The Economics of Renewable Energy Technologies in the Context of Australia

*By Anthony D. Owen**

Introduction

Despite the apparent environmental attractiveness of renewable energy, excluding hydropower its market penetration has been limited to date relative to past projections. This failure has not, however, been due to any failure in its anticipated reduction in cost. For all major renewable technologies, future cost projections for successive generations have either agreed with previous projections or have been even more optimistic. Their lack of commercial success has in large part been due to declining fossil fuel prices for conventional technologies, combined with energy market reforms that have tended (at least in the short run) to return substantial cost savings for utilities utilizing these technologies. Global environmental concerns over emissions of carbon dioxide, however, are likely to exert significant pressure on governments in industrialized countries to encourage power generation by means of more environmentally benign technologies and micro-power supply sources.

It is widely recognised that one of the most important barriers to the large-scale exploitation of renewable energy technologies is related to their relatively high initial capital cost as compared with conventional generation, transmission and distribution networks[1]. The latter have often benefited from loans at favourable interest rates with extended repayment periods, whereas renewable energy technologies (particularly those best suited to distributed rather than centralised use) must raise capital privately at prevailing market rates. Although capital costs have decreased with market penetration, technological development, and economies of scale, and running costs are generally relatively low, it is estimated that, under current market conditions, most renewable technologies will not be able to compete with conventional ones before the middle of the current century. However, these financial viability comparisons are based upon costs that generally ignore environmental externalities associated with the combustion of fossil fuels. Results from the ExternE project conducted recently in the European Union (1998) show that external cost estimates may significantly change the current perception about the economic attractiveness of different energy sources and has stimulated a vigorous debate on the potential exploitation of the resulting figures in energy decision making.

This article specifically addresses externalities associated with electric power generation, arising from both renewable and non-renewable sources. It focuses on emissions of carbon dioxide (CO_2) and their imputed environmental costs since, being global in nature, such costs can be considered to be uniform per unit of emissions across all countries (even though ultimately the costs/benefits to individual countries resulting from the accumulation of such emissions may vary greatly). The data relate to Australian conditions, but the conclusions should have must broader implications.

Environmental Externalities in Power Generation

Externalities are defined as benefits or costs generated as an unintended by-product of an economic activity, that do not accrue to the parties involved in the activity. Environmental externalities are benefits or costs that manifest themselves through changes in the physical-biological environment.

Pollution emitted by fossil fuel fired power plants during power generation may result in harm to both people and the environment. In addition upstream and downstream externalities, associated with securing fuel and waste disposal respectively, are generally not included in a utility's costs. To the extent that the electricity industry does not pay these environmental costs, or does not compensate people for harm done to them, consumers do not face the full cost of electricity they purchase and thus energy resources will not be allocated efficiently.

The two principal methods for assessing the value of externalities are calculation of damage costs and calculation of control (or mitigation) costs.

Estimation of damage costs involves assessment of four factors: emission quantities, emission concentrations at receptor points or areas, the physical effect of those concentrations on that point, and the economic value of those effects in terms of willingness to pay to avoid damage arising from the emissions. All four factors are subject to significant uncertainty.

Control costs are generally used as a surrogate for damage costs as they are easier to estimate. The implicit assumption in control costing is that society controls pollution until the benefits of additional controls would be outweighed by the costs. Generally control costs are viewed as a poor substitute for estimating damage costs, although when derived as a function of a market in emission permits, at least in theory, they yield a minimum cost solution for compliance in reaching a set target (although the actual cost of achieving this target will only be known ex poste).

For simplicity, externalities of fossil fuel combustion can be divided into three broad categories:

- hidden costs borne by governments, including tax subsidies, direct energy industry subsidies, and support of research and development costs;
- costs of the damage caused to health and the environment by emissions other than CO_2; and
- the costs of global warming attributable to CO_2 emissions.

The second category is costs due to emissions that cause damage to the environment or to people. These include a wide variety of effects, including damage from acid rain and health damage from oxides of sulphur and nitrogen from coal fired power stations. Other costs in this category are power industry accidents, whether they occur in coal mines, on offshore oil or gas rigs, in nuclear plant, on wind farms, or at hydro plants.

The third category refers to external costs due to greenhouse gas emissions from electricity generating facilities that

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[1] See footnotes at end of text.

cause global warming with all its associated effects. This is a very contentious area, and the range of estimates for the possible economic implications of global warming is huge. Costs associated with climate change, flooding, changes in agriculture patterns and other effects all need to be taken into account. However, there is a lot of uncertainty about the magnitude of such costs, since the ultimate physical impact of enhanced levels of global warming has yet to be determined with precision. Thus, deriving monetary values on this basis of limited knowledge is, at present, an imprecise exercise.

Energy Subsidies

Support that lowers the cost of power generation can take many forms, including support to the use of inputs (e.g., water, fuels, etc.), public financing at interest rates below the market value, tax relief on corporate income, lump sum support to fixed capital investment in research and development, etc. Examples include the exemption of government-owned electricity generators from corporate income tax payments (increasing the relative after tax rate of return compared with electricity generation by private enterprises) or the provision of loans at interest rates well below market rates, or over repayment periods in excess of market terms (which favour capital intensive energy forms, such as nuclear and coal, and encourages over-investment).

It is not the purpose of this paper to examine the full range and costs associated with energy subsidies world-wide, but their adverse impact on global emissions of CO_2 has been, and remains, significant (see Mountford (2000) and Schneider and Saunders(2001)).

Emissions Other Than CO_2

Among the major external impacts attributed to electricity generation are those caused by air pollutants, such as particulates, sulfur dioxide (SO_2) and nitrogen oxide (NO_x). Table 1 gives emissions of these, and other, pollutants from a typical 2000 MW fossil-fuel power station. Emissions of SO_2 and NO_x have long range transboundary effects, which makes calculation of damages an imprecise exercise. Such calculations require measurement to be based upon the unique link between fuel composition, characteristics of the power unit, and features of the receptor areas. Thus estimated damage costs vary widely across countries. For example, for member countries of the European Union, damage costs arising from power plant emissions of SO_2 range from Euro 1,027-1,486/tonne for Finland[2] to Euro 11,388-12,141/tonne for Belgium.

The External Damage Costs of Emissions of Carbon Dioxide

Table 2 gives life-cycle CO_2 emissions (in tonnes per GWh) of the major forms of electric power generation. From this table it is evident that CO_2 emissions from coal and oil-based technologies far exceed those of the “renewables” and are twice those of gas.

The European Commission (1998) has calculated an indicative 95% confidence interval for damage costs arising from CO_2 emissions (from all sources), with limits of Euro 3.8/tonne CO_2 and Euro 139/tonne CO_2. “Base case” estimates were Euro 18/tonne CO_2 and Euro 46/tonne CO_2 (or approximately A$33/tonne and A$85/tonne respectively at current exchange rates).

These cost bands are relatively wide, and the corresponding “damage” per MWh is, therefore, of a corresponding dimension. Combining these “base case” cost estimates with the data contained in Table 2 yields base case “damages”, from CO_2 emissions alone, from conventional coal fired plant in the range of A$32/MWh up to A$82/MWh

Table 3 gives current costs (in A$/MWh) of electricity generation by both renewable and non-renewable technologies. From this table it is clear that, depending on the value within the range that is chosen, coal may either lose a major cost advantage or be rendered financially non-viable with respect to some renewable technologies (and in particular wind and biomass) if CO_2 emission damages alone were to be internalised into production costs. With respect to gas, coal’s current (small) cost advantage would be lost entirely.

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Table 1
Emissions from Typical 2000 MW Fossil-fuel Power Station

Pollutant	Conventional Coal (tonnes per year)	Conventional Oil (tonnes per year)	Combined-cycle Gas (tonnes per year)
Carbon dioxide	11 million	9 million	6 million
Sulphur dioxide	150000	170000	Negligible
Nitrogen oxides	45000	32000	10000
Airborne particulates	7000	3000	Negligible
Carbon monoxide	2500	3600	270
Hydrocarbons	750	260	180
Hydrochloric acid	5000-20000	Negligible	Negligible
Solid waste and ash	840000	Negligible	Negligible
Ionising radiation (Bq)	10^{11}	10^{9}	10^{12}
Trace elements		Depends on source	

Abbreviation: Bq Becquerel
Source: IEE (1993)

Table 2
CO_2 Emissions from Different Electricity Generation Technologies

Technology	CO_2 Emissions (tonnes per GWh) Fuel Extraction	Construction	Operation	Total
Coal-fired (Con)	1	1	962	964
AFBC	1	1	961	963
IGCC	1	1	748	751
Oil-fired	-	-	726	726
Gas-fired	-	-	484	484
OTEC	N/A	4	300	304
Geothermal	<1	1	56	57
Small hydro	N/A	10	N/A	10
Nuclear	~2	1	5	8
Wind	N/A	7	N/A	7
Photovoltaics	N/A	5	N/A	5
Large hydro	N/A	4	N/A	4
Solar thermal	N/A	3	N/A	3
Wood (SH)	-1509	3	1346	-160

Abbreviations:

AFBC	Atmospheric Fluidised Bed Combustion
BWR	Boiling Water Reactor
Con	Conventional
IGCC	Integrated Gasification Combined Cycle
OTEC	Ocean Thermal Energy Conversion
SH	Sustainable Harvest

Source: IEA (1989)

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Although the majority of US State utility commissions currently take environmental externalities into consideration in their resource planning process, only seven have explicitly specified monetary externality values for designated air emissions from power plants. Such values form part of the utilities "Integrated Resource Planning" (IRP) process, and are not actually internalised into their power pricing structures. The values (all in 1992 dollars) are largely based upon "control" costs, with ranges reflecting differing ideas over the extent of such costs. For example, the Massachusetts figure is based upon the marginal cost of planting trees in order to sequester carbon. The Oregon range represents U.S. Department of Energy "low" and "high" estimates.

California	US$9/ton CO_2
Massachusetts	US$24/ton CO_2
Minnesota	US$5.99-13.60/ton CO_2
Nevada	US$24/ton CO_2
New York	US$8.6/ton CO_2
Oregon	US$10-40/ton CO_2
Wisconsin	US$15/ton CO_2

In a study incorporating three of these States, the U.S. Department of Energy (EIA, 1995) concluded that "The requirement to incorporate externalities in the resource planning process had negligible impacts on the planned resource mix of the utilities in each of the three States."

Making allowances for inflation since 1992, and adjusting the units of measurement, these figures would (roughly) correspond to the range derived by the EU. However, it should be emphasized that only external damage costs associated with emissions of CO_2 have been considered here. Those associated with other forms of environmental degradation must also be estimated in order to achieve a reasonable balance across the range of power generating technologies, both renewable and non-renewable.

Internalising the Externalities

The leading renewable energy technologies are characterised by relatively high initial capital costs per MW of installed capacity, but very low running costs. This structure can make renewable technologies financially unattractive compared with traditional fossil fuel derived power using traditional project evaluation techniques based upon the anticipated life of the electricity generating facility (say, 30 years). However, in terms of an economic/environmental evaluation, the relevant time frame should be set by the date at which all of the consequences attributable to the project had ceased to exist. In the context of CO_2 emissions from fossil fuel power stations this period could exceed 100 years. Further, it is likely that the value of emission reduction will continue to rise into the future given projected world population growth, economic growth, and the subsequent difficulties in meeting global climate change agreements. In this context, the rate of discount is crucial in assessing the relative cost and benefit streams of alternative energy technologies.

It has been argued that for intergenerational damages (i.e., damages caused by the actions of one generation that affect another generation) individual time preference is

Table 3
Cost of Renewable Energy Technologies – Current and Expected Trends (Australian 1998 dollars)

Energy Source	Technology	Cost $/MWh*	Expected trend	Comments
Coal	Coal-fired steam	30-40	Stable	
Gas		35-60	Small decrease	
Solar radiation	Solar hot water	40-70[1]	↓20% with increase in market size	Typical domestic system cost is $2000
	High temperature solar thermal	70-190	Longer term cost ↓ expected with mass production	
	Solar thermal electric	200-270	Cost may halve by 2010	
	Photovoltaics PV RAPS	300-500 350-600	↓ 50+% by 2010	
Wind	Wind turbine/generator Wind RAPS	90-120 150-400	↓ to 75% of current cost by 2005 ↓ 15 to 30% by 2010	Site (wind resource) variation is reason for the range in costs
Fuel wood	Boiler	70-110		
	Pyrolysis furnace	0.45-0.85/litre		Cost assumes biomass is provided at a cost of between $20 and $50 per tonne
Bagasse	Boiler (cogeneration)	40-50	Slight reduction	Also embedded generator network cost savings
	Gasification	30-100[2]	Energy costs expected to ↓ with ↑ in efficiency	
Various wastes	Boiler (cogeneration)			
	Gasifier/gas engine	80-200[2]	25% ↓ expected by 2010	
Suger, starch, cellulose	Hydrolysis/fermentation/distillation	$0.28-$0.69/litre	Competitive with oil by 2010	Worldwide the cost of production from sugar & starch has ↓ 50% over past 10 years
Organic wet waste	Biogas digestor/gas engine	30-200	↑ beyond 2005	Economics depend on negative cost of fuel and value of by-products
Landfill gas, Sewage gas	Gas Engine	55-90	No change to 2010	Most of resource recoverable at $65/MWh
Hydro	Hydro turbine/ generator Micro hydro RAPS	40-100 70-250	↑ as most attractive sites are used. Remain constant	Cost is very site specific
Geothermal hot dry rock	Heat exchanger/ turbine	90-130	Unknown	Speculative technology, costs are rough estimates. Cost also site dependent
Tides	Low head hydro turbine/generator	80-150	No change	Very site specific
Waves	Various devices/ generator	100-200[2]		

Source: DISR (1999)

* unit is MWh except where specified otherwise

1. Cost of delivered energy from the solar component of a solar hot water system. Calculation based on the installed capital cost differential between the solar unit and competing unit of $1500.

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irrelevant. It follows that a discount rate equal to the per capita growth rate is appropriate, which would probably lie between 1% and 3%. In addition, without assumptions regarding the preferences of future generations, adjusting future cost and benefit streams to reflect such changes would be a very subjective action. Nevertheless, benefits of CO_2 emission reductions are likely to increase (in real terms) over a significant part of the current century, given the long time lags inherent in the breakdown of CO_2 in the atmosphere.

Once monetary values have been derived to reflect the external costs of differing technologies, the next step is to devise a mechanism for "internalising" them into market prices. In theory, an energy tax would represent a relatively straightforward solution, although the practicalities of its imposition would be fairly complicated. The tax would be required to be imposed at differential rates, depending upon the total estimated damages resulting from the fuel in question. A simple carbon tax alone, for example, would not impose any cost on the nuclear power industry. The tax would also have to be imposed by all nations, to ensure that the competitiveness of their industries in global markets was not compromised. The resulting tax revenue would also have to be distributed in such a way that implicit energy subsidies were not introduced. Finally, the worst of any social impact of energy taxes on poorer sections of society would have to be offset to insure that the tax burden was not disproportionate in its incidence.

An alternative approach to the problem of reflecting external costs, and one that would possibly cause less economic disturbance, would be to introduce "environmental credits" for the uptake of renewable energy technologies. Examples are currently commonplace. However, such credits do not "internalise" the social costs of energy production but rather subsidise renewables. In addition, the taxpayer pays the subsidy and not the electricity consumer, thus rejecting the "polluter pays principle".

Conclusions

On the basis of CO_2-imposed externalities alone, it has be shown in this article that estimates of damage costs resulting from combustion of fossil fuels, if internalized into the price of the resulting output of electricity, would clearly render a number of renewable technologies (specifically wind and biomass) financially competitive with coal-fired generation. However, gas-fired power generation would clearly have a marked financial advantage over both coal and renewables under current technology and market conditions. The internalization of other environmental externalities has not been addressed in this article, but it is evident from Table 1 that including costs associated with power station emissions of sulfur dioxide and nitrogen oxides would further strengthen the competitive position of renewable technologies. In addition, over the next couple of decades, the cost of renewable technologies (particularly those that are "directly" solar-based) is likely to decline markedly as technical progress and economies of scale combine to reduce unit generating costs. Incorporating environmental externalities explicitly into the electricity tariff would serve to hasten this process.

These results are specific to Australia, where electricity generated by coal-fired power stations is, by world standards, relatively cheap (largely due to Australia's large endowment of domestic coal resources, institutional factors relating to past financing practices for government-owned power stations, and recent electricity industry re-organization). Nevertheless, the principle of internalizing the environmental externalities of fossil combustion is of global validation. Whether this is achieved directly through imposition of a carbon tax or indirectly as a result of ensuring compliance with Kyoto targets, a similar result is likely to be achieved; i.e., a rise in the cost of power generation based upon fossil fuel combustion and a relative improvement in the competitive position of an increasing range of renewable energy technologies.

Footnotes

[1] See Watt and Outhred (2001) for a detailed analysis of market impediments facing renewable energy technologies.

[2] The data for Finland underestimate damages due to lack of data from non-European receptor points.

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