goals as Ontario. The *GEA* requires a certain percentage of domestic Ontario content in a project before it is eligible for funding,[35] in order to ensure that jobs are created in Ontario. However many US states and

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[34] Betamax and Blackberry are network goods which have a special competitive dynamic, but Besen and Farrell (1994, p. 118) note that other goods that involve economies of scale or learning by doing exhibit similar competitive properties.

[35] FIT Rules Version 1.5.1, October, 2011, section 6.4, (p. 16) provide that wind projects must have 25% or 50% domestic Ontario content depending on the commercial operation date, while solar projects must have 40% to 60% domestic content depending on size and date.
http://fit.powerauthority.on.ca/sites/default/files/FIT%20Rules%20Version%201%205%201_Program%20Review.pdf .

other jurisdictions that subsidize renewable energy have similar domestic content requirements. This seriously limits the prospects for Ontario manufacturing firms exporting components to the US or elsewhere. Moreover Japan and the EU filed complaints with the World Trade Organization and on December 19, 2012 a WTO panel reported that the domestic content requirements violate international trade law.[36] We risk creating a small industry that will have limited access to world markets and that will wither when our willingness to pay high prices for renewable power wanes.

It has been suggested that Ontario's subsidy for wind and solar electricity will spur technological progress, bringing down the cost of this technology to the point where it can compete on its own. Other jurisdictions have made similar arguments. To assess this argument we must look at Ontario's fraction of world support for PV solar. If our spending is half of world spending, we should expect to have a significant effect; if we are 10% or less of world spending, we should expect little or no effect on the pace of development. Canada's increase in wind generation capacity in 2011 represented 3.09% of the world increase.[37] Ontario's planned wind generation capacity investment from 2012 through 2016 is, on an average annual basis, 2.7% of the world net increase in 2011.[38] Ontario's planned investment in solar from 2012 through 2016 is 4,896MW[39] while the world increase in 2010 was 16,629 MW, so Ontario's average annual addition over these five years represents 5.89% of the world addition in 2010. With such a small share of the installation of both technologies, Ontario should have little effect on the pace of development of these technologies. Accelerating the pace of technological development seems to be a poor argument for Ontario spending money on expensive solar power today.

Trebilcock and Wilson (2010, p. 6) also note that when governments promote particular "green" technologies, they will likely focus on the short run and favour existing technology that will yield some local jobs or profits with no assurance that this technology is actually environmentally sound or the best technology in the long run. They point to the US subsidy for corn ethanol as a supposedly green policy for which the environmental benefits are small to negative because of the pollution arising from raising the corn and refining the corn to ethanol. Sold as environmental policy, the ethanol subsidy is in fact a farm subsidy in disguise.

Governments in both Canada and the US have invested large amounts of money promoting nuclear power for electricity generation. One could view this support as successful in that a considerable amount of power has been generated by nuclear plants and we have not

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[36] WTO, Dispute Settlement: Dispute DS412, "Canada-Certain Measures Affecting the Renewable Energy Generation Sector" http://www.wto.org/english/tratop_e/dispu_e/cases_e/ds412_e.htm .

[37] Canada's installed wind capacity increased from 4,008 MW in 2010 to 5,265 MW in 2011, while the world installed capacity increased by 40,714 MW. (Earth Policy Institute, "Cumulative Installed Wind Power Capacity in Top Ten countries and the World, 1980-2011." http://www.earth-policy.org/data_center/C23 .)

38 Bruce Sharpe, Aegent Energy Advisors, 2012, "Ontario Electricity Price Increase Forecast December 2011 to December 2016," submission to the Ontario Energy Board, 21 March, 2012, OEB files EB-2010-0377, 0378, 0379; EB-2011-0043 and 0004, Table 1, pp. 23, 25 for annual capacity additions 2012-2016 under FIT and the Samsung contracts. Add 2011 plus 2012-2016 FIT plus 2014-16 Samsung =6,107, divide by 6 = 1018MW/year. This is 2.5% of the world addition to wind capacity in 2011.

[39] Ibid. 2012-16 = 2396MW new capacity divided by 5 = 479MW/year annual average. This is 5.1378% of world addition in 2010.

suffered disasters of the sort that occurred in Ukraine and in Japan, although the Three-Mile Island accident in Harrisburg was worrisome. On the other hand, in both countries nuclear power has proven to be expensive, bankrupting some US utilities and leaving Ontario with a large debt to be paid off. The reliability of nuclear plants has been mixed. Today, there is vigorous debate over the wisdom of continuing to subsidize our nuclear technology despite the lower cost of natural gas.

In conclusion, I have found no compelling evidence that government subsidies for renewable technologies will in general create industries that are successful in the long run.

7. Conclusions

Economic theory and common sense suggest that we should compare the cost of renewable power with the cost savings from displaced fossil generation plus the avoided harm from reduced emissions of air pollution and greenhouse gases. While this requires estimating the value of the harm from air pollution and from greenhouse gases, many studies over many years have produced defensible estimates of a reasonable range of these values.

Comparing the generation cost and the air pollution and greenhouse gas harm from coal and natural gas generation in Ontario suggests that natural gas has lower total social costs unless one attaches little value to the pollution and greenhouse gases. This means that replacing coal generation with natural gas generation is good policy for Ontario.

If we replace coal with gas, then the effect of renewable power is to displace natural gas generation and to reduce its emissions or to generate excess baseload power.

Some renewable generation sources, such as biogas, biomass and some hydroelectric sites are dispatchable and can operate at any time. These sources displace baseload gas generation and justify prices of $95 to $130/MWh in Ontario. Some Ontario Feed-in-Tariff prices are in this range; others are far higher than this.

Wind and solar power are not dispatchable because they generate only when the wind blows or the sun shines. The value of their power depends on system marginal costs when they generate. Recent Ontario data suggest that the cost of power displaced by wind is on average 5% below the average system marginal costs while the power displaced by solar is on average 10% above the average system marginal cost. Wind power displaces only 0.14 MW of gas capacity for every MW of wind capacity, while one MW of solar power displaces 0.4 MW. Timing matters in evaluating intermittent power sources.

Wind power justifies prices of $60 to $95/MWh, well below the 2012 Ontario FIT price of $115. Wind can be justified only by the most pessimistic view of health harm and very high expected gas prices or a value of greenhouse gases exceeding $100/tonne.

Solar power justifies prices of $117 to $152/MWh, which is more than wind because solar power is concentrated in the daytime when demand and spot prices are higher. Still, these values are a fraction of the 2012 Ontario FIT prices of $347 to $549/MWh. Solar can be justified only by the most pessimistic view of health harm, very high expected gas prices, and a value of greenhouse gases more than $400/tonne. This is not reasonable. We could create far greater environmental improvement for the same cost with wind power or conservation programs.

Finally, there is no theoretical or empirical basis for believing that government subsidies for any particular green power technology will give Ontario or Canada a long-term economic advantage. The track record of governments in promoting specific technologies is poor and provides no basis for believing that technology-specific green power initiatives will yield benefits that exceed their costs. Furthermore green energy projects are no better than other publicly funded projects at short-run job creation. We should think of green energy projects not as creating jobs but as moving jobs from one sector of the economy to another and from the future to the present. Any claims of 'job creation' should include estimates of jobs destroyed by the higher prices or taxes that subsidize the green power.

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