Chapter 15

Environmental Imperatives and Renewable Sources of Energy

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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 is a typical example of this dependence, with 95 percent 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 of 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 chapter divides energy sources into 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 (i.e., a finite stock), so reducing future options, renewable energy sources employ energy income (i.e., the stock remains constant). At present utilizing 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 that degrade the environment and impose costs on society—for example, 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, such as energy capital maintenance and lower pollution, are ignored. 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.

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 (e.g., Piper Alpha in the North Sea) and oil spills. Transport accidents have received considerable attention due to oil tanker spills, such as the *Amoco Cadiz*, *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 that affect health, cause acid rain, and contribute to the greenhouse effect. Acid deposition is the result of sulfur 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 United Kingdom and Eastern Europe (*Acid News* 1992: 10–12). Similarly, acid deposition in Canada is attributed to fossil fuel combustion in 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 percent, 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 and 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: 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 power stations. The issue of nuclear accidents has loomed large since the Chernobyl reactor partial meltdown, 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.

ALTERNATIVE ENERGY SOURCES

The energy flow absorbed by planet Earth in just one year is 100 times the world's proven fossil fuel reserves (Flood 1991). Given current technology, the potential energy that could be recovered is: solar 1,000 TkW (tera kilowatts or 10^{12} kilowatts) wind 10 TkW, wave 0.5–1.0 TkW, hydroelectric 1.5–2.0 TkW, tidal 0.1 TkW, and biomass 30 TkW (Jackson 1992). Present world energy demand is approximately 10 TkW. The energy technologies analyzed here are the renewables: solar, wind, ocean, hydroelectric, and biomass; and nonrenewable geothermal energy.

Solar Energy

There are three solar technologies: passive solar, thermal conversion, and photovoltaic. In a good solar climate (such as Southern California) the average energy available will be 5–6 KWh/m^2/day (kilowatt hours per meter squared per day), while in poorer areas (such as Northern Europe) the mean is 2–3 KWh/m^2/day (Charters 1991: 738).

Passive Solar

Passive solar 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: 739). Reduced air exchange from insulation may cause the buildup 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 (polystyrene and mineral wool), and the use of glass fiber and metal foil for insulating roofs could have some environmental impacts.

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—such as in deserts where 80 percent of radiation is direct. Successful conversion occurs when working fluids are supplied to a turbine at temperatures above 175°C (OECD 1988: 27). Currently the largest such plant is 354 MW (megawatts) at Luz, California, with contracts for another 320 MW (Charters 1991). Air pollution could occur due to an accident involving the by-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 glycols (OECD 1988: 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.

Photovoltaic

Photovoltaic methods of energy extraction directly convert light into electricity using silicon solar cells. Environmental concerns arise as a result of 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 decommissioning of cells and when chemicals are being transported (Jackson 1992: 873). The fabrication of photovoltaic cells requires large quantities of gases such as arsine or diobrane, which are among 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 1,500 MW of capacity has been installed using 1,600 terawatt (TW) stations with medium-size machines (250–300 KW) standing 50 meters high (Clarke 1991: 743). Wind turbines have proved to be viable in the 75–300 KW range in both Europe and the United States (Dawber 1992). The principal impact is visual, but 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 meters around the station. A California study showed that only 4 percent 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 that have been raised but seem minimal are health risks (see Clarke 1991: 751), electromagnetic interference, and bird kills. Electromagnetic interference may occur with some aircraft navigation systems within 1 to 5 kilometers, 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 United Kingdom led the Royal Society for the Protection of Birds (RSPB) to conclude there was no impact on any birdlife (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 percent of the land is used by the wind plant, and in Altamont Pass no more than 5 percent of leased land is removed from grazing (Gipe 1991: 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. Andrew Young (1993) has estimated that in-shore wave power at three Scottish islands could supply 35 percent 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—buoys, Salter's ducks, and rafts. The U.K. government funded research into a 2 gigawatt (GW) off-shore station during the 1970s and 1980s 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 centers. The removal of energy in large quantities from marine ecosystems will have some impacts as shorelines have high-energy input-output ecologies. Silt could build up along coastlines, 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, such as coastal defenses.

OTEC

OTEC 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) 1,000 meters below (Odum 1988: 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 (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 and create cold water sinks. This could affect plankton and thus 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 rerelease of rinse water. Pollution emissions from OTEC could arise owing to the discharge of working fluids and bioaids, and the potential release of CO_2 from deep water sites. Other concerns include the production, use, and decommissioning of the bioaids and their accidental release. Beneficial by-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 release 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—a 240 MW station has been operating for 20 years at La Rance, 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 longer, although this can contrast with a decrease in flooding. As the velocity of tidal currents is reduced, the water's 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 offshore side, erosion of sedimentary banks will destroy habitats irreversibly (a problem that prevented a barrage across the Severn, in England). Potentially there could be a buildup 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—for example, the 10,000 MW La Grande River development at James Bay in Canada versus 100 KW at Lyemouth Gorge, U.K. Mega projects threaten widespread impacts—for example, proposed dams in the Himalayas of Nepal (Chisapani Gorge) would lower sedimentary yields and runoff for the whole subcontinent, 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 oil replenishment and increasing erosion downstream. Thermal stratification, especially in deep reservoirs, can lead to the formation of ammonia and hydrogen sulfide, 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 (e.g., the mayfly), which is a building block of ecosystem structure. The creation of large reservoirs will also affect migratory patterns of larger mammals, such as 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 like salmon may fail to pass through larger lakes, thereby 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, such as the snail darter, a protected bird, threatened by Telic Dam in Tennessee (OECD 1988: 78). Health and safety concerns arise because dams often create favorable conditions for disease-carrying agents—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 because of the construction of large reservoirs like the one at La Grande.

On the beneficial side, a well-constructed and implemented dam can lead to better water management, as shown by the Danube in Austria. The water body created by a dam does provide recreational opportunities and can be an attraction for tourists. Effects on the microclimate 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: 779).

Biomass

The discussion of biomass is complicated by the wide range of production choices that can be made to achieve the same energy output. In general terms biomass can be broken down into two categories: energy plantations, and clean-up biomass. The latter category can be further split into biomass from farming residues, and waste from industrial and noncommercial processes. The energy product from biomass can be provided in several different forms: 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, such as monoculture conifer plantations, short rotation coppice, or natural woodland. Where the land was under intensive agriculture a reduction in fertilizer use can be expected (Rowan 1991: 80), as well as improvements in soil structure, nutrient retention, and nitrate leaching. However, the routine application of chemicals from the air to protect monocultures seriously affects insect life. Afforestation of some soil types can also be negative (by drying out peat bogs) while in other areas it can be used for water management (by 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 that were previously present (Moss 1978).

The choice of trees and felling methods are important determinants of environmental impacts. Conifers can acidify soils and mobilize heavy metals, such as aluminum, 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 exacerbates 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 scarred. 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: 1298). Air pollution from domestic wood burning can be avoided by regulating stove and fuel types. 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. Solid waste, low in toxins, can be used as a fertilizer.

Clean-up Biomass

Farming residues can be classified as waste from current activities that are normally dumped. In the United Kingdom 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 United Kingdom 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 (e.g., nitrate leaching from manure). The levels of NO_x and SO_x are 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 fertilizer (Department of Energy 1993: 10–12). Human waste products from hospitals, industry, and sewage stations can also be used for the generation of energy. There is a 975 KW sewage station at Finham, U.K. The economic incentive is provided by avoiding disposal costs (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: 6).

Geothermal Energy

Geothermal energy is extracted from the accessible heat in the outer 15 kilometers of the Earth's crust. Three broad categories are hydrothermal, reservoirs of steam or water; geopressurized, reservoirs of brine; and 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 percent in the United States (DiPippo 1991: 799). In the United States the potential is for some 25,000 MW of (electrical) energy, but this will last for only 40 years because the heat reservoirs will become exhausted.

Air pollution will occur in relatively small quantities. Carbon dioxide is always the principal gas released but the quantities are only 10 percent of those from oil for an equivalent amount of energy. Other gases include hydrogen sulfide, 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 of chemicals, dependent upon rock composition, water pollution is minimized by reinjection into the ground, which is common practice. Reinjection can cost $10–20 per KW with a corresponding decrease in output of 10–20 percent; 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 at 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 localized it can fracture pipelines and requires monitoring.

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 that 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 percent or more of the land in other activities (Gipe 1991: 764). However, over their life-cycle fossil fuels can use large areas—oil requires land for wells, drilling, refining, storage, terminals, generating plants, 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: 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, causing 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 be 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 aluminum 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 pence/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 smokestacks, 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 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 dependent on 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 localized. Photovoltaics create some risk of emissions during the production of solar panels.

Aesthetics

Visual intrusion is a matter of the perception of people toward 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 meters high. However, in a California 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 (Clarke 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 occurred 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 that cause a major visual intrusion, such as in the United Kingdom.

Health and Safety

Risks to workers in oil fields and coal mines are often internalized 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—such as 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 fuels these include the incidents of respiratory 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.

CONCLUSIONS

It 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). Olar 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 expenditures 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 will 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 (e.g., 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 versus renewable energy sources tends to be an argument over global versus 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 overcapacity. 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. However, the specific sites involved in the development of renewable energy sources is a key to their social cost.

In summary, we can generalize that fossil fuels tend to have dispersed (temporal and spatial) chemical impacts, while renewable energy sources tend to have more local physical ones. The principal advantage of renewable energy is the lower level of environmental impact. However, renewable energy sources do create their own set of externalities that need to be acknowledged 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, such as exotics in photovoltaics, sensitive sites for wind and wave energy, fertilizer 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. December 5, 1992.

Charters, William W. S. "Solar Energy Current Status and Future Prospects." *Energy Policy* 19(8) (October, 1991): 738–741.

Ciborowski, Peter. "Sources, Sinks, Trends and Opportunities." In Dean E. Abrahamson (ed.), *The Challenge of Global Warming*. Washington, DC: Island Press, 1989.

Clarke, Alexi. "Wind Energy: Progress and Potential." *Energy Policy* 19(8) (October 1991): 742–755.

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

Department of Energy, United Kingdom. "Poultry Power: An Offbeat Source of Energy." *Review Issue* 20 (March 1993): 10–12.

———. *Energy Trends*. London: Department of Energy, 1992.

———. "What Next for Straw?" *Review Issue* 17 (Autumn, 1991): 18–20.

DiPippo, Ronald. "Geothermal Energy, Electrical and Environmental Impact." *Energy Policy* 19(8) (October, 1991): 798–807.

Flood, N. *Energy Without End*. Washington, DC: Friends of the Earth, 1991.

Gipe, Paul. "Wind Energy Comes of Age: California and Denmark." *Energy Policy* 19 (8) (October, 1991): 756–767.

Hohmeyer, Olav. "Social Costs of Electricity Generation: Wind and Photovoltaic versus Fossil and Nuclear." *Contemporary Policy Issues* 8 (July 1990): 1–29.

IEA. *Energy and the Environment: Policy Overview*. Paris: OECD, 1989.

Independent, The. "Power of the Himalayas." December 1, 1991, p. 64.

Jackson, Tim. "Renewable Energy." *Energy Policy*, September 1992, pp. 861–888.

Moss, D. "Songbird Populations in Forest Plantations." *Quarterly Journal of Forestry*, 72 (1978): 288–292.

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

OECD. *The Compass Project: Environmental Impacts of Renewable Energy*. Paris: OECD, 1988.

Pasquatti, Martin and E. Butler. "Public Reaction to Wind Development in California." *International Journal of Ambient Energy* 8(2) (August 1987).

Routley, R. and V. Routley. "Nuclear Energy and Obligations to the Future." In E. Partridge (ed.), *Responsibilities to Future Generations*. New York: Prometheus Books, 1980.

Rowan, Leslie. ''An Analysis of the Potential of Wood for Energy in the U.K.'' B. S. dissertation, University of Stirling, Scotland, 1991.

Sims, Geoffery P. ''Hydroelectric Energy.'' *Energy Policy* 19(8) (October 1991): 776–786.

Spash, Clive. L. ''Double CO_2 and Beyond.'' *Ecological Economics*, forthcoming, 1994.

Spash, Clive L. and Nick Hanley. ''Cost-Benefit Analysis and the Greenhouse Effect.'' Economics Department Working Paper, University of Stirling, U.K., 1993.

Thurlaw, G. (ed.). *Technological Responses to the Greenhouse Effect.* Watt Committee Report. Ser. No. 23, 1990.

Twidell, John and Robert Brice. ''Strategies for Implementing Renewable Energy: Lessons from Europe.'' *Energy Policy* (May 1992).

Young, Andrew. ''Inshore Wave Power for Electricity Generation in Island Communities.'' Unpublished manuscript, Economics Department, University of Stirling, 1993, p. 142.