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Renewable energy: Externality costs as market barriers

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Abstract

This paper addresses the impact of environmentally based market failure constraints on the adoption of renewable energy technologies through the quantification in financial terms of the externalities of electric power generation, for a range of alternative commercial and almost-commercial technologies. It is shown that estimates of damage costs resulting from combustion of fossil fuels, if internalised into the price of the resulting output of electricity, could lead to a number of renewable technologies being financially competitive with generation from coal plants. However, combined cycle natural gas technology would have a significant financial advantage over both coal and renewables under current technology options and market conditions. On the basis of cost projections made under the assumption of mature technologies and the existence of economies of scale, renewable technologies would possess a significant social cost advantage if the externalities of power production were to be "internalised". Incorporating environmental externalities explicitly into the electricity tariff today would serve to hasten this transition process.

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1. Introduction

The past three decades have witnessed two major (and a number of "minor") oil shocks, a severe accident at the Chernobyl power plant, the doomsday perspective of *Limits to Growth*, major concerns relating to climate change linked to the combustion of fossil fuels, severe energy supply constraints in developing countries and widespread concern over the security of energy (and particularly oil) supply lines. Yet 95% of world commercial energy production still comes from fossil fuels or nuclear power, with oil continuing to play a pivotal role. The conventional wisdom appears to be that changes in technology are triggered principally by price signals, and as fossil fuels become increasingly scarce renewable energy technologies will be increasingly exploited. But is the market's so-called "invisible hand" capable of ensuring the provision of a sustainable energy future. Has the approach of benign neglect been appropriate? Have the "right" price signals been sent? This paper addresses a major constraint on the emerging market for renewable energy technologies: market barriers. Specifically, it focuses on barriers that give rise to "market failure".

The same period has witnessed remarkable growth in electricity production from "new" renewables, averaging 9.3% per annum (albeit from a very low base).[1] However, entry of these environmentally more benign energy technologies into the main stream of the power sector has been constrained by a range of obstacles, in addition to their (generally) higher unit cost of power production. Such obstacles can be viewed from three different but overlapping, perspectives[2]:

- The *research, development and deployment perspective* focuses on the nature of innovation, industry strategies and the learning process associated with new technologies. Investment in new technologies and the 'learning by doing' that arises from their use improve technical performance and reduce costs, thereby further stimulating investment in research and development.
- The *market barriers perspective* characterises the adoption of a new technology as a market process and

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[1] "New" renewables exclude hydro and waste incineration.

[2] These definitions come from IEA (2003a).

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Table 1
Types of market barriers and measures that can alleviate them

Barrier	Key characteristics	Typical measures
Uncompetitive market price	Scale economies and learning benefits have not yet been realised	• Learning investments • Additional technical development
Price distortion	Costs associated with incumbent technologies may not be included in their prices; incumbent technologies may be subsidised	• Regulation to internalise 'externalities' or remove subsidies • Special offsetting taxes or levies • Removal of subsidies
Information	Availability and nature of a product must be understood at the time of investment	• Standardisation • Labelling
Transactions costs	Costs of administering a decision to purchase and use equipment(overlaps with "Information" above)	• Reliable independent information sources • Convenient & transparent calculation methods for decision making
Buyer's risk	• Perception of risk may differ from actual risk (e.g. 'pay-back gap') • Difficulty in forecasting over an appropriate time period	• Demonstration • Routines to make life-cycle cost calculations easy
Finance	• Initial cost may be high threshold • Imperfections in market access to funds	• Third party financing options • Special funding • Adjust financial structure
Inefficient market organisation in relation to new technologies	• Incentives inappropriately split—owner/designer/user not the same • Traditional business boundaries may be inappropriate • Established companies may have market power to guard their positions	• Restructure markets • Market liberalisation could force market participants to find new solutions
Excessive/inefficient regulation	Regulation based on industry tradition laid down in standards and codes not in pace with developments	• Regulatory reform • Performance based regulation
Capital stock turnover rates	Sunk costs, tax rules that require long depreciation & inertia	• Adjust tax rules • Capital subsidies
Technology-specific barriers	Often related to existing infrastructures in regard to hardware and the institutional skill to handle it	• Focus on system aspects in use of technology • Connect measures to other important business issues (productivity, environment)

Source: IEA (2003a).

focuses on the frameworks within which decisions are made by investors and consumers. Anything that slows the rate at which the market for a technology expands can be referred to as a market barrier.

- The *market transformation perspective* focuses on what needs to be done in practical terms to build markets for new energy technologies. It is concerned with the behaviour and roles of market actors, how their attitudes guide decisions and how these attitudes can be influenced.

This paper focuses on the market barriers perspective, since this is largely the domain of the economist. Table 1 summarises types of market barriers and typical measures that can be employed to alleviate them. However, it is important to distinguish between market barriers that are intrinsic operational aspects of energy (and other) markets and those that arise because of market failure. In the case of the former, examples are barriers such as the high risk of product failure and the high cost of finance for small borrowers that generally influence decisions in most markets.[3] The latter is dominated by the existence of 'externalities', where certain environmental costs of production are not reflected in the market cost of the

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[3] Although it should be noted that controversy exists between economists as to whether such "barriers" are legitimate "market barriers" or simply normal operating characteristics of a conventional market.

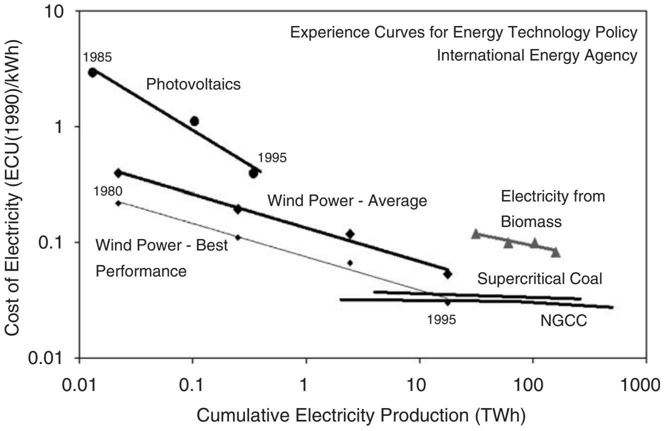

Fig. 1. Electric technologies in EU 1980–1995. *Source*: IEA (2000).

commodity (in this case, energy). To the extent that the ultimate consumer of these products does not pay these costs, or does not compensate people for harm done to them, they do not face the full cost of the services they purchase (i.e. implicitly their energy use is being subsidised) and thus energy resources will not be allocated efficiently.

2. The cost of renewable energy technologies

Fig. 1 illustrates how electricity-generating costs for five technologies in the EU have declined since 1980 as the level of installed capacity has increased. The figure shows how technologies such as wind, solar photovoltaics and biomass have had much steeper "learning curves" than advanced fossil fuel technologies such as natural gas combined cycle (NGCC) and coal, giving the impression that their costs could ultimately be lower per kWh. It should be noted, however, that the axes are expressed in terms of units of exponential growth, thus effectively yielding a dimension-reducing transformation of the cost "gap". A transformation that makes the historical cost of electricity from coal and gas technologies look relatively static, whereas in reality they are still declining, albeit at a relatively slow rate.[4]

NGCC consistently shows a cost advantage over the other technologies, which helps to explain its dominant role in current investment decisions in the electric power sector. As a result, the IEA (2003b) has projected that the share of natural gas in total world electricity generation will rise from 17% in 2000 to 31% in 2030, although the rate of growth is expected to decline with projected real increases in the price of gas. For many developed countries, NGCC will dominate new plant investment and that raises the potential for a technology "lock-in". Whilst a technology "lock-in" is not intrinsically undesirable, if significant externalities are not priced into the marketplace then associated environmental degradation will also be "locked-in" and, as a consequence, more environmentally benign technologies could be "locked-out".

Table 2 gives (indicative) levellised electricity costs (in Euro-cent (€¢/kWh) for electricity generation by the major renewable and non-renewable technologies. Both coal and gas exhibit a clear absolute cost advantage over the bulk of renewable technologies, although electricity generated by "best performance" wind power has recently approached similar cost levels. Back-up generation costs associated with the intermittency of renewables to ensure reliability of supply are not included. Thus, on purely financial grounds (inclusive of all forms of subsidy), renewable technologies would, in general, currently appear to be non-competitive. The cost "gap" has been narrowed significantly over the past two decades, a process that is expected to continue as reflected in projected cost levels for 2020 (Table 2). However, without significant policy actions to encourage enhanced levels of investment in research and development and purchasing incentives designed to deliver economies of scale in production, the gap is unlikely to be closed quickly enough to assist governments to meet their Kyoto Protocol (or other) commitments on global climate change initiatives in any major way.

The cost data presented in Table 2, however, give a misleading indication of the extent of the cost disadvantage of renewables.

- Unlike fossil fuel technologies, the efficiency of renewable technologies is generally very site specific. Thus, it would be expected that photovoltaics in the UK would incur a higher cost per kWh than countries located at lower latitudes. In contrast, coal and (to a lesser extent) gas-fired power plants use a fuel that is internationally traded and therefore of similar cost (net of transport charges) throughout the world. Thus, comparisons should be made on the basis of "optimal conditions" costs, rather than the full range that may incorporate old technologies and inappropriate siting decisions.
- Photovoltaics is generally "delivered" as distributed electricity. Thus, its cost should be compared with "delivered" (i.e. inclusive of transmission and distribution costs) electricity from other sources, both renewable and fossil fuel. In Table 2, cost ranges for delivered electricity are also given. Outside of rural electrification in developing countries the cost difference still favours fossil fuel technologies, but the divergence is considerably smaller than when delivery is ignored.
- Fossil fuel price volatility is ignored in the calculations, thus placing an implicit value of zero on fuel price stability. Whilst this would be an appropriate assumption for renewable technologies (sunshine is delivered free-of-charge whether it is wanted or not),

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[4] This transformation also reduces the variability of observations around the estimated individual time lines. Hence, the apparent high degree of "fit" to the data points. The results of any extrapolation of these trends should, therefore, be interpreted with great care.

Table 2
Cost of traditional and renewable energy technologies current and expected trends

Energy source	Technology	Current cost of delivered energy (Euro-¢/kWh)	Expected future costs beyond 2020 as technology matures (Euro-¢/kWh)
Coal	Grid supply (generation only)	3–5	Capital costs to decline slightly with technical progress. This may be offset by increases in the (real) price of fossil fuels
Gas	Combined cycle (generation only)	2–4	
Delivered grid electricity from fossil fuels	Off-peak	2–3	
	Peak	15–25	
	Average	8–10	
	Rural electrification	25–80	
Nuclear		4–6	3–5
Solar	Thermal electricity (annual insolation of 2500 kWh/m^2)	12–18	4–10
Solar	Grid connected photovoltaics		
	Annual 1000 kWh/m^2 (e.g. UK)	50–80	~8
	Annual 1500 kWh/m^2 (e.g. Southern Europe)	30–50	~5
		20–40	~4
	Annual 2500 kWh/m^2 (e.g. lower latitude countries)	40–60	~10
Geothermal	Electricity	2–10	1–8
	Heat	0.5–5.0	0.5–5.0
Wind	Onshore	3–5	2–3
	Offshore	6–10	2–5
Marine	Tidal barrage (e.g. proposed River Severn Barrage)	12	12
	Tidal stream	8–15	8–15
	Wave	8–20	5–7
Biomass	Electricity	5–15	4–10
	Heat	1–5	1–5
Biofuels	Ethanol (cf. petrol & diesel)	3–9 (1.5–2.2)	2–4 (1.5–2.2)
Hydro	Large scale	2–8	2–8
	Small scale	4–10	3–10

Source: Adapted from ICCEPT (2002).

building price volatility into generating costs for fossil fuel technologies increases those costs significantly.[5]

3. Assessing the externalities of power generation

Costs borne by governments, including direct subsidies, tax concessions, indirect energy industry subsidies (e.g. the cost of fuel supply security) and support of research and development costs, are not externalities. They do, however, distort markets in a similar way to negative externalities, leading to increased consumption and hence increased environmental degradation.

In order to effectively address these environmental matters, together with energy supply security concerns, radical changes in power generation, automotive engine and fuel technologies will probably be required. Such changes must offer the potential for achieving negligible emissions of air pollutants and greenhouse gases, and must diversify the energy sector away from its present heavy reliance on fossil fuels (and particularly gasoline in the transportation sector). A number of technologies, including those that are solar or hydrogen based, offer the long-term potential for an energy system that meets these criteria.

However, a number of policy objectives that are more difficult to quantify are also of significance in the planning of future technology options. Currently, the most important of these would appear to be the security of supply of energy resources and their associated transmission and distribution systems.[6]

Environmental externalities of energy production/consumption (whether based upon fossil fuel combustion, nuclear power or renewable technologies) can be divided into two broad (net) cost categories that distinguish

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[5] A detailed analysis is given in Awerbuch (2003).

[6] In the case of oil, this issue is covered in greater detail in Owen (2004).

emissions of pollutants with local and/or regional impacts from those with global impacts:

- costs of the damage caused to health and the environment by emissions of pollutants other than those associated with climate change and
- costs resulting from the impact of climate change attributable to emissions of greenhouse gases.

The distinction is important, since the scale of damages arising from the former is highly dependent upon the geographic location of source and receptor points. The geographic source is irrelevant for damages arising from emissions of greenhouse gases.

3.1. Pollution damage from emissions other than CO_2

This category refers to costs arising from 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 fossil fuel power plants. Other costs in this category include factors such as power industry accidents (whether they occur in coal mines, on offshore oil or gas rigs, in nuclear plants, on wind farms, or at hydro plants), visual pollution and noise.

Among the major external impacts attributed to electricity generation are those caused by atmospheric emissions of pollutants, such as particulates, sulphur dioxide (SO_2) and nitrogen oxide (NO_x), and their impacts on public health, materials, crops, forests, fisheries and unmanaged ecosystems. 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 may vary widely across continents, and even within individual countries.

Estimated damages per tonne of pollutant for SO_2, NO_x and particulates vary greatly because of a number of contributing factors throughout the fuel cycle. Briefly these are:

- mining and fuel transportation externalities (particularly accidents);
- fuel quality (particularly coal);
- vintage of combustion technologies and presence of associated emission-reducing devices such as flue gas desulphurisation or low NO_x burners and
- population density in receptor areas for airborne pollutants.

The major source of pollution is at the power generation stage for fossil fuels, whereas for renewables it tends to be during equipment manufacturing stages.

However, damage estimates are dominated by costs arising from human health effects, which are largely determined by the population affected. Estimation of health impacts is generally based upon exposure–response epidemiological studies and methodologies for placing a valuation on human life remain controversial.[7] As might be expected, countries that are sparsely populated, or populated in largely non-receptor areas, tend to have relatively low health damage costs.

The European Commission's (EC's) ExternE[8] study has produced estimates of human health damages and other non-climate change pollution damages for the coal fuel cycle that range from 0.2 to 4.0 €¢/kWh.[9] For the gas fuel cycle, where SO_2 emissions are negligible, combined cycle gas turbine technology produces damages that are considerably lower per kWh than for coal, particularly for combined heat and power plants. Again, the largest damages occur where the plants are located close to high population density areas. Even then, damages do not exceed 1.0 €¢/kWh, and are generally considerably lower than this figure. While power generation damages arising from the oil fuel cycle are, on average, marginally lower than those associated with coal, they too exhibit significant variation between plants.

It is evident from these damage values that the country-specific nature of these estimates does not permit an "average" global damage figure to be derived, although it may be concluded that damage values can be at least as great as direct generation costs for some coal-based technologies. Clearly, country (or regional)-specific policies would be required in order to reduce existing damage levels. This could occur automatically if investment in new plant derived benefits from utilising technological developments that further reduced pollutants, whilst existing plants could be retrofitted with improved technology as it became available.

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[7] Pearce (2002) raises questions regarding the appropriateness of the ExternE methodology used to derive these monetary estimates of health impacts.

[8] Externe was the first comprehensive attempt to use a consistent "bottom-up" methodology to evaluate the external costs associated with a range of different fuel cycles. The European Commission (EC) launched the project in collaboration with the US Department of Energy in 1991. The EC and US teams jointly developed the conceptual approach and the methodology and shared scientific information for its application to a range of fuel cycles. The main objectives were to apply the methodology to a wide range of different fossil, nuclear and renewable fuel cycles for power generation and energy conservation options. Although the US withdrew from the project, a series of National Implementation Programmes to realise the methodology for reference sites throughout Europe was completed. The methodology was extended to address the evaluation of externalities associated with the use of energy in the transport and domestic sectors, and a number of non-environmental externalities such as those associated with security of supply.

[9] European Commission (1998). The impact of atmospheric pollutants on forests, fisheries and unmanaged ecosystems are also important but were not quantified by the EC.

Table 3
CO_2 emissions from different electricity generation technologies

CO_2 emissions (tonne/GWh)				
Technology	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).

3.2. The external damage costs of emissions of carbon dioxide

This category refers to external costs arising from greenhouse gas emissions from electricity-generating facilities that lead to climate change with all its associated effects. This is a very contentious area, and the range of estimates for the possible economic ramifications of global climate change is vast. Costs associated with climate change, such as damage from 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 climate change is yet to be determined with precision. Thus, deriving monetary values on this basis of limited knowledge is, at present, an imprecise exercise.

Table 3 gives life-cycle CO_2 emissions (in tonne/GWh) of the major forms of electric power generation. From this table it is clear that CO_2 emissions from coal and oil-based technologies far exceed those of the "renewables" and are twice those of gas.

3.3. External damage costs for electricity production

Table 4 gives cost ranges (in €¢/kWh) for quantifiable[10] external costs (including CO_2 damage costs) associated with the range of electricity generation technologies for countries within the European Union. The ranges are often relatively large, reflecting variations in generation technology (and hence emission levels per kWh) and geographic location (and hence damage costs per kWh). To derive a "representative" value, for each technology the median value of the lower bounds over all reporting countries was selected. The lower bounds should reflect optimal operating conditions and appropriate technology for each country. Taking the median value should minimise geographic and other country-specific factors influencing external costs.

These median lower bounds indicate that the external costs associated with coal technologies are (approximately) four times those of gas and a very large multiple of those for renewable energy technologies.[11] Combining these "externality adders" with the lower bounds of the "current" cost data given in Table 2 would give gas a marked societal cost advantage over all other modes of generation with the exception of wind and hydro.

If the "environmental adders" were to be imposed upon expected future costs, then it is clear that by 2020, under the best operating conditions, many other renewables will become less costly than either gas or coal on the basis of the societal cost of electricity production. However, such a comparison is fraught with problems, as the external costs per kWh associated with both emissions of pollutants and climate change in 2020 are likely to differ significantly from those given in Table 4. To a large extent differences will depend upon the success or otherwise of GHG abatement programs over the same period. A decline in damage costs arising from emissions of non-GHGs can also be expected to occur as a consequence of continuing improvements in emission-reduction technology and retirement of older plants.

Tol (2005) has reviewed 88 estimates, from 22 published studies, of the marginal cost of carbon dioxide emissions and combined them to form a probability density function. He found that the function is strongly skewed to the right, with a mode of \$5/tC, a mean of \$104/tC and a 95th percentile of \$446/tC. Including only peer-reviewed studies in the analysis, gave corresponding estimates of \$5, \$57 and \$307, respectively. Thus not only is the mean estimate substantially reduced, but so is the degree of uncertainty. Equity weighting and changing discount rates were also shown to have significant effects on these estimates.[12] Overall, Tol concluded that, for all practical purposes, it is unlikely that the marginal costs of CO_2 emissions would exceed \$50/tC and are likely to be substantially lower.

Based upon a constant discount rate and without equity weighting, Pearce (2003) quotes a range of \$4–9/tC. Equity weighting, using a marginal utility of income elasticity of

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[10] A number of impacts were ignored either due to their being of a very minor nature or where insufficient knowledge is available to derive credible estimates (e.g. the impact of climate change on biodiversity).

[11] The exception being some biomass technologies.

[12] Equity weighting gives a higher weight to damages that occur in poor countries relative to the same cost of damage in a rich country. It requires the specification of a social welfare function in order derive the weights. Pearce (2003) illustrates the effects of equity weighting on damages arising from climate change.

Table 4
External costs for electricity production in the EU (range: Euro-¢/kWh)

Country	Coal & lignite	Peat	Oil	Gas	Nuclear	Biomass	Hydro	PV	Wind
Austria				1–3		2–3	0.1		
Belgium	4–15			1–2	0.5				
Germany	3–6		5–8	1–2	0.2	3		0.6	0.05
Denmark	4–7			2–3		1			0.1
Spain	5–8			1–2		3–5			0.2
Finland	2–4	2–5				1			
France	7–10		8–11	2–4	0.3	1	1		
Greece	5–8		3–5	1		0–0.8	1		0.25
Ireland	6–8	3–4							
Italy			3–6	2–3			0.3		
Netherlands	3–4			1–2	0.7	0.5			
Norway				1–2		0.2	0.2		0–0.25
Portugal	4–7			1–2		1–2	0.03		
Sweden	2–4					0.3	0–0.7		
United Kingdom	4–7		3–5	1–2	0.25	1			0.15
EU range	2–15	2–5	3–11	1–4	0.2–0.7	0–5	0–1	0.6	0–0.25
Median Lower Bound	4	2.5	3	1	0.3	1	0.2	0.6	0.125

Source: Adapted from European Commission (2003).

unity, changes the range to \$3.6–22.5/tC. A time varying discount rate raised this range to \$6.5–40.5/tC. All estimates, therefore, are well below Tol's upper bound of \$50/tC.[13]

4. Internalising the externalities of electricity production

4.1. Internalising externalities

At least in theory, the most efficient process for imposing the "polluter pays principle" would be to internalise as many of the externalities of power generation as possible. Using the marketplace would permit energy producers and consumers to respond to such price signals in the most efficient and cost-effective way.

However, it should be emphasised that only external damage costs associated with emissions from fossil fuel combustion have been considered explicitly in these calculations. Those associated with other forms of power generation, in addition to security of supply considerations and energy subsidies must also be incorporated into the analysis in order to achieve a reasonable balance across the range of power-generating technologies, both conventional and renewable. For example, without such action nuclear power, with its negligible level of CO_2 emissions per kWh but significant subsidies and radioactive waste management costs, would possess a marked competitive advantage over all other technologies (with the exception of some hydro systems), both renewable and non-renewable. However, as noted earlier, costs associated with emission of pollutants other than CO_2 can be very variable and tend to be site specific.

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 (re-) introduced. Finally, the worst of any social impact of energy taxes on poorer sections of society would have to be offset to ensure 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

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[13] For comparison, the influential IPCC (1996) report quoted an estimated damage range of \$5–125/tonne C.

principle". Their attractiveness to governments is that they can be justified as a carbon offsetting initiative that is far more politically palatable than a carbon tax.

As noted earlier, leading renewable energy technologies are characterised by relatively high initial capital costs per MW of installed capacity, but very low running costs. This characteristic 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, and in the case of spent-fuel storage for nuclear plants many thousands of 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 in the context of intergenerational equity.[14]

4.2. Policy options for "internalising" externalities

Estimated damage costs associated with externalities of fossil fuel combustion tend to lack precision, which would make the imposition of environmental "adders" a very controversial policy option.[15] Further, it should be remembered that valuation of externalities is predicated on the discipline of welfare economics, where economic (or allocative) efficiency is the guiding principle. Distributional assumptions are, at least at that level, ignored. In addition, most actions will be based upon control or abatement costs and therefore their relationship with the precise cost of damage arising from the externality may be very tenuous.[16] However, a number of second-best options are available that could, at least partially, approximate the desired outcome.

4.3. Government and voluntary actions

Governments generally exercise effective control over many parts of western economies, including buildings, employees, vehicle fleets, infrastructure, government corporations, joint ventures, land and resource management and the allocation of research and development budgets. Because externalities are a form of market failure, Government intervention is justified in order to minimise their impacts on the community. Where taxing polluters is deemed to be politically unacceptable, then environmentally benign technology could be encouraged through grants and subsidies.

Governments may try to influence the actions of households and firms by voluntary means, such as information campaigns, advertising, environmental product labelling, demonstration projects and facilitating voluntary environmental initiatives.

4.4. Economic instruments

In principal, this would involve imposing an emissions tax on consumption of the commodity in question, reflecting the damage incurred by society. In practice, this is more likely to involve taxation at a level that would control emissions to an acceptable standard (i.e. a control cost). Alternatively, tradeable permits could be introduced to restrict emissions to the required standard. In theory the two instruments are equivalent for meeting a given standard, although in practice they can differ significantly in their impacts.[17]

Although the implementation of carbon taxes at the international level has been discussed extensively, politically it has never been acceptable to a wide range of countries. Both the negotiation of a carbon tax rate at the international level and the implementation of a carbon tax regime have turned out to be too complex. Difficulties lie in deciding on a level of tax and on how the resulting revenue should be used or redistributed.

One of the first proposals for a carbon tax was US President Clinton's 'BTU' tax, which was discarded in 1994. In 1992, the EC put forward a proposal for a European Union-wide tax on all energy products, except renewable energy sources. Half of the tax would have been based on the energy content, and half on the carbon content of fuels. After the EC proposal had been faced by severe opposition by the British government it was eventually abandoned at the end of the 1990s. The EC subsequently encouraged its member states to adopt carbon taxes at the national level.

"Carbon taxes" have been implemented in Denmark, Finland, Germany, the Netherlands, Norway, Sweden and the United Kingdom. Details are given in Table 5. Although these taxes have been named carbon taxes, they do not usually have a common tax base. For example, carbon taxes in Denmark and the United Kingdom are imposed on a per kWh basis on the consumption of electricity, whilst carbon taxes on natural gas in Denmark, Norway, Sweden and the United Kingdom are imposed on cubic metres (m^3) of natural gas consumed.[18] Thus it is

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[14] Refs.: Philibert (1999), Newell and Pizer (2003) and Weitzman (2001).

[15] See Sundqvist (2004) for an analysis of the causes of the disparity of electricity externality estimates.

[16] See Owen (2004) for a discussion of the distinction between control and damage costs.

[17] See Missfeldt and Hauff (2004) for elaboration of this point.

[18] In the case of the Climate Change Levy in the UK, Pearce (2003) has calculated implicit carbon tax rates to be £16/tC for coal, £30/tC for gas and £31/tC for electricity. For a genuine carbon text, of course, these rates should be identical. Further, the UK government has adopted £70/tC (under review) as its measure of marginal damage resulting from climate

Table 5
Taxes in OECD member countries levied on electricity consumption

Country	Tax	Tax rate (in Euro/kWh, except where otherwise indicated)
Austria	Energy tax	0.015
Belgium	Energy fee (low-frequency electricity)	0.0013641
Denmark	Duty on CO_2	0.0134
Denmark	Duty on electricity (heating)	0.0673
Denmark	Duty on electricity (other purposes)	0.076
Finland	Excise on fuels (manufacturing sector)	0.0042073
Finland	Excise on fuels (rest of the economy)	0.0069
Finland	Strategic stockpile fee	0.0001262
Germany	Duty on electricity	0.0128
Italy	Additional tax on electricity, towns/provinces (private dwellings)	Varies
Italy	Additional tax on electricity, towns/provinces (industry)	Varies
Italy	Tax on electrical energy, state	0.003
Italy	Tax on electrical energy, state	0.0021
Japan	Promotion of power resource development tax	0.0041
Netherlands	Regulatory energy tax (up to 10,000 kWh/year)	0.0601
Netherlands	Regulatory energy tax (10,000–50,000 kWh/year)	0.02
Netherlands	Regulatory energy tax (50,000–10 million kWh/year)	0.0061
Norway	Tax on consumption of electricity	0.0128
Spain	Tax on electricity	4.864%
Sweden	Energy tax on electricity (households)	0.0214
Sweden	Energy tax on electricity (manufacturing and commercial greenhouses)	0
Sweden	Energy tax on electricity (other sectors)	0.0151
Sweden	Energy tax on electricity (material permitted for abstraction >200,000 tonne)	0.0015
United Kingdom	Climate Change Levy (ordinary rate)	0.0069
United Kingdom	Climate Change Levy (reduced rate)	0.0014
United States	Delaware: Public utilities tax.	4.25% of gross receipts

Source: OECD (2003).

probably more appropriate to designate such taxes as "energy" rather than "carbon" taxes.

In addition, there are many countries that have adopted taxes on energy consumption that act implicitly as a carbon tax without, however, being called a carbon tax. Moreover, the impact of these carbon taxes not only hinges on the size of the tax rate but also on the modalities and rules for the recycling of the revenue of these taxes. These are commonly very complex, as they are the result of negotiations of all stakeholders, especially those firms who will be affected by the tax.

Unlike carbon taxes, the first carbon emissions trading regime to emerge was at the international level. In fact, the agreement on the Kyoto Protocol negotiations in 1997 could only be achieved by adopting provisions for trading greenhouse gas emissions internationally. The regime under the Kyoto Protocol is a cap-and-trade regime. The most important driving factor was the concern of the USA that they would not be able to implement sufficiently strong domestic policies to meet their 7% emissions reduction target, and that they needed a cost-effective means of meeting their emissions reductions. The trading mechanisms adopted under the Kyoto Protocol are commonly referred to as 'flexibility mechanisms'.

As part of countries' efforts to comply with their obligations under the Kyoto Protocol, and also to be able to fully participate in international emissions trading, a number of national and industry systems have emerged. These include one regional scheme: the trading regime of the European Union.

Among the existing domestic regimes are Denmark, the United Kingdom, ERU-PT—a Dutch programme and the US state of Oregon. Of these, only the Danish trading regime is a pure cap-and-trade regime. Among the industry schemes are the internal trading programmes of Shell and British Petroleum (BP) and the Canadian Pilot Emission Reduction Trading (PERT). Existing and emerging domestic trading regimes are given in Table 6.

A European-wide scheme was adopted by the European Parliament in 2002. The scheme provides for the introduction of legally binding, absolute emission caps from 2005 for around 4000–5000 power stations and industrial plants with high levels of energy consumption. The European trading scheme covers plants midstream rather than in a

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(*footnote continued*)
change. So the long-term carbon tax is a long way from reflecting a true Pigovian tax rate. In contrast, Pearce notes that the rate of a carbon tax implicit in UK fuel excise duty far exceeds (by a factor of 5) this £70 figure (which in itself appears to be unrealistically high).

Table 6
Existing and emerging domestic trading regimes

Trading scheme	Participation	Status of systems	Scope of scheme	Start, end date	Absolute or rate-based limits	Emissions covered
Oregon	M	E	R	1997	A	CO_2 emissions, indirect reductions
Denmark	M	E	N	2001, 2003	A	CO_2 emissions
ER-UPT	V	E	N	2000	R	Multiple gases, indirect reductions
United Kingdom	V[a]	E	N	2001	[b]	Direct and indirect CO_2 emissions
Australia	M	P	N	2008 (?)	A	Not yet decided
Canada	M	P	N	2008 (?)	A	All Kyoto gases under broad option
European Union	M	E	R	2005	A	Direct CO_2 emissions only
France	M[c]	P	N	2002	[d]	Direct CO_2, possibly indirect
Germany	M	P	N	2005 (?)	A	Direct CO_2 initially, expand to other gases
Norway	M	P	N	2008	A	All Kyoto gases
Slovakia	M	P	N	2005, 2008[e]	A[f]	Direct CO_2 emissions
Sweden	M	P	N	2005	A	Direct CO_2, possibly other gases
Switzerland	V	P	N	2008	A[g]	Direct CO_2 from fossil fuel combustion
PERT	V	E	I	1996	R	Direct and indirect CO_2, CH_4 and non-GHGs
BP	[h]	E	I	2000	A	Direct CO_2, CH_4
Shell	V	E	I	2000, 2002	A	Direct CO_2, CH_4
Chicago Stock Exchange	V	P	I	2002, 2005	A	All Kyoto gases

Source: Haites and Mullins (2001).
Notes: M—Mandatory Scheme, V—Voluntary Scheme, E—Existing Scheme, P—Planned Scheme, N—National Scheme, I—Industry Scheme, R—(Sub-)Regional Scheme, A—absolute limits/emissions cap, R—rate-based limits/credit baseline approach.

[a] Participation in the UK scheme is voluntary, but strong incentives exist to encourage participation.

[b] The UK system has both absolute and rate-based participants.

[c] Participation in the French programme would be through voluntary agreements. In the event that a voluntary agreement could not be negotiated, the government could impose limits on firms.

[d] Both absolute and rate-based limits are proposed for the French system.

[e] A pilot phase would begin in 2005, the full programme would start in 2008.

[f] The allowances allocated would exceed their current emissions for most sources

[g] The emission limitation commitment may be rate-based, but the allocation will be an absolute quantity based on projected output with the allocation adjusted ex post to reflect actual output.

[h] Participation is voluntary for BP, but mandatory for the operating units.

purely up- or downstream fashion. Thus, the following industries have been included: Power and heat generation (in plants with a thermal input capacity exceeding 20 MW), mineral oil processing; coke ovens; metal processing; cement and lime production, other building material and ceramics, glass and glass fibre and paper and cellulose. Minimum sizes apply, and initially only CO_2 emissions will be covered.

4.5. *Regulation and property rights*

This involves placing mandatory thresholds on the adoption of low emission technologies or practices by power utilities and car manufacturers, energy use in buildings and land and other resource management codes. Renewables obligations are being increasingly adopted by governments around the world. Known as Portfolio Standards in the US, Renewables Obligation in the UK and as the Mandatory Renewable Energy Target in Australia, such legislation obliges electric utilities to use renewable energy sources to meet a specified target percentage of their supply. The aim is to bring "green" energy online quicker than would otherwise happen by providing incentives for renewables generation. The targets are mandatory, with financial penalties for those who fail to meet them.

By setting minimum standards for public exposure to pollutants, governments give property rights to individuals or groups of individuals that would enable them to take civil action against polluters who exceed mandated standards.

5. Conclusions

This paper has considered the environmentally based market failure constraints on the adoption of renewable energy technologies through the quantification in financial terms of the externalities of electric power generation, for a range of alternative commercial and almost-commercial technologies.

It has been shown that estimates of damage costs resulting from combustion of fossil fuels, if internalised into the price of the resulting output of electricity, could clearly lead to a number of renewable technologies (specifically wind and some applications of biomass) being financially competitive with generation from coal plants. However, combined cycle natural gas technology would have a significant financial advantage over both coal and renewables under current technology options and market conditions. Over the next few decades, the costs of renewable technologies (particularly those that are "directly" solar based) are likely to decline markedly as technical progress and economies of scale combine to reduce unit-generating costs. On the basis of cost projections made under the assumption of mature technologies and the existence of economies of scale, renewable technologies would possess a significant social cost advantage if the externalities of power production were to be "internalised". Incorporating environmental externalities explicitly into the electricity tariff today would serve to hasten this transition process.

Justification of energy subsidies to developing technologies may be based upon the desire of a government to achieve certain environmental goals (e.g. enhanced market penetration of low GHG emissions technology). However, in general, case-specific direct action is likely to give a more efficient outcome. Thus penalising high GHG emitting technologies not only creates incentives for "new" technologies, but it also encourages the adoption of energy efficiency measures with existing technologies and consequently lower GHG emissions and other pollutants per unit of output. In addition, if the existence of market failures is restricting the diffusion of renewable energy technologies, then addressing those failures directly may again provide an efficient outcome.

The principle of internalising the environmental externalities of CO_2 emissions (and other pollutants) resulting from fossil fuel combustion is of global validity. Whether this is achieved directly through imposition of a universal carbon tax and emission charges, or indirectly as a result of ensuring compliance with Kyoto targets and other environmental standards, a similar result is likely to be achieved. Specifically, 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. In other words, the removal of both direct and indirect subsidies to power-generation technologies and the appropriate pricing of fossil (and nuclear) fuels to reflect the environmental damage (local, regional and global) created by their combustion are essential policy strategies for stimulating the development of renewable energy technologies.

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