Environmental Externalities, Market Distortions and the Economics of Renewable Energy Technologies†

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This paper reviews life cycle analyses of alternative energy technologies in terms of both their private and societal costs (that is, inclusive of externalities and net of taxes and subsidies). The economic viability of renewable energy technologies is shown to be heavily dependent upon the removal of market distortions. In other words, the removal of subsidies to fossil fuel-based technologies and the appropriate pricing of these 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 in the stationary power sector. Policy options designed to "internalize" these externalities are briefly addressed.

INTRODUCTION

The twentieth century witnessed historically unprecedented rates of growth in energy systems, supported by the widespread availability of fossil fuel resources. During the second half of the century, however, concerns associated with high levels of fossil fuel dependence began to surface. Two issues were of particular significance: the impact of modern energy systems on the environment and security issues associated with fuel supply lines.

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Environmental concerns had been evident in more localised areas for many hundreds of years. Ancient Rome burned wood and Emperor Nero's tutor, Seneca, complained of the bad effect that smoke had on his health and of smoke damage to temples, whilst anecdotal evidence indicates that air pollution had been a concern in England as early as 1352 when a ban was introduced on coal burning in London. Today, local pollution from energy systems remains a threat to the health of the living environment. However, in the latter decades of the twentieth century, pollution resulting from combustion of fossil fuels became a global concern, with the publication of credible scientific evidence that the planet's climate was changing as the result of a build up of so-called greenhouse gases in the atmosphere.

Historically, regulatory instruments have been the basic mechanism for enacting environmental policy throughout the industrialised world. Environmental quality has been seen as a public good that the state must secure by preventing private agents from damaging it. Direct regulation involves the imposition of standards (or even bans) regarding emissions and discharges, product or process characteristics, etc., through licensing and monitoring. Legislation usually forms the basis for this form of control, and compliance is generally mandatory with sanctions for non-compliance.

The proposal to impose taxes on pollution, whilst more recent, is also far from new, having been advanced at the turn of the last century by the famous British economist Arthur Cecil Pigou as a means of reducing London's famous fogs (or smogs). Pigou observed that pollution imposed uncovered costs on third parties that were not included in ordinary market transactions. His proposal was to tax pollution by means of a so-called externality tax[1] in order to internalise within ordinary market transactions the damages caused by pollution. At the time Pigou's proposal was regarded as an academic curiosity, but several generations later it was rejuvenated as the core of the "polluter pays principle."

Contemporary energy policy issues are dominated, directly and indirectly, by major concerns at both local and global levels of environmental degradation arising from combustion of fossil fuels. Even countries with relatively modest fossil fuel requirements, such as the poorer nations of Africa, Asia, and the South Pacific, could experience significant adverse consequences if the world's requirement for energy from fossil fuels does not abate within a relatively short time frame. Consequently, the economics of renewable energy technologies has a core position in energy policy formulation over the foreseeable future.

However, a number of non-quantifiable policy objectives are also of significance in the planning of future energy technology options. Currently,

1. Also known as a "Pigouvian" tax.

the most important of these would appear to be the security of supply of energy resources and their associated transmission and distribution systems. To the extent that governments bear the security costs associated with ensuring that uninterrupted supplies of fuels reach the relevant markets, then these fuels are being subsidised and hence there exists an inefficient allocation of resources. The price to the ultimate consumer would be too low, and consequently demand (and pollution) levels would be higher than in the absence of the subsidy.

This paper commences with a summary of the economics of environmental externalities. An overview of the methodology of life cycle analysis and its application to the energy sector to derive estimates of environmental externalities is then given. The implicit costs of externalities attributable to power generation (from both commercial and potentially commercial technologies) are then compared with the private costs that are generally passed on to the consumer.

2. EXTERNALITIES[2]

2.1 Definition

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 and where no compensation takes place. Environmental externalities are benefits or costs that manifest themselves through changes in the physical-biological environment.

Pollution emitted by road vehicles and by fossil fuel fired power plants during power generation is known to 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 power or fuel costs. To the extent that the ultimate consumer of these products does not pay these environmental costs, nor compensates 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.

The origin of an externality is typically the absence of fully defined and enforceable property rights. However, rectifying this situation through establishing such rights is not always an easy task. In such circumstances, at least in theory, the appropriate corrective device is a Pigouvian tax equal to

2. In this paper, the term "externality" will be used only in the context of "environmental externalities." Non-environmental externalities in the energy sector, with the exceptions of mining deaths and traffic accidents, are likely to be relatively minor and site-specific.

marginal social damage levied on the generator of the externality. If the tax is subsequently used to compensate the sufferer(s), then the externality is said to have been “internalised.”

2.2 Externality Adders

In the context of energy markets, an “externality adder” is simply the unit externality cost added to the standard resource cost of energy to reflect the social cost of its use. For power generation, the externality adder would generally be specified in terms of milli-dollars (1000^{th} of a dollar) per kWh (m$/kWh) or ¢/kWh. For the transport sector the corresponding units would be m$/vkm (i.e., one-thousandth of a $ per vehicle kilometre) for passenger vehicles and m$/tkm (i.e., one-thousandth of a $ per tonne kilometre) for goods vehicles, or the equivalent in cents.

Pearce (2002) lists five uses for externality adders:

i. For public or quasi-public ownership of sources of electric power generation, the full social cost of alternative technologies could be used to plan future capacity with preference being given to that with the lowest social cost. Where electric power generation is privately owned, then regulators could use the full social cost to influence new investment, perhaps through an effective environmental tax.

ii. Environmental adders can be used to estimate the appropriate level of environmental taxes. Although estimates of environmental adders have been derived for a number of applications, examples of their actual implementation are few.

iii. Environmental adders could be used to adjust national accounts data to reflect depreciation of natural resources and damage to the environment arising from economic activity, yielding so-called “green” national accounts.

iv. Environmental adders could be used for “awareness raising”; i.e., to inform the public of the degree to which alternative energy sources have externalities that give rise to economically inefficient allocation of resources.

v. Environmental adders might assist in determining environmental policy priorities.

The task of estimating the value of an externality adder involves a substantial commitment of resources and expertise in order to ensure credible information for policy purposes. In the context of the energy sector, a life cycle approach must be adopted in order to identify and quantify environmental adders associated with the provision of energy services. The approach also provides a conceptual framework for a detailed and comprehensive comparative evaluation of energy supply options (based upon both conventional and renewable sources). The methodology employed is the subject of the next section.

3. LIFE CYCLE ANALYSIS

When comparing the environmental footprints of alternative energy technologies, it is important that the power generation or combustion stage of the technology not be isolated from other stages of the "cycle." For example, fuel cells emit virtually no greenhouse gases (GHGs) in their operation. However production of their "fuel" (hydrogen) from fossil fuels may involve increases in GHG emissions in excess of those that would arise from using current commercial fossil fuel technologies to meet the same level of energy requirements. To avoid such distortions, the concept of life cycle analysis has been developed.

Life cycle analysis (LCA) is based upon a comprehensive accounting of all energy and material flows, from "cradle to grave," associated with a system or process. The approach has typically been used to compare the environmental impacts associated with different products that perform similar functions, such as plastic and glass bottles. In the context of an energy product, process, or service, a LCA would analyse the site-specific environmental impact of fuel extraction, transportation and preparation of fuels and other inputs, plant construction, plant operation/fuel combustion, waste disposal, and plant decommissioning. Thus it encompasses all segments including upstream and downstream processes and consequently permits an overall comparison (in a cost benefit analysis framework) of short- and long-term environmental implications of alternative energy technologies. Central to this assessment is the valuation of environmental externalities of current and prospective fuel and energy technology cycles. It should be noted, however, that only material and energy flows are assessed in an LCA, thus ignoring some externalities (such as supply security) and technology reliability and flexibility.

For the purpose of this paper, life cycle analysis will involve the following methodological steps:[3]

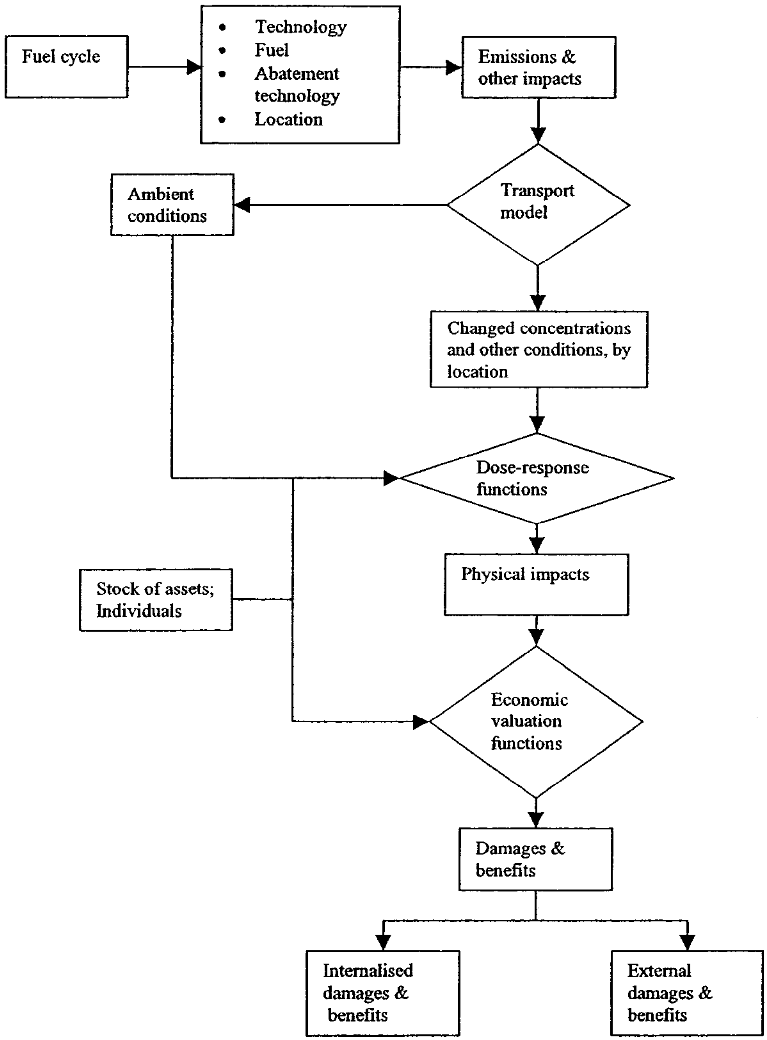
- Definition of the product cycle's geographical, temporal, and technical boundaries;
- Identification of the environmental emissions and their resulting physical impacts on receptor areas; and
- Quantifying these physical impacts in terms of monetary values.

Traditionally, LCA has omitted the third of these steps and the final analysis has therefore been expressed in terms of just the biophysical impacts that can be quantified. The extension to include costing of these impacts is generally known as the "impact pathway" methodology. Essentially, however, it can be considered as a specific application of LCA. This methodology formed the theoretical basis for the European Commission's ExternE[4] study, which 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 main steps are illustrated in Figure 1.

3. These steps describe a "bottom up," as distinct from a "top down," methodology for life cycle analysis. Top-down studies use highly aggregated data to estimate the external costs of pollution. They are typically undertaken at the national or regional level using estimates of total quantities of emissions and estimates of resulting total damage. The proportion of such damage attributable to certain activities (e.g., the transport sector) is then determined, and a resulting monetary cost derived. The exercise is generic in character, and does not take into account impacts that are site specific. However, its data requirements are relatively minor compared with the "bottom up" approach. The latter involves analysis of the impact of emissions from a single source along an impact pathway. Thus all technology data are project specific. When this is combined with emission dispersion models, receptor point data, and dose-response functions, monetised values of the impacts of specific externalities can be derived. Data requirements are relatively large compared with the "top down" methodology, and therefore omissions may be significant.

4. 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. Krewitt (2002) has provided a critique of the evolution of the methodologies used in the ExternE analyses.

Figure 1. The Impact Pathway Methodology



Source: Adapted from Sundqvist and Söderholm (2002)

3.1 Definition of the Product Cycle's Boundaries

The first task is to identify, both in terms of activities and geographic locations, the various stages of the fuel/technology cycle. Each energy form is viewed as a product, and impacts are included for the actual pathway. The precise list of stages is clearly dependent on the fuel chain in question, but would include activities linked to the manufacture of materials for plant construction, demolition and site restoration as well as power generation. Other stages may also be appropriate, such as exploration, extraction, processing and transport of fuel, and the generation of wastes and by-products, and their treatment prior to disposal.

The extent to which the boundaries must encompass indirect impacts is determined by the order of magnitude of their resulting emissions. For example, in theory externalities associated with the construction of plants to make the steel that is used to make coal wagons to transport the coal to the power plants should be included in the power plant's LCA. In reality, however, such externalities are likely to have a relatively insignificant impact. In addition, externalities that pass into another product's boundaries must be excised from the analysis to avoid double counting. For example, the ultimate environmental externality of by-products of power generation that are fully utilised in another industry fall within the latter's life cycle as soon as product transfer occurs.

For each fuel/technology cycle, boundaries are likely to vary, particularly in relation to upstream impacts, and consequently derivation of a "generic" LCA for each technology may be unrealistic. For example, identical coal-fired power plants located in different areas of the same country may use coal from different sources (perhaps one uses imported coal, the other domestic), there may be variations in fuel quality or variations in atmospheric dispersion, or there may be differences in the sensitivity of the human and natural environment upon which fuel chain burdens impact. When different generations of coal-fired plants enter the analysis, use of a generic approach may lead to a further drop in precision. However, the increased precision achieved by deriving a site specific LCA for all projects may well be offset by the cost of such exercises. In reality, indicative or generic estimates may be unavoidable.

The system boundary will also have spatial and temporal dimensions. These will have major implications for the analysis of the effects of air pollution in particular. For many air pollutants, such as ozone and SO_2, the analysis may need to focus on a regional, rather than local, scale in order to determine their total impact. For emissions of GHGs, the appropriate range is clearly global. Impacts must also be assessed over the full term of their effect, a period that may extend over many decades or even centuries in the case of emissions of GHGs and long-term storage of some nuclear waste products.

This introduces a significant degree of uncertainty into the analysis, as it requires projections to be made of a number of variables that will form the basis of future society. Among these would be the size of the global population, the level of economic growth, technological developments, the sustainability of fossil fuel consumption, and the sensitivity of the climate system to anthropogenic emissions.

A generic "chain" for coal-fired electricity generation is illustrated in Figure 2. Even from this simplified illustration, however, it is clear that the data requirements to undertake a LCA are formidable, particularly where sources in other countries have to be accessed. Data limitations and cost constraints will obviously combine to prevent a complete enumeration of the emissions of a given process. It is essential, therefore, that when this situation is reached the proportion left unaccounted should be clearly specified.

3.2 Identification of the Environmental Emissions and Their Resulting Physical Impacts on Receptor Areas

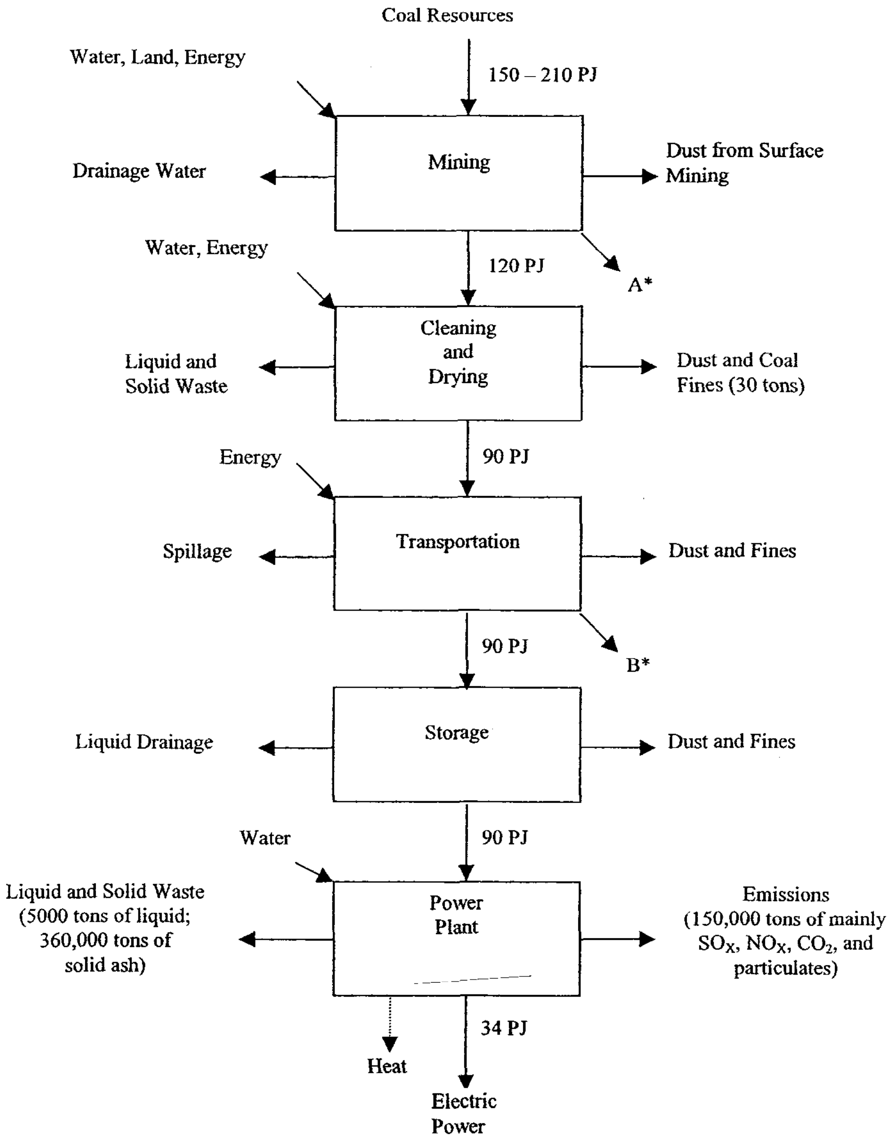
Environmental emissions (or burdens) from the energy sector that are capable of causing some form of impact can be identified in the following broad categories:

- Solid wastes;
- Liquid wastes;
- Gaseous and particulate air pollutants;
- Risk of accidents;
- Occupational exposure to hazardous substances;
- Noise; and
- Others (e.g., exposure to electro-magnetic fields, emissions of heat).

All potential physical impacts of the identified burdens for all fuel chains must be analysed comprehensively. However, it is possible to produce several hundred burdens and impacts for the various fuel chains. Thus, for practical reasons, the analysis must concentrate on those that are considered to be non-negligible in terms of their externalities.

Some impact pathways may be relatively simple. For example, the construction of a wind farm will affect the appearance of a landscape, leading to a change in visual amenity. In other cases, the link between the burden, physical impact, and monetary cost is far more complex. In reality, much of the required data is either incomplete or simply does not exist. Thus any analysis is, of necessity, only partial.

Figure 2. Generic Coal-Based Electricity Fuel Cycle Chain



* These impacts pass into another product's boundaries
Source: Adapted from Sorensen (2000)

Comparisons of alternative power generation technologies utilising LCA are generally standardised as emissions per unit of energy produced (kWh) in order to allow for different plant sizes and capacity factors. However, the data used to quantify burdens is, to varying degrees, technology specific. For example, emissions of carbon dioxide (CO_2) in power generation depend only on the efficiency of the equipment and the carbon/hydrogen ratio of the fuel; uncertainty is negligible. Whereas emissions of SO_2 can vary by an order of magnitude depending on the grade of oil or coal and the extent to which emission abatement technologies have been adopted. As a general rule, one should adopt the most efficient technology currently in use in the country of implementation in order to compare environmental pollutants across different technologies.

Quantifying the physical impacts of emissions of pollutants requires an environmental assessment that ranges over a vast area, extending over the entire planet in the case of CO_2 emissions. Thus the dispersion of pollutants emitted from fuel chains must be modelled and their resulting impact on the environment measured by means of a dose-response function. Generally, for damages to humans, such functions are derived from studies that are epidemiological; assessing the effects of exposure to pollutants in real life situations.

3.3 Cost of Damage or Cost of Abatement?

The two principal methods generally used for assessing the value of externalities are calculation of damage costs and calculation of control (or abatement) costs. Although control costs are often (mistakenly) seen as estimates of damage costs, conceptually they are very different. Damage costs are a measure of society's loss of wellbeing resulting from the damage arising from a specific adverse environmental impact. Control costs are what it costs society to achieve a given standard that restricts the extent of the impact to an acceptable level, and are thus likely to be only tenuously related to damage.

Control costs are often used as a surrogate for damage costs as they are a relatively straightforward concept, are relatively easy to derive, and can be applied to most environmental impacts. Essentially, control costs can be calculated simply by dividing the cost of mandated controls by the emissions reduction achieved by the controls. In general, however, control costs must be viewed as a poor substitute for estimating damage costs, since the methodology is subject to inherent flaws. The implicit assumption in control costing is that society controls pollution until the benefits of additional controls would be outweighed by the costs of their imposition. But using the cost of regulation to estimate the benefits is rather a meaningless, circular, procedure, given that a cost benefit ratio of unity will always be achieved. A further flaw is that use of control costs to value externalities implies that legislators are able to make optimal decisions when imposing policy instruments to modify polluting behaviour to achieve such an “optimal” outcome. However, in practice, epidemiological studies of cost per life saved (for example) have indicated large variations in the values implied by the costs and benefits of different regulations.

Estimation of damage costs has economic theory as its basis. It focuses directly on explicitly expressed preferences as revealed by willingness to pay to avoid environmental damage or by stated preferences in either real or simulated markets. In addition, it can be combined with financial assessment of investment options in order to provide a societal estimate for the impacts of an investment in a common numeraire. This methodology is fundamental to the attribution of financial values to environmental impacts identified in LCA. The last of the four stages in the environmental “impact pathway” involves calculation of the economic value of the biophysical effects in terms of willingness to pay to avoid damage arising from the emission of pollutants. Clearly, however, a major disadvantage is the scale of the data requirements for deriving estimates of these damage costs.

There is no reason why the two concepts should be of comparable dimension. In fact, rationally, control costs should always be less than the estimated level of damages.

3.4 Quantifying Physical Damage in Terms of Monetary Values

The many receptors that may be affected by fuel chain activities are valued in a number of different ways. For example, forests are valued not just for the timber that they produce, but also for providing recreational resources, habitats for wildlife, their interaction (both direct and indirect) with climate, the hydrological cycle, protection from soil erosion, etc. All such aspects have to be valued in an externality analysis.

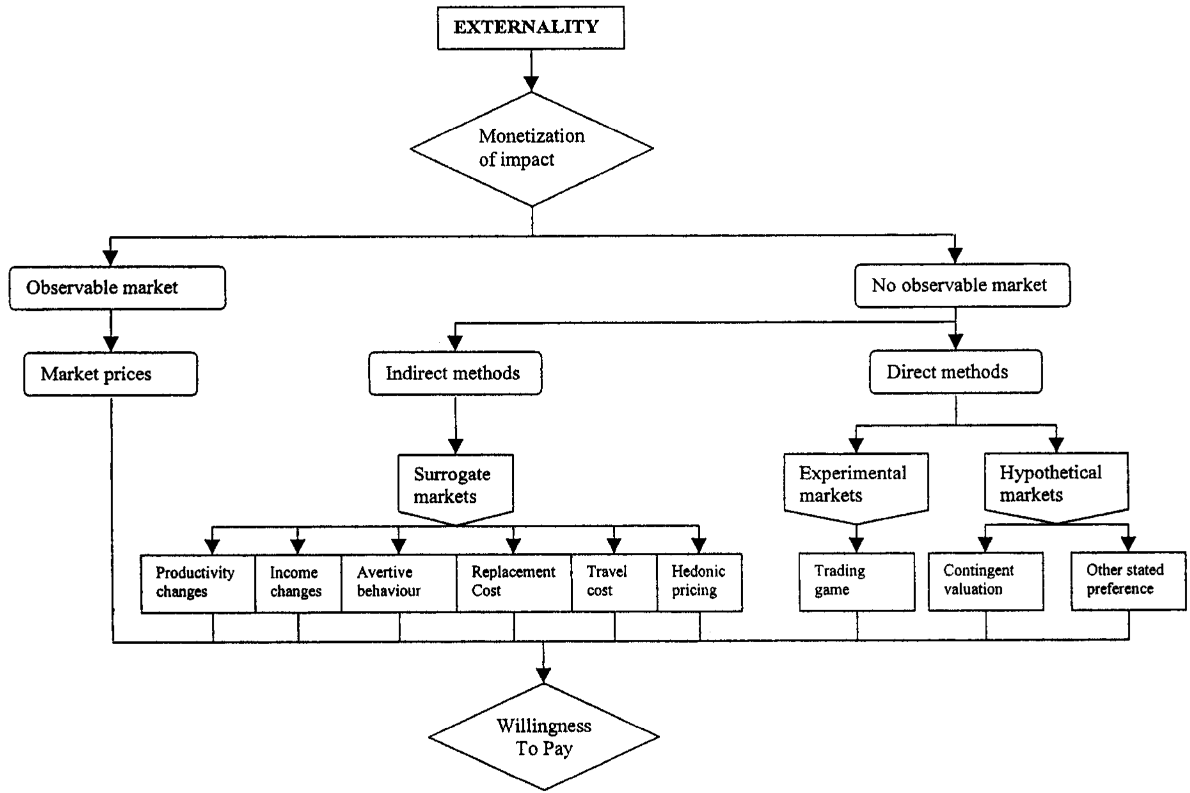
Figure 3 illustrates the major valuation methodologies that have been developed in order to attribute a monetary value to the biophysical impacts of environmental externalities. Commercial, observable, markets exist for some goods, e.g., crops, timber, buildings, etc., and consequently valuation data are relatively easy to derive. However, conventional markets do not exist for assessing damage from many other impacts, such as human health, ecological systems, and non-timber benefits of forests. A number of techniques have been developed for assessing willingness to pay (WTP) for such “goods,” and these are set out in the figure.[5]

The temporal valuation of the cost of damage resulting from energy sector emissions also raises the controversial issue of the appropriate rate for discounting over future generations.[6]

5. A detailed explanation of these techniques, with practical examples, is given in Part III of OECD (1994).

6. See Pearce (2003) for a summary of these issues.

Figure 3. Externality Valuation Methodologies



Source: Adapted from Sundqvist and Söderholm (2002)

4. THE COSTS OF ELECTRICITY GENERATING TECHNOLOGIES

Power plants are most frequently compared on the basis of their levelized electricity cost (LEC), which relates the discounted capital cost of the plant, its annual operating and maintenance costs and fuel prices to the annual production of electricity to yield a value in cents per kWh.[7]

Renewable energy technologies that are, by their very nature, intermittent would incur fuel costs to the extent that backup capacity was used in order to maintain the desired supply of peaking power to the grid. At low levels of renewables penetration additional system costs would be negligible compared with generation costs, since variability would still be within normal tolerance levels for the system as a whole. Thereafter, higher levels of penetration will involve additional cost, since additional generation or electricity storage capacity would be required to meet peak demand if, for example, wind were unavailable.[8] As a consequence, at a purely financial level, the value of intermittent generation should be less than that of conventional generation by approximately these additional costs.[9]

Table 1 gives (indicative) levelized electricity costs in euro-cents per kilowatt hour (euro¢/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, 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 1). However, it is clear that significant policy actions to increase investment in research and development and to stimulate economies of scale in production and dissemination of renewables are required to meet environmental commitments on global climate change in any major way.

7. See, for example, Sorensen (2000) for a more detailed definition of levelized electricity costs.

8. A high rate of penetration by intermittent renewables without electric storage could be facilitated by emphasis on advanced gas turbine power generating systems. Such power generating systems (characterised by low capital cost, high thermodynamic efficiency, and the flexibility to vary the electrical output quickly in response to changes in the output of intermittent power generating systems) would make it possible to back up the intermittent renewables at low cost, with little need for electrical storage.

9. The costs to the system of coping with unpredictable intermittency in the UK have been explored by Milborrow (2001).

Table 1. Cost of Traditional and Renewable Energy Technologies Current and Expected Trends

Energy Source	Technology	Current cost (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 · Peak · Average Rural electrification	2-3 15-25 8-10 25-80	
Nuclear		4-6	3-5
Solar	Thermal electricity (annual insolation of 2500kWh/m^2)	12-18	4-10
Solar	Grid connected photovoltaics (annual electrical output) · Annual 1000kWh per kW (e.g., UK) · Annual 1500kWh per kW (e.g., Southern Europe) · Annual 2500kWh per kW (e.g., lower latitude countries)	 50-80 30-50 20-40	 ~ 8 ~ 5 ~ 4
Geothermal	· Electricity · Heat	2-10 0.5-5.0	1-8 0.5-5.0
Wind	· Onshore · Offshore	3-5 6-10	2-3 2-5
Marine	· Tidal barrage (e.g. proposed River Severn Barrage) · Tidal stream · Wave	12 8-15 8-20	12 8-15 5-7
Biomass	· Electricity · Heat	5-15 1-5	4-10 1-5
Biofuels	Ethanol (*cf.* petrol & diesel)	3-9 (1.5-2.2)	2-4 (1.5-2.2)
Hydro	· Large scale · Small scale	2-8 4-10	2-8 3-10

Source: Adapted from ICCEPT (2002). Units are euro-cents per kWh.

The cost data presented in Table 1, 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. For example, 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 1, 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.

5. ASSESSING THE EXTERNALITIES OF POWER GENERATION

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 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.

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 address effectively 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.[10]

5.1 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 such factors as 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), 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 and crops. The impact of these atmospheric pollutants on forests, fisheries and unmanaged ecosystems are also important but have not yet been quantified. 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 factors. Briefly these are:

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

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.

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

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.[11] 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 ExternE 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 euro¢/kWh to 4.0 euro¢/kWh.[12] 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 euro¢/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, and thus 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.

However, Rabl and Spadaro (2000) have estimated "typical" quantifiable,[13] average European conditions, non-CO_2 damages to be 4.54 euro¢/kWh for the coal fuel cycle, with a comparable estimate for gas of 1.12 euro¢/kWh. The discrepancy between these estimates and those of the ExternE study quoted earlier (that produced separate damage costs estimates for each pollutant in each country in the EU) is due to the higher damage costs attributed to the pollutants by Rabl and Spadaro (2000).

11. See Aunan (1996) for a survey of exposure-response epidemiological studies. Rabl and Spadaro (2000) discuss the ExternE methodology used to derive monetary estimates of health impacts, whilst Pearce (2002) raises questions regarding the ExternE methodology.

12. European Commission (1998).

13. 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.

5.2 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 has yet to be determined with precision. Thus, deriving monetary values on this basis of limited knowledge is, at present, an imprecise exercise.

Table 2. CO_2 Emissions from Different Electricity Generation Technologies

	CO_2 Emissions (tonnes per 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

Source: IEA (1989)
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

Table 2 sets out typical life-cycle CO_2 emissions (in tonnes per GWh) of the major forms of electric power generation. From this table it can be noted that CO_2 emissions from coal and oil-based technologies far exceed those of the "renewables" and are about twice those of gas. In terms of damage costs from CO_2 alone, based upon an updated ExternE estimate[14] of 29 euro/tonne CO_2, (or 8 euro/tonne C) a "typical," average European conditions, coal fuel cycle would cause damage equivalent to 2.8 euro¢/kWh. The comparable damage cost for gas would be 1.4 euro¢/kWh.[15]

5.3 External Damage Costs for Electricity Production

Table 3 gives cost ranges (euro¢/kWh) for quantifiable external 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).

Based upon the Rabl and Spadaro estimates, a typical, average European conditions, new baseload plant, would have total quantifiable damage costs of 7.27 euro¢/kWh for a coal fuel cycle, and 2.37 euro¢/kWh for gas. Both of these estimates fall within their respective "EU range" in Table 3, despite the relatively high assumed damage costs relative to the ExternE study.

These "typical" estimates indicate that total damage costs associated with the coal cycle are (approximately) three times those of gas and a very large multiple of those for renewable energy technologies.[16] If these typical "externality adders" are combined with the lower bounds of the "current" cost data given in Table 1, the gas fuel cycle would exhibit 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. Such a comparison is fraught with problems, however, 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 3.[17] 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

14. Rabl and Spadaro (2000).

15. For new baseload plants these damages are likely to be a little lower, reflecting higher levels of efficiency in power generation. In this context, Rabl and Spadaro (2000) quote estimates of 2.73 euro¢/kWh and 1.25 euro¢/kWh for coal and gas respectively.

16. The exception being some biomass technologies.

17. In addition, the implicit assumption that the real price of fossil fuels will remain constant may not be valid.

emissions of non-GHGs can also be expected to occur as a consequence of continuing improvements in emission-reduction technology and retirement of older plant.

Table 3. 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**

Source: Adapted from European Commission (2003)

5.4 Uncertainty and the Marginal Costs of CO_2 Emissions[18]

Tol (2003) 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/tonne of carbon (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[19] and changing discount rates were also shown to have significant effects on these estimates. Overall, Tol concluded that, for all practical purposes,

18. Original data were quoted in US\$. At the time of writing, US\$1.0 was equivalent to approximately 1.25 euro.

19. 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.

it is unlikely that the marginal costs of CO_2 emissions would exceed $50/tC or (40 euro/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 unity, changes the range to $3.6-$22.5 (2.9-18.0 euro)/tC. A time varying discount rate raised this range to $6.5-$40.5 (5.2-32.4 euro)/tC. All estimates, therefore, are well below Tol's upper bound of $50/tC (40 euro/tC), and the $8/tC quoted earlier falls towards the lower bound of Pearce's final range.

6. INTERNALISING THE EXTERNALITIES OF ELECTRICITY PRODUCTION

6.1 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 an apparent 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 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 hundreds 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 (Philibert, 1999; Newell and Pizer, 2003; and Weitzman, 2001).

6.2 Policy Options for "Internalising" Externalities

Estimated damage costs associated with externalities of fossil fuel combustion tend to lack precision,[20] which would make the imposition of environmental "adders" a very controversial policy option. 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.[21] However, a number of second-

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

21. See Section 9 for an extended discussion of the distinction between control and damage costs.

best options are available that could, at least partially, approximate the desired outcome.

Direct Government 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.

Voluntary Actions

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.

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.[22]

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 European Commission (EC) put forward a proposal for a European Union-wide tax on

22. See Missfeldt and Hauff (2004) for elaboration of this point.

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 nineties. 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 4. Although these taxes have been named carbon taxes, they don't usually have a common tax base. For example, carbon taxes in Denmark and the United Kingdom are imposed on a per kilowatt hour 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.[23]

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'.

23. 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 fore 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 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 4. Taxes in OECD Member Countries Levied on Electricity Consumption

Country	Tax	Tax rate (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 tonnes)	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)

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 5.

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 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.

Regulation

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.

Property Rights

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.

Table 5. Existing and Emerging Domestic Trading Rregimes

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(1)	E	N	2001	(4)	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(2)	P	N	2002	(5)	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(6)	A(7)	Direct CO_2 emissions
Sweden	M	P	N	2005	A	Direct CO_2, possibly other gases
Switzerland	V	P	N	2008	A(8)	Direct CO_2 from fossil fuel combustion
PERT	V	E	I	1996	R	Direct and indirect CO_2, CH_4 and non-GHGs
BP	(3)	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.

(1) Participation in the UK scheme is voluntary, but strong incentives exist to encourage participation. (2) 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. (3) Participation is voluntary for BP, but mandatory for the operating units. (4) The UK system has both absolute and rate-based participants. (5) Both absolute and rate-based limits are proposed for the French system. (6) A pilot phase would begin in 2005, the full programme would start in 2008. (7) The allowances allocated would exceed their current emissions for most sources. (8) 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.

7. CONCLUSIONS

This paper has considered the economics of renewable energy technologies through the quantification in financial terms of the major environmental 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 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 process of transition.

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 (or other pollutant) 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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