UNIVERSITY of STIRLING
INNOVATION and EXCELLENCE

Discussion Paper in Ecological Economics

94/3

Series Editor Dr. Clive L. Spash

SOURCES OF ENERGY AND THE ENVIRONMENT

CLIVE L SPASH AND A YOUNG

MARCH 1994

Environmental Economics Research Group
Department of Economics
University of Stirling

STIRLING DISCUSSION PAPERS IN ECOLOGICAL ECONOMICS

1994 SERIES

94/1 Preferences, Information and Biodiversity Preservation
Clive L Spash and Nick Hanley, March 1994

94/2 The Benefits of Preventing Crop Loss Due to Tropospheric Ozone
Clive L Spash, March 1994

94/3 Sources of Energy and the Environment
Clive L Spash and A Young, March 1994

94/4 Economic Instruments and Waste Minimization: the Need for Discard- and Purchase-Relevant Instruments
Nick Hanley and R Fenton (University of Winnipeg), March 1994

94/5 The Effects of Information in Contingent Markets for Environmental Goods
Nick Hanley and Alistair Munro (University of East Anglia), March 1994

94/6 Cost-Benefit Analysis and the Greenhouse Effect
Clive L Spash and Nick Hanley, March 1994

Copies available from Departmental Secretary, Department of Economics, University of Stirling, Stirling FK9 4LA. The series is circulated on an exchange basis to academic and other institutions, while single copies are available at £3. Cheques/money orders in sterling should be made payable to **The University of Stirling**.

SOURCES OF ENERGY AND THE ENVIRONMENT

Clive L. Spash

and

A. Young

Economics Department, University of Stirling, Stirling, FK9 4LA, Scotland, UK.

Abbreviations

CO_2	carbon dioxide
GW	gigawatts
KWh	kilowatt hour
$KWh/m^2/day$	kilowatt hours per meter squared per day
H_2S	hydrogen sulphide
MW	megawatt
m^2/MW	square meters per megawatt
NO_x	nitrogen oxides
OPEC	Organisation of Petroleum Exporting Countries
p/KWh	pence per kilowatt hour
RSPB	Royal Society for the Protection of Birds
SO_x	sulphur oxides
TkW	tera kilowatts (10^{12} kilowatts)
UK	United Kingdom

I. INTRODUCTION

Energy in accessible forms is central to modern day existence with industrial economies based upon the use of fossil fuels in ever increasing quantities. The United Kingdom (UK) is a typical example of this dependence with 95% of final energy consumption derived from fossil fuels (Department of Energy, 1992). The insecurity of foreign oil supplies (exemplified by OPEC price rises, the Iranian revolution and the invasion Kuwait by Iraq) and growing awareness of the social costs of fossil fuel use have encouraged the development of alternative energy sources. This second incentive is analyzed here.

The paper divides energy sources in to fossil fuels and nuclear power, as the conventional sources, and renewable and geothermal energy, as the alternatives. While conventional and geothermal sources use energy capital (ie., a finite stock) so reducing future options, renewable energy sources employ energy income (ie., the stock remains constant). At present utilising capital appears to be most efficient, however the true cost of fossil fuel use is misrepresented by market prices. For example, fossil fuel combustion produces emissions which degrade the environment and impose costs on society eg., through poorer health. Thus, pricing is inaccurate and excessive energy use occurs from polluting sources. The hypothesis we wish to investigate here is that renewable energy sources are falsely seen as too expensive because their external benefits to society are ignored eg., energy capital maintenance and lower pollution. We review the environmental impacts of each energy source, and use this to draw-out key features of the debate over the potential for fossil fuel substitution by renewable energy sources.

II. CONVENTIONAL ENERGY SOURCES

Oil, Coal and Natural Gas

A considerable amount of resources are used in the exploration for and extraction of oil and gas. Oil and gas wells cause visual, noise and ecological impacts and rely on extensive transportation, storage and refining sectors. Environmental impacts from coal extraction vary with the choice of open-cast versus closed-pit mining. Both can cause acid mine drainage affecting local water supplies and the ecosystems they feed. In the case of the open cast mines a major aesthetic impact occurs and the site may never be returned to its former condition (despite attempts at reconstruction). During oil extraction there is the risk of accidents, such as subsidence of spent fields, rig disasters (eg., Piper Alpha in the North sea) and oil spills. Transport accidents have received considerable attention due to oil tanker spills, such as the Amico Cadez, Exxon Valdez and Braer. In the case of the Exxon Valdez damages ran into millions of dollars and the spill partially destroyed a habitat of international importance.

Fossil fuel combustion releases gases which affect health, cause acid rain and contribute to the greenhouse effect. Acid deposition is the result of sulphur oxides (SO_x) and nitrogen oxides (NO_x) becoming weak acids, and falling to the ground as particulates (dry deposition) and acidic rain (wet deposition). Dry deposition can lead to respiratory illness in humans and acidify water and soils. Regionally acid deposition can be transported over large distances affecting whole continents. For example, the air pollution damage to West German and Scandinavian forests and lakes has been attributed to acid deposition originating from the UK and Eastern Europe (Acid News, 1992 pp.10-12). Similarly, acid deposition in Canada is attributed to fossil fuel combustion in the central and eastern

United States. Most important among the greenhouse gases are carbon dioxide (CO_2), methane and nitrous oxide (N_2O), which contribute 50%, 11% and 6% respectively to climate forcing (Spash and Hanley, 1993). The ratios of CO_2 per unit of energy are 5 for coal, 4 for oil and 3 for gas (Thurlow, 1990). Emissions of greenhouse gases prior to 1985 have already committed the earth to a warming between 0.9°C to 2.4°C, of which 0.5 has already been experienced (Ciborowski, 1989). This may cause the instability of atmospheric systems resulting in sea level rise, loss of agricultural productivity, and reductions in biodiversity. The costs are globally distributed and will be pushed onto future generations (Spash, 1994).

Other environmental impacts include thermal pollution, the aesthetics of the power plant and land use. Thermal pollution can be measured by the ratio of thermal power rejected to the total electrical output produced. This gives a ratio of 1.7, 1.6 and 3.0 for coal, oil and gas fired power stations respectively and 2.5 for nuclear (Dipippo, 1991 p.804). Control of thermal pollution requires coolant water which can adversely affect the ecology of water courses upon release.

Nuclear Power

Environmental impacts from nuclear power range from the mining of uranium through nuclear accidents and contamination to the disposal of wastes and decommissioning the power stations. The issue of nuclear accidents has loomed large since the Chernobyl reactor partial melt-down which released radiation around the globe. The problem of where to store nuclear waste remains unsolved and raises the issue of intergenerational ethics (Routley and Routley, 1980). The decommissioning process still awaits practical experience as governments prefer to keep old stations open rather than face up to the problems posed by the disposal of thousands of tons of materials contaminated with low levels of radiation.

III. ALTERNATIVE ENERGY SOURCES

The energy flow absorbed by planet Earth in just one year is 100 times the worlds proven fossil fuel reserves (Flood, 1991). Given current technology, the potential energy which could be recovered is: solar 1000 TkW, wind 10 TkW, wave 0.5-1.0 TkW, hydroelectric 1.5-2.0 TkW, tidal 0.1, and biomass 30 TkW, where TkW is tera kilowatts or 10^{12} kilowatts (Jackson 1992). Present world energy demand is approximately 10 TkW. The energy technologies analyzed below are the renewables: solar, wind, ocean, hydroelectric and biomass; and non-renewable geothermal energy.

Solar Energy

There are 3 solar technologies: (a) passive solar, (b) thermal conversion, and (c) photovoltaic. In a good solar climate (eg., Southern California) the average energy available will be 5-6 $KWh/m^2/day$ (kilowatt hours per meter squared per day), whilst in poorer areas (eg., Northern Europe) the mean is 2-3 $KWh/m^2/day$ (Charters, 1991 p738).

(a) Passive solar. This can be an almost benign method of extracting energy relying on building design. Factors to be considered include: site selection, building orientation, insulation and thermal mass for storage. In many temperate and tropical regions zero energy structures can be designed; requiring no energy input other than solar for both space and water heating (Charters, 1991 p.739). Reduced air exchange from insulation

may cause the build-up of gases such as carbon monoxide, radon, or formaldehyde leading to health risks, but this can be prevented by improved ventilation. The manufacture of fillers for cavity-walls (eg., polystyrene and mineral wool), and the use of glass-fibre and metal foil for insulating roofs could have some environmental impacts.

(b) Thermal Conversion. Thermal conversion refers to the concentration of sunlight using parabolic mirrors to reflect onto a central receiver. Turbidity affects the diffusion of radiation reducing the efficiency of focusing on the central receiver making clear skies preferable eg., deserts where 80% of radiation is direct. Successful conversion occurs when working fluids are supplied to a turbine at temperatures above 175°C (OECD, 1988 p.27). Currently the largest such plant is 354 MW (megawatts) at Luz in California, with contracts for another 320 MW (Charters, 1991). Air pollution could occur due to an accident involving the bi-products of the heat transfer systems (NO_x, sodium monoxide and peroxide). Water pollution via planned or accidental release will vary with the type of system, but could include oil, corrosion inhibitors, bactericides and glcols (OECD, 1988 p.28). In both cases the quantities are small but could cause significant local impacts. Washing the mirrors would use large quantities of water which could be problematic if the oil based detergent or heated water is released into the environment. Some effects on local climate may occur such as wind deflection and reduced albedo.

(c) Photovoltaic. Photovoltaic methods of energy extraction directly convert light into electricity using silicon solar cells. Environmental concerns arise due to the introduction of exotic materials, such as gallium arsenide, which are used to increase cell efficiency. Careful handling is required during the refining, fabrication and de-commissioning of cells

and when chemicals are being transported (Jackson, 1992 p.873). The fabrication of photovoltaic cells requires large quantities of gases such as arsine or diobrane, which are amongst a list of 17 highly toxic and potentially lethal chemicals identified by the OECD (1988). While such chemicals are already used in industry with a good safety record the risk of accidents will rise with the scale of fabrication.

Wind Power

Wind power has proved to be one of the most successful renewable energy sources. The engineering design is relatively simple, the raw materials are fairly common and the waste problem is minimal. In California 1500 MW of capacity has been installed using 1600 terawatt (TW) stations with medium size machines (250-300 KW) standing 50 metres high (Clarke, 1991 p.743). Wind turbines have proved to be viable in the 75 to 300 KW range in both Europe and the US (Dawber, 1992). The principal impact is visual, however the effect is largely limited to a local area. The need for stable and adequate wind flows means the most economic sites are inland elevated areas or exposed coastal areas, which are both sensitive to visual intrusion. Noise may be a problem but is usually restricted to a zone of 300 metres around the station. A Californian study showed that only 4% of people living within two miles of a large wind turbine development at San Gorgino Pass were disturbed by the noise (Pasquatti and Butler, 1987). Other concerns which have been raised but seem minimal are health risks (see Clarke, 1991 p.751), electromagnetic interference and bird kills. Electromagnetic interference may occur with some aircraft navigation systems within 1 to 5 kilometres, while a booster station can counter radio and television interference (OECD, 1988). At Altamont Pass, California, bird strikes have been recorded, but monitoring at a test site in the UK lead the Royal Society for the

Protection of Birds (RSPB) to conclude there was no impact on any bird-life (Clarke, 1991). Claims that large land areas will be employed have ignored the potential for multiple land use. For example, in Velling Maersk, Denmark tillage is allowed up to the tower base so that only 3.2% of the land is used by the wind plant, and in Altamont Pass no more than 5% of leased land is removed from grazing (Gipe, 1991 p.764). In addition, by reducing wind speeds soil erosion can be reduced in some areas.

Ocean Energy Systems

There are four ocean energy systems: on and off-shore wave, ocean thermal electrical conversion (OTEC) and tidal barrages.

On-shore and Off-shore Wave Energy. The potential for the extraction of wave energy is considerable and predictable. Young (1993) has estimated that in-shore wave power at three Scottish islands could supply 35% of Scotland's current demand. The potential for on-shore energy can be enhanced by natural or man-made gullies and there are operational stations in Scotland (100 KW) and Norway. Off-shore stations have been tried using several types of technology eg., buoys, Salter's ducks and rafts. The UK government funded research into a 2 gigawatt (GW) off-shore station during the 1970's and 1980's, but withdrew support as economic feasibility drew near. Without practical experience environmental impacts are highly speculative but seem minimal. The visual impacts are small as on-shore facilities are sited in gullies, while off-shore facilities are usually far from any population centres. The removal of energy in large quantities from marine ecosystems will have some impacts as shore-lines have high energy input-output ecologies. Silt could build-up along coast lines changing habitats with uncertain effects on aquatic life. Hydraulic fluid could leak from off-shore units. Health and safety risks may occur during maintenance of off-shore facilities. Potential benefits include the provision of habitat for fish and, via a dampening of wave power, reduced wear and tear on coastal structures and facilities eg., coastal defences.

OTEC. This requires a temperature gradient of at least 20°C to get sufficient energy. For example, the gradient between the hot surface water (27°C) of the tropical seas and the cold bottom water (2°C) a thousand meters below (Odum, 1988 p.86). A 50 KW demonstration project is currently running in Hawaii, but without a comprehensive environmental impact analysis. The impacts will be dependent upon site characteristics, the scale of the station and the energy extraction technique ie., open or closed systems. In open systems cold nutrient rinse water is released back into the sea changing water temperature and salinity, which can alter circulation patterns eg., creating cold water sinks. This could affect plankton and so fish and aquatic life. In addition, coral reefs might be damaged as they are sensitive to thermal and nutrient pollution. Closed systems try to mitigate such impacts by preventing the re-release of rinse water. Pollution emissions from OTEC could arise due to the discharge of working fluids and bio-aids, and the potential release of CO_2 from deep water sites. Other concerns include the production, use and de-commissioning of the bio-aids and their accidental release. Beneficial bi-products of OTEC are pure water and nutrients. In Hawaii the generation station has sold nutrient rich waters to farmers.

Tidal Barrages. Tidal power harnesses the gravitational pull of the moon and sun using a barrage across an estuary to extract the power released when water passes through a vertical distance (the "head"). The turn of each tide generates electricity via the use of turbines, providing a highly predictable amount of energy. The technology is well-developed eg., a 240 MW station has been operating for 20 years at La Rance in France. Such stations totally alter the estuary and the overall ecosystem affects, while mixed, tend to be negative. The water table is liable to rise as a result of holding tides for longer, although this can contrast with a decrease in flooding. As the velocity of tidal currants is reduced, the waters power to erode and transport sediments changes. This causes sediments (which largely govern estuarine ecology) on the on-shore side to "freeze", where they would normally be mobile, and decreases turbidity. This can provide a more stable environment for organisms living in muddy deposits, which in turn leads to higher invertebrate populations benefiting wading birds. Meanwhile, on the off-shore side erosion of sedimentary banks will destroy habitats irreversibly (a problem which prevented a barrage across the Severn, UK). Potentially there could be a build up of pollutants leading to toxicity and eutrophication, although this would be dependent upon chemical and nutrient inputs to the site. One unavoidable change is decreasing salinity upstream causing the domination of fresh water species, while the brackish water zone is impoverished and moves downstream. The reduced salinity will affect breeding zones for crustacea and shellfish with resulting economic impacts on fishermen. Where an estuary is a major fish run or on the migratory path of birds impacts can be international.

Hydroelectric Dams

Hydropower extracts the ambient flow of solar power expressed as the evaporation of water and its release on higher ground. Dams vary widely in size; affecting the environmental impacts eg., 10,000 MW La Grande River development at James Bay in

Canada versus 100 KW at Lyemouth gorge, UK. Mega projects threaten wide spread impacts eg., proposed dams in the Himalayas of Napal (Chisapani gorge) would lower sedimentary yields and run-off for the whole sub-continent, besides making 70,000 people homeless (The Independent, 1991).

The environmental damages are various. The dam creates a reservoir behind which the land (often fertile valley bottoms) is inundated with water precluding it from other uses. The standing water in the reservoir causes sedimentation while clearer water leaves the dam reducing soil replenishment and increasing erosion down-stream. Thermal stratification, especially in deep reservoirs, can lead to the formation of ammonia and hydrogen sulphide which are toxic to marine life. Water passing through the turbine will be heated and on release can lead to a reduction in insect life (eg., the May fly) which is a building block of ecosystem structure. The creation of large reservoirs will also effect migratory patterns of large mammals eg., reindeer in Canada. The change from riverine to lacustrine (river to lake) environment changes water flow, nutrient content, temperature, oxygen content and sedimentation. As a result spawning fish, eg., salmon, may fail to pass through larger lakes, dying or turning back. Fish migration will be restricted by the creation of the dam requiring fish ladders where feasible. Other species may be harder to protect eg., the Snail darter, a protected bird, threatened by Telic Dam in Tenessee (OECD, 1988 p.78). Health and safety concerns arise because dams often create favourable conditions for disease carrying agents eg., an increased frequency of Malaria and bilharzia at the Selingua dam in Mali (Sims, 1991). The potential failure of large dams poses the risk of disastrous flooding and there can be a temporary increase in seismic activity due to the construction of large reservoirs eg., La Grande.

On the beneficial side a well constructed and implemented dam can lead to better water management eg., the Danube, Austria. The water body created by a dam does provide recreational opportunities and can be an attraction for tourists. Effects on the micro-climate near the dam can also be beneficial. Large water bodies ameliorate temperatures and decrease convection reducing cloud cover, thus benefiting agriculture by preventing freezing (Sims, 1991, p.779).

Biomass

The discussion of biomass is complicated by the wide range of production choices which can be made to achieve the same energy output. In general terms biomass can be broken down into two categories: (i) energy plantations and (ii) clean-up biomass. This latter category can be further split into: (a) biomass from farming residues and (b) waste from industrial and non-commercial processes. The energy product from biomass can be provided in several different forms eg., electricity, liquid fuel or gas.

Energy Plantations. The impact of a large switch into biomass depends upon the previous land use and the type of plantation eg., monoculture conifer plantations, short rotation coppice or natural woodland. Where the land was under intensive agriculture a reduction in fertiliser use can be expected (Rowan, 1991 p.80), as well as improvements in soil structure, nutrient retention and nitrate leaching. Although, the routine application of chemicals from the air to protect monocultures seriously affects insect life. Afforestation of some soil types can also be negative (eg., drying out peat bogs) while in other areas it can be used for water management (eg., preventing floods). If the use prior to biomass production was grassland bird habitat may be reduced. Monoculture conifer plantations reduce biodiversity although this may be ameliorated by careful siting and interspersing other tree species. Generally, the greater the age structure and species diversity the richer the habitat. Monocultures provide only canopy feeders and often result in irreversible loss of species which were previously present (Moss 1978).

The choice of trees and felling methods are important determinants of environmental impacts. Conifers can acidify soils and mobilise heavy metals, such as aluminium, which kill fish and cause irreversible damage to water courses. During planting and felling the use of large machines results in soil compaction and erosion. Clear felling exasperates this situation by exposing mineral soils to leaching and extremes of climate; reducing the level of organic matter under short rotation coppice and monoculture plantations. When clear felling occurs there will be an obvious visual impact as the land is scared. Selective felling (silviculture) can avoid these impacts.

End-use decisions will also determine the extent of social costs. Drying wood can greatly increase fuel efficiency but bark decomposition while drying can allow tannic acid to leach into water courses. Unregulated wood combustion causes more air pollution by weight per thermal unit than oil and coal (IEA, 1989 p.198). Air pollution from domestic wood burning can be avoided by regulating stove and fuel type. A major advantage is that net CO_2 release is zero over the rotation of a plantation. Thermal pollution can be avoided by using low grade heat for community water heating as in Denmark. While solid waste, low in toxins, can be used as a fertiliser.

Clean-up Biomass. Farming residues can be classified as waste from current activities which are normally dumped eg., in the UK there is a surplus of 5 to 7 million tons of straw and 1,400,000 tons of poultry waste per year. Denmark has 54 straw fired district heating systems of 3-5 MW (Department of Energy, 1991). The UK has a 30 MW station using 25,000 tons of straw annually and two projects using straw and poultry litter. There are significant environmental advantages in terms of reducing pollution associated with waste disposal eg., nitrate leaching from manure. The levels of NO_x and SO_x are a small fractions of those from coal fired stations. The emissions are low in particulates and have a quarter of the CO_2 and equivalent greenhouse gases of coal fired plants. The main by-product is nitrogen free ash which is an environmentally friendly fertiliser (Department of Energy, 1993 pp.10-12). Human waste products from hospitals, industry and sewage stations can also be used for the generation of energy, eg., a 975 KW sewage station at Finham, UK. The economic incentive is provided by avoiding disposal costs eg., in London municipal waste disposal costs £10 per ton. However, if the biomass waste is contaminated, emissions after combustion can contain high levels of toxic substances including heavy metals and dioxins (Department of Energy, 1993 p6).

Geothermal energy

Geothermal energy is extracted from the accessible heat in the outer 15 kilometres of the earths crust. Three broad categories are: (i) hydrothermal, reservoirs of steam or water; (ii) geo-pressurised, reservoirs of brine; and (iii) hot dry rock, often too deep for tapping but viable where molten rock has broken through the Earth's crust. At the end of 1990 installed geothermal capacity worldwide was 6,071 MW from 330 individual turbines with 47% in the USA (Dipippo, 1991 p.799). In the USA the potential is for some 25,000 MW of (electrical) energy, but this will only last for 40 years because the heat reservoirs become exhausted.

Air pollution will occur in relatively small quantities. Carbon dioxide is always the principal gas released but the quantities are only 10% of those from oil for an equivalent amount of energy. Other gases include hydrogen sulphide, H_2S, a toxic foul smelling gas. However, most geothermal areas are already burdened by such gases and therefore nearby vegetation should already be resistant. Although, wastes can contain a whole cocktail chemicals, dependent upon rock composition, water pollution is minimised by reinjection into the ground which is common practise. Reinjection can cost between $10-20 per KW with a corresponding decrease in output of 10-20%; resulting in a $85-$90 per KW loss in annual revenue on a 50 MW station. When venting steam from the plant noise can reach 114 decibels at a range of 8 meters; comparable to a jet plane (120-130 decibels). Subsidence and seismic activity can occur. At Wairakei, New Zealand, the ground level has dropped 7.5 meters in some places and continues at 0.4 meters per year. While subsidence is localised it can fracture pipelines and requires monitoring.

IV. ALTERNATIVE ENERGY SOURCES VERSUS FOSSIL FUELS

In order to draw a general picture from the evidence presented so far we can consider only those environmental impacts which seem most important to the substitution debate. That is, we wish to discern the relative merits of alternative energy sources from the way in which they affect the environment. More specifically we consider the following impacts: land use, physical changes, air pollution, aesthetics, and health and safety.

Land use. Generally renewable energy sources appear to cover a greater land area than fossil fuels. Photovoltaics require 66,000 m^2/MW compared to 40,000 m^2/MW for coal derived from a strip mine over 30 years (Dipippo, 1991). Wind power uses a larger area but allows continued use of 95% or more of the land in other activities (Gipe, 1991 p764). However, over their life-cycle fossil fuels can use large areas, eg., oil requires land for wells, drilling, refining, storage, terminals, generating plant and transportation systems. Certainly passive solar will release land from current energy production thus providing net gains. Biomass can also be designed for multiple use and dams create recreational opportunities. The relative merits of opportunities lost and gained is central to alternative energy in contrast to fossil fuels where land use is exclusive.

Physical Changes. In the case of fossil fuels, impacts can be numerous and widespread eg oil spills at sea, strip mining, slag heaps, dead trees due to acid rain and so on. In the case of renewable energy sources there are often profound and irreversible physical changes, but these are normally limited spatially. Damming a river valley produces irreversible change throughout the water course eg., revised flows, thermal pollution, clear water poison and lower oxygen content. Biomass also totally alters the environment but can provide benefits such as reduced soil erosion, lower nitrates in water courses and increased biodiversity. The net outcome of such a development is site specific, but unique areas can be destroyed. Wind, solar and geothermal appear the most benign physically. The only wider spatial effects of alternative energy sources are if the area has a unique ecology (endangered species) or if the areas are particularly sensitive (such as estuaries where migrating birds feed), in which case there can international costs.

Air Pollution. The large scale release of chemicals associated with fossil fuels (previously stored within the biosphere) damages terrestrial and aquatic ecosystems at local, regional and global scales. Regional impacts include acidification of water and soils and the release of aluminium to water courses, which leads to tree damage, fish deaths and reduced biodiversity. As a direct cost, the estimates lie in the range of 0.17-4.5 p/KWh, without the costs of health and global warming, estimated at a further 2-4 p/KWh (Twidell and Brice, 1992). SO_x and NO_x can be removed from smoke stacks, but this process produces gypsum salts as solid waste. Disposal of these wastes can result in leaching causing significant local or regional acidification. Lime used in some control systems is mined, which will create its own environmental costs.

Renewable energy sources would reduce air pollution compared to fossil fuels, although biomass and can create significant emissions. Energy plantation biomass has zero net CO_2 emissions over a complete rotation period and the benefit of storing more free CO_2 within the cycle as use increases, while controlled combustion releases NO_x in smaller quantities than fossil fuels. Energy from organic waste appears to reduce pollution compared to other disposal methods. The trade-off in terms of emissions is dependant upon fuel type and combustion method, but is similar to energy crops, and definitely less than fossil fuels. Incinerating waste probably has negative impacts in the long run through discouraging recycling, while creating toxic emissions. Geothermal has relatively low CO_2 emissions, so there are temporal benefits and other emissions are localised. While photovoltaics create some risk of emissions during the production of solar panels.

Aesthetics. Visual intrusion is a matter of the perception of people towards a specific structure. This issue has been raised most often with regard to wind power which tends to be spread-out with structures standing up to 50 metres high. However, in a Californian study a "Not In My Backyard" (NIMBY) index was created on the basis of visual intrusion and acceptability. The findings show wind was rated as more acceptable than either biomass or fossil fuels, with the latter being most unacceptable of the three (Clark, 1991). As far as other renewable energy sources are concerned, visual intrusion is usually limited. While the change can be drastic with the construction of a dam the scale of the effect is a function of the size of the development. The extent to which renewable energies can be expected to impact visually is heavily site dependent. Thus, if the demand for energy from renewable sources grows we can expect more sensitive sites to be employed. The push for larger dams or wind generators on exposed sites in open moorland and national parks will result in a greater impact, as has occured with the drive to find fossil fuels in such areas. The movement to small scale local generation of electricity which some renewables offer would remove the need for national grid lines which cause a major visual intrusion eg., in the UK.

Health and Safety. Risks to workers in oil fields and coal mines are often internalised through higher wages and compensation from accidents such as Piper Alpha. Therefore we might expect that any risks resulting from the production of renewable energy sources, eg., exotic materials involved in the production of photovoltaics would be treated similarly. This excludes effects borne by society in general. In the case of fossil fuel these include the incidents of raspatory disease, cancer, asthma and ozone smogs. The costs are borne either by the individual or the state through medical bills and lost production. As noted above biomass combustion will release similar gases to fossil fuels but, with controlled combustion, in small net quantities. However, other renewable energy sources are less prone to cause externalities of this sort. Thus, one of the major benefits of renewable energy sources is in terms of human health.

V. CONCLUSIONS

In terms of generating costs renewable energy is generally more expensive than fossil fuels. Including the social costs of fossil fuels in their price would dramatically change this picture (Jackson, 1992). Hohmeyer (1990) has calculated the social costs of generation for the Federal Republic of Germany and shows how wind power has positive benefits over conventional sources. Research and development expenditure on alternative energy sources have been minuscule relative to nuclear power where the returns have been poor. The implication is that research in the area of renewable energy generation would seem to offer great potential returns for society. However, the costs associated with alternative energy sources will increase and benefits decrease with greater substitution for fossil fuels. That is, the more valuable ecological areas dependent upon particular energy flows will be disrupted or destroyed. The remaining natural areas will therefore become more highly valued. As emissions from fossil fuels decline the social costs per KWh will fall so that renewable energy prevents fewer less important externalities.

Air pollution from fossil fuel combustion is one of its most serious environmental impacts. Emissions disperse widely, degrading the environment indirectly via chemical changes, such as acidification which kills trees and fish. Cause-effect relationships are hard to discern because damages are separated from the emitter eg., CO_2 released 100 years ago contributing to global warming now. At the same time fossil fuels are a finite resource so that their depletion can reduce the opportunities and capabilities of future generations.

The replacement of fossil fuels by renewable energy sources creates a different set of impacts. The social costs of renewable energy sources tend to occur at a specific site and are normally highly visible. Thus the argument over fossil fuels verses renewable energy sources tends to be an argument over global verses local impacts on the environment. Social benefits of renewable energy can include decreased pollution, maintenance of depleted fossil fuel reserves, flood control, greater national security, higher employment, and reduced investment in over capacity. Over their life-cycle, from extraction to disposal and end-use, renewable energy sources have the potential to give significant benefits over current fossil fuel use. Although, the specific sites involved in the development of renewable energy sources is a key to their social cost.

In summary, we can generalise that fossil fuels tend to have dispersed (temporal and spacial) chemical impacts, while renewable energy sources tend to have more local physical ones. The principle advantage of renewable energy is the lower level of environmental impact. However, renewable energy sources do create their own set of externalities which need to be acknowledge in order to avoid the type of backlash of public opinion nuclear power has created. The impact of renewables can be expected to increase with their scale of use eg., exotics in photovoltaics, sensitive sites for wind and wave, fertiliser use in energy plantations. The choice between fossil fuels and renewable energy appears to turn on the decision of whether to accept definite changes today in local ecosystems or uncertain changes tomorrow in regional and global systems.

REFERENCES

Acid News (1992) 5th December 1992

Charters William W S (1991) "Solar energy current status and future prospects" Energy Policy 19 no.8 (October): 738-741.

Ciborowski Peter (1989) "Sources, sinks, trends and opportunities". In The Challenge of Global Warming edited by Dean E Abrahamson. Washington, CD: Island Press.

Clarke Alexi "Wind energy: progress and potential" Energy Policy 19 no.8 (October): 742-755.

Dawber Keith (1992) "Harnessing the wind in Otago (and in the rest of the world)." The Otago Graduate Otago University, New Zealand pp. 12-13.

Department of Energy, UK (1993) "Poultry power: an offbeat source of energy" Review Issue 20 (March): 10-12.

Department of Energy, UK (1992) Energy Trends London: Department of Energy.

Department of Energy, UK (1991) "What next for straw" Review Issue 17 (Autumn): 18-20.

Dipippo Ronald (1991) "Geothermal energy, electrical and environmental impact" Energy Policy 19 no.8 (October): 798-807.

Flood N (1991) Energy Without End Friends of the Earth.

Gipe Paul (1991) "Wind energy comes of age: California and Denmark" Energy Policy 19 no.8 (October): 756-767.

Independent (1991) "Power of the Himalayas" The Independent (1st December): 64.

Jackson Tim (1992) "Renewable energy" Energy Policy September: 861-888.

Hohmeyer Olav (1990) "Social costs of electricity generation: wind and photovoltaic versus fossil and nuclear" Contemporary Policy Issues VIII July: 1-29.

IEA (1989) Energy and the Environment: Policy Overview Paris: OECD.

OECD (1988) The Compass Project: Environmental Impacts of Renewable Energy Paris.

Odum Howard T (1988) Energy, Environment and Public Policy: a Guide to the Analysis of Systems UNEP Regional Seas Reports and Studies No.95, UNEP.

Pasquatti Martin and E Butler (1987) "Public reaction to wind development in California" International Journal of Ambient Energy 8 no.2 (August).

Routley R and V Routley (1980) "Nuclear energy and obligations to the future" in E Partridge (editor) Responsibilities to Future Generations New York: Prometheus Books.

Sims Geoffery P (1991) "Hydroelectric energy" Energy Policy 19 no.8 (October): 776-786.

Spash Clive L and Nick Hanley (1993) "Cost-benefit analysis and the greenhouse effect" Economics Department Working Paper, University of Stirling.

Spash Clive L (1994) "Double CO_2 and Beyond" Ecological Economics forthcoming.

Twidell John and Robert Brice (1992) "Strategies for implementing renewable energy: lessons from Europe" Energy Policy (May).

Young Andrew (1993) "Inshore wave power for electricity generation in island communities" Unpublished manuscript, Economics Department, University of Stirling pp142.

Department of Economics
University of Stirling
Stirling
FK9 4LA