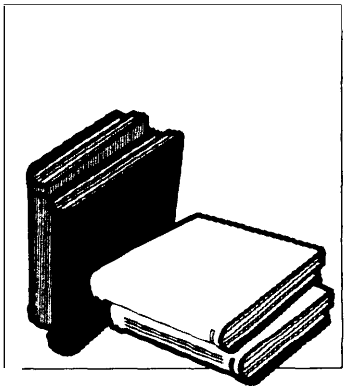
Studies of Environmental Costs 2

Much of the technical debate over the environmental costs of electricity concerns a set of quantitative studies. These studies were conducted mostly within the past two decades, and they attempt to evaluate the environmental costs associated with different electricity generating technologies. The studies serve as focal points for discussion. Their methodology, assumptions, results, and recommendations are being examined and challenged by various stakeholders.

In many cases, the methods and assumptions of these studies reflect the underlying values of the analysts who conduct the studies and the groups that sponsor them. These values often lie at the heart of disagreements over estimates of environmental costs. Understanding the technical methodology and assumptions of environmental cost studies can help to clarify the values that are at issue.

This chapter covers three areas. First, it discusses the general structure and purpose of environmental cost studies. Second, it summarizes the history and quantitative conclusions of a selected group of studies. Third, it compares and contrasts the selected studies in an effort to identify similarities and differences.

This chapter does not provide a detailed explanation of the methodological issues surrounding environmental cost studies or a detailed analysis of which methods are more or less appropriate. This report focuses on different issues—the values and assumptions that underlie estimates of environmental costs and the implications for using these studies in policymaking. These topics are discussed at greater length in chapters 3 and 4.



THE PURPOSE AND STRUCTURE OF ENVIRONMENTAL COST STUDIES

Environmental cost studies are a relatively recent phenomenon.[1] The earliest studies that compared several energy sources date from the 1970s, but nearly all studies of current interest date from the 1980s and 1990s.

Many other studies exist that analyze other types of costs (see box 2-1), but particular attention has focused on the environmental costs of electricity. One reason is that such studies have a built-in audience of government officials who regulate the environmental effects of electricity generation at both the state and federal levels. State and federal agencies have funded several studies, and many states have set policies based on the studies' results. Another reason is that, to conduct an environmental cost study, a large body of scientific research on environmental effects must exist or must be created. Such an extensive base of research may not exist in other areas.

Environmental cost studies are structured to facilitate comparison of energy sources by using monetary values to summarize the environmental effects of each source. A study examines a range of environmental effects (e.g., health impacts of air pollution and ecological damage resulting from mining operations) of several energy sources (e.g., coal, nuclear, and solar), and applies the same general methods to each source. The cost of each effect is quantified using a monetary value and then, for each source, the monetary values are added together to estimate the total cost of the environmental effects associated with that energy source.

Environmental cost studies generally make estimates for several electricity generating technologies, including coal, nuclear, natural gas, oil, hydroelectric, solar, and wind.[2] In addition, several forms of each technology are often evaluated. For example, fossil fuel plants may use different technologies for pollution control, and there are several approaches to generating electricity from solar energy. Because each of these technologies can produce different environmental effects, studies often treat them separately.

Environmental cost studies trace environmental effects through at least three related stages (see figure 2-1):[3,4]

- Identifying emissions—the environmental releases of byproducts of generation and use of electricity. For example, air emissions from

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[1] For a general introduction, see Harold M. Hubbard, "The Real Cost of Energy," *Scientific American,* April 1991, pp. 36-42. For a more in-depth treatment, see Temple, Barker & Sloane, Inc. and Electric Power Research Institute, *Environmental Externalities: An Overview of Theory and Practice, CU/EN-7294* (Palo Alto, CA: May 1991). For a technical introduction to economic theory and practice of environmental cost studies, see G.M. Brown, Jr. and J.M. Callaway, U.S. National Acid Precipitation Assessment Program, "Report 27: Methods for Valuing Acidic Deposition and Air Pollution Effects," *Acidic Deposition: State of Science and Technology, Volume IV: Control Technologies, Future Emissions, and Effects Valuation* (Washington, DC: U.S. Government Printing Office, September 1990). For an extensive bibliography, see Consumer Energy Council of America, *Incorporating Environmental Externalities Into Utility Planning: Seeking a Cost-Effective Means of Assuring Environmental Quality* (Washington, DC: July 1993).

[2] Some studies even discuss the environment costs of energy efficiency measures. For example, Ottinger mentions two possible effects: 1) indoor air quality may decline when buildings are weatherized, and 2) increased efficiency may lower a region's peak energy demand and shift load from gas-fired peaking turbines to base-load coal or oil plants. Richard L. Ottinger et al., Pace University Center for Environmental Legal Studies, *Environmental Costs of Electricity (New* York, NY: Oceana Publications, 1990).

[3] Adapted from the discussion in: Oak Ridge National Laboratory and Resources for the Future, *U.S.-EC Fuel Cycle Study: Background Document to the Approach and Issues,* ORNL/M-2500 *(Oak* Ridge, TN: Oak Ridge National Laboratory, November 1992). Early reviews of externality studies also explicitly cite a similar structure. For example, Holdren establishes a four-step process: 1) sources, 2) insults, 3) stresses, 4) consequences. John P. Holdren, *Integrated Assessment for Energy-Related Environmental Standards: A Summary of Issues and Findings,* LBL-12779 (Berkeley, CA: Lawrence Berkeley Laboratory, October 1980).

[4] There is no entirely satisfactory taxonomy of externalities. They can be categorized by pollutant, by source, by impact, or by fuel cycle phase (e.g., mining, processing, generation, use). See Andrew Stirling, "Regulating the Electricity Supply Industry By Valuing Environmental Effects: How Much Is the Emperor Wearing," *Futures,* December 1992, pp. 1024-1047.

BOX 2-1: Types of Studies Not Covered in This Report

This report focuses exclusively on the environmental costs of electricity generation, but several other types of related studies exist. Some studies focus on nonenvironmental costs of energy. For example, federal energy subsidies represent a nonenvironmental cost.[1] Tax dollars are used to pay the costs of federal loan guarantees, energy assistance programs, research and development, energy services, and funding of some administrative agencies. Energy consumers do not pay directly for these subsidies, instead, all U.S. taxpayers bear the costs of these programs. Although nearly all taxpayers use the energy sources affected by federal subsidies (and vice versa), users do not pay for those subsidies in proportion to the amount of energy they use, Other nonenvironmental costs include induced public expenditures (e.g., defense costs) and economic effects (e.g., production, employment, and trade balance).

Several other studies examine benefits as well as costs.[2] For example, energy generation facilities can increase employment. Whether an effect is a cost or a benefit can depend on factors other than the effect itself. For example, additional jobs created by an electricity generating facility could be an economic benefit to an area with high unemployment. Alternatively, that same job creation could be a cost to an area with labor shortages.[3]

Finally, some studies focus on topics other than electricity. For example, a number of studies examine various costs of transportation that may not be completely included in prices (e.g., subsidized parking and roads, vulnerability to oil supply disruptions, congestion, and accidents).[4] Some of these effects are energy-related (e. g., vulnerability to oil supply disruptions), but most of the effects examined by these other studies have little direct bearing on electricity generation.

[1] U.S. Department of Energy, Energy Information Administration, *Federal Energy Subsidies. Direct and Indirect Interventions in Energy Markets,* SR/EMEU/92-02 (Washington, DC: November 1992); and Douglas N. Koplow, *Federal Energy Subsidies" Energy, Environmental, and Fiscal Impacts* (Washington, DC Alliance To Save Energy, April 1993).

[2] The terms costs and *benefits* are used differently in different contexts, Deaths attributable to air pollution can be termed a cost of energy generation; preventing those deaths can also be termed a benefit of air pollution regulations. This report generally conforms to the first usage

[3] Ajay K Sanghi, "Should Economic Impacts Be Treated as Externalities?" *The Electricity Journal*, March 1991, PP 54-59

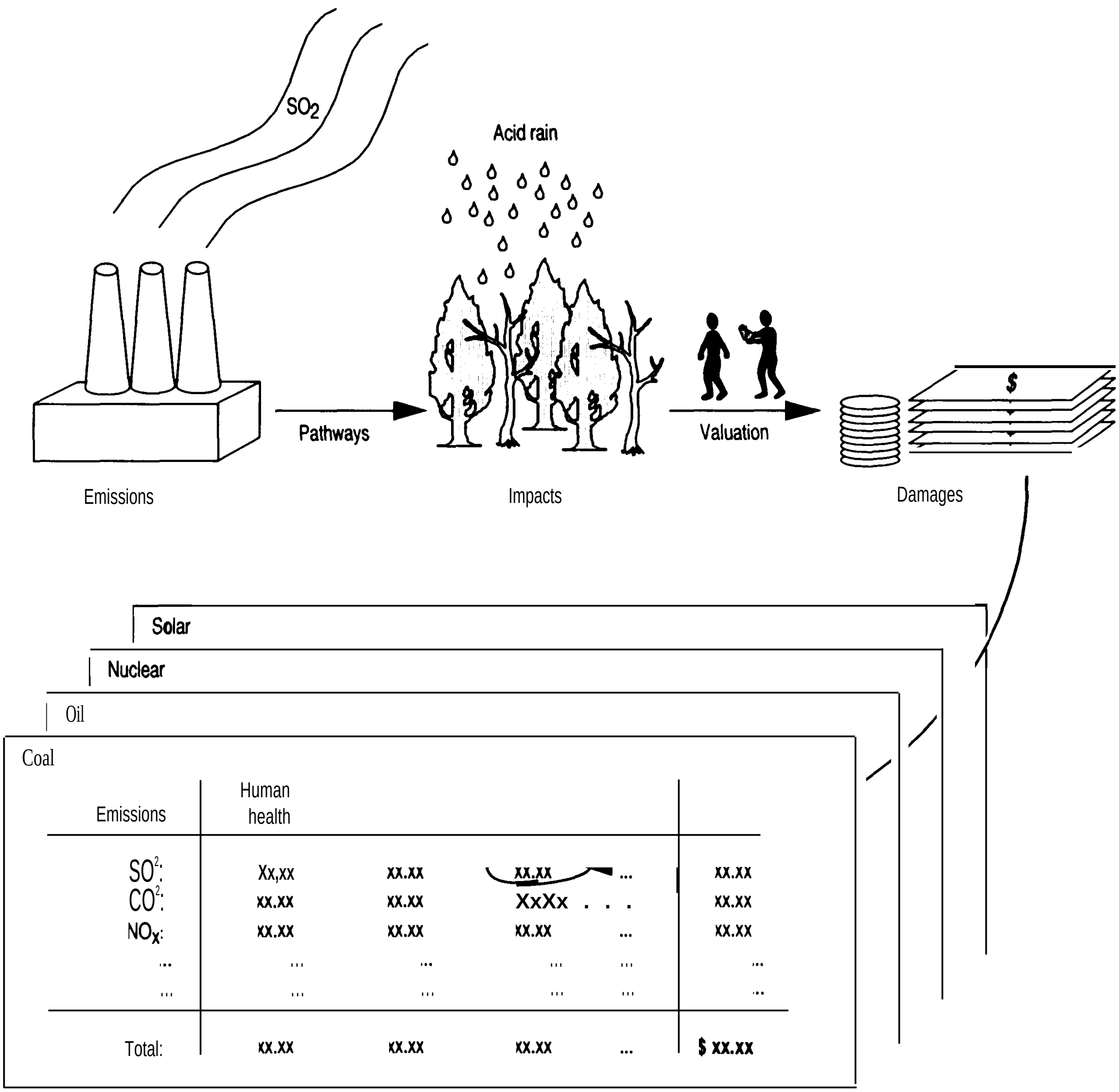
[4] U S Congress, Office of Technology Assessment, *Saving Energy in the U.S. Transportation System,* OTA-ETI-589 (Washington, DC U S Government Printing Office, July 1994), U S Congress, Congressional Research Service, "The External Costs of 011 Used in Transportation," June 3, 1992; James J. MacKenzie et al., *The Going Rate: What/? Really Costs To Drive* (Washington, DC: World Resources Institute, June 1992); David L. Greene and Paul N. Leiby, *The Social Costs to the U.S. of the Monopolization of the World Oil Market, 1972-1991, ORNL-6744* (Oak Ridge, TN Oak Ridge National Laboratory, March 1993), and Peter Miller and John Moffet, *The Price of Mobility Uncovering the Hidden Costs of Transportation* (New York, NY: Natural Resources Defense Council, October 1993).

SOURCE Office of Technology Assessment, 1994

burning fossil fuels include SO_2, CO_2, and particulates. See table 2-1 for additional examples.

- Identifying and evaluating impacts—the physical or socioeconomic effects of emissions on human health (e.g., cancer and emphysema), property (e.g., loss of commercial fishing or erosion of stonework by acid rain), and ecological systems (e.g., decreases in biodiversity). See table 2-1 for additional examples.
- Evaluating *damages-the* monetary value of impacts. To the extent that environmental costing focuses on reducing all environmental impacts to a single scale (e.g., dollars), evaluating damages becomes a necessary step in the analysis.

FIGURE 2-1: The Process of Estimating the Environmental Costs of Energy



NOTE: This figure does not show the process for studies that relyexclusivelyon damage costing approaches (see chapters3 and 4 foradescription) It also does not show the process of analyzing whether some damages are included in current electricity prices, a step that most existing studies have not taken.

SOURCE Office of Technology Assessment, 1994

TABLE 2-1: Examples of Emissions and Impacts

Emissions
Air emissions: SO_x, $NO_{x1,}$ CO_x, particulate, trace elements, air toxics
Waste generation: Toxic, radioactive, solid, liquid
Radiation
Electromagnetic fields (EMF)
Thermal
Noise
Pesticide use around power lines
Runoff from mining, processing, and fuel storage
Impacts
Human deaths and illness: accidents, cancer, respiratory illness, acute poisoning
Reduced production of crops, timber, or fisheries
Degradation of structures from atmospheric pollutants
Lost recreational opportunities
Degraded visibility
Loss of habitat and biodiversity
Use of land, water, and minerals

NOTE The lists are not comprehensive Not all impacts are tied to emissions or pathways.

SOURCE Office of Technology Assessment, 1994

Environmental cost studies use emissions to estimate impacts. Emissions travel through *pathways* to create an environmental impact. For example, some studies estimate trace emissions of $S0_2$ through the pathway of acid rain to the eventual environmental impacts on forest ecosystems (see figure 2-l). In addition to emission-related impacts, studies make estimates of impacts that arise independent of emissions. For example, some accidental deaths and injuries result from coal mining.

Next, environmental cost studies use impacts to estimate monetary damages. Impacts are converted to damages through a process of *valuation.* For example, the monetary damages associated with a lost forest ecosystem can be valued by surveying nearby residents who use the forest for recreation (see figure 2-l). It is not always possible to attach monetary damages to impacts. Some impacts are left out of damage estimates either because estimating damages is too difficult or because the damages are assumed to be negligible.

Although these three stages are common to many studies, they are far from universal. First, some analysts advocate adding another stage to environmental cost studies-evaluating whether damages represent an economic *externality (see* box 2-2). They argue that merely assessing damages provides only part of the information that is important for policymaking. Second, some environmental cost studies do not derive damages based on impacts, but instead make damage estimates based on existing legislative, regulatory, and judicial decisions. These valuation methods, referred to as *control cost methods, are* covered in more detail in chapter 3.

SELECTED STUDIES

OTA selected eight environmental cost studies to examine for this report (see tables 2-2 and 2-3). There are several other recent and ongoing studies in addition to those that OTA examined in detail (see box 2-3). The eight selected studies demonstrate both the promise and problems of environmental cost studies. The studies were selected based on the following criteria:

- *Comprehensiveness:* Each study covers a range of energy sources and environmental effects.
- *lnfluence:* Each study continues to influence current thinking of analysts and decisionmakers.[5]

[5]For example, one study (Inhaber, 1978) was excluded on this bask. The Inhaber report has been strongly criticized for a variety of errors (e.g., Holdren, 1979) and has little influence on current thinking. Herbert Inhaber, *Risk of Energy Production,* AECB-1119/REV-2 (Ottawa, Canada: Atomic Energy Control Board, November 1978); and John P. Holdren et al., *Risk of Renewable Energy Sources: A Critique of the Inhaber Report,* ERG 79-3 (Berkeley, CA: University of California, Energy and Resources Group, June 1979).

BOX 2-2: Economic Theory of Environmental Costs

Economists have devised a formal theory of environmental costs, They define some environmental effects as externalities-costs imposed on society that are not included in the prices of the goods or services. These costs are external, or outside, the existing system of energy pricing, By adding externalities to the market costs of energy, an analyst can estimate the total cost or social cost of energy.

Some externalities have been avoided through environmental controls. Many environmental effects are well documented and have resulted in environmental statutes, such as the Clean Air Act, Because there are serious consequences for violating the statutes, utilities have installed pollution control equipment to control emissions. Some of the cost of this equipment is passed on to consumers.

Other externalities have been included-or internalized—-in energy prices. For example, many analysts believe that wages in some industries (e.g., mining and construction) compensate workers for the relatively higher risks they may bear. Wages of workers in these industries are included in the market prices of energy, Other examples include settlements mandated by court verdicts in cases of environmental damage and the costs of purchasing $S0_2$ emissions permits under the Clean Air Act. These costs are incorporated into prices and thus partially or completely internalize the externalities,

Some environmental effects are not considered to be externalities. Environmental effects may remain even after an externality has been fully internalized. For example, suppose a power plant releases an air pollutant that is currently unregulated. If the pollutant has an environmental cost of $5 per ton, one way of internalizing these costs is to charge utilities $5 for every ton of the pollutant their plants emit. Such a tax would cause utilities to install pollution-control equipment-up to the point that the equipment costs more than the emissions it prevents, Some residual emissions would remain because they are too costly to prevent. At this point, it is cheaper for the utility to pay the tax than to control the remaining emissions.

Some critics of applying environmental costs argue that current regulations completely internalize the environmental costs for many pollutants. If regulations implicitly or explicitly balance social costs and benefits, then emissions have been reduced to an “optimal” level and the costs of that reduction are passed on to energy consumers. If regulations do *not* accurately balance social costs and benefits, then some environmental externalities may remain (if standards are set too low) or an economic externality may be created (if standards are set too high).

However, other analysts point out that, even if existing regulations balance costs and benefits, the remaining emissions still may represent an externality. Consider two different methods of reducing emissions of a pollutant to the same level. One method is an emission tax, set at a level equal to the marginal damages caused by the pollutant. ' Under this method, a utility will: 1) reduce emissions up to the point where the cost of control is equal to the cost of the tax, and 2) pay the tax on the remaining emissions. The utility either eliminates emissions or pays for the damages those emissions cause, An alternative method of regulating a pollutant is a mandated cap on emissions, set so marginal costs and benefits are equal. Under this method, a utility will reduce its emissions to the mandated level, In contrast to the first method, the utility will not incur any costs for its remaining emissions. Under this method, the utility eliminates some of its emissions, but does not pay for the damages caused by the remaining emissions. In the latter case, the damages represent an externality.

[1]The term *marginal damages* refers to the damages associated with the “next” quantity of pollutant, rather than the average damages associated with all previous quantities. Because the costs and benefits of controlling emissions of pollutants can change with the amount already controlled, it is important to *examine marginal*, rather than average, values See chapter 4 for additional explanation,

BOX 2-2 (cont'd.): Economic Theory of Environmental Costs

Some environmental effects of energy remain largely unregulated. If the environmental damages from such pollutants exist, they represent clear examples of externalities. For example, the $C0_2$ emissions of electric utilities are thought to contribute to global warming, but these emissions are not regulated on the federal level, Several state public utility commissions (PUCs) have recognized the potential of future damages associated with $C0_2$ emissions as an externality, and they require that utilities consider $C0_2$ emissions during new capacity planning. To the extent that global warming is a serious environmental threat, unregulated $C0_2$ emissions represent an externality-a cost of energy use not included in the market price.

SOURCE Office of Technology Assessment, 1994.

- *Methodological discussion:* Each study presents a substantive discussion of the methods used to create its estimates.[6]

Despite these similarities, the studies also differ in many respects:

- *Analysts and sponsors:* Groups that conducted studies include academic groups, consulting firms, research organizations, environmental groups, and government laboratories (e.g., respectively, Pace University Center for Environmental Legal Studies, RCG/Hagler Bailly Inc., Resources for the Future, Natural Resources Defense Council, and Oak Ridge National Laboratory). Sponsors include utilities, state governments, citizens' groups, and federal agencies (e.g., respectively, Boston Gas Co., New York State, Northwest Conservation Act Coalition, and the U.S. Department of Energy).
- *Age: The* oldest study was published in 1982. The newest studies (New York State and DOW EC) are due to be completed in late 1994. In the intervening years, there have been new developments in valuation methodology, available data, and understanding of pollutant emissions, transport, and health effects.
- *Size and complexity:* Some studies are relatively short and simple (e.g., Shuman and Cavanagh's estimates are presented in less than 60 pages). Others are quite long and complex (e.g., Pace's analysis runs more than 700 pages).
- *Energy sources:* Some studies deal only with fossil fuels (e.g., coal, oil and natural gas). Other studies estimate costs for a range of other sources (e.g., nuclear, solar, wind, biomass) as well as energy -efficiency measures.
- Methods: Methods vary widely among studies (this topic is dealt within greater detail in chapters 3 and 4).
- *Environmental: effects: The* studies do not all cover the same environmental effects. Some studies deal almost exclusively with air emis-

[6] For example, one frequently cited study (Schilberg et al., 1989) was excluded on this basis. The study cited and compared a number of estimates, but did not contain extensive methodological discussion of its own. Gayatri M. Schilberg et al., "Valuing Reductions in Air Emissions and Incorporating Into Electric Resource Planning: Theoretical and Quantitative Aspects," California Energy Commission Docket 88-ER-8, JBS Energy, *Inc.*, report prepared for the Independent Energy Producers, Sacramento, CA, Aug. 25, 1989.

TABLE 2-2: Major Studies of the Environmental Cost of Ele

Name	Date	Authors	Sponsors	Comments
U.S. Department of Energy (DOE) and Commission of the European Communities (EC)	(forthcoming)	Resources for the Future Oak Ridge National Laboratories	U.S. Department of Energy; Commission of the European Communities	Unfinished. Resources: $3 million and 36 months.
New York State	(forthcoming)	RCG/Hagler, Bailly, Inc.	New York State Energy Research and Development Authority; Empire State Electric Energy Research Corp. Electric Power Research Institute	Unfinished. Resources: $1.75 million and 36 months. Will rely partially on DOE\EC results.
Pace	1990	Richard Ottinger, et al. Pace University Center for Environmental Legal Studies	New York State Energy Research and Development Authority; U.S. Department of Energy	
Tellus Insitutute	1990/1991	Stephen Bernow et al. Tellus Institute	Several state energy agencies and utility regulatory bodies (Vermont, Massachusetts, California, and Rhode Island)	Limited to air emissions of fossil fuels. Specific to California and Northeastern Us.
Chernick and Caverhill	1989	Paul Chernick and Emily Caverhill PLC, inc.	Boston Gas Co.; filed with the Massachusetts Department of Public Utilities	
Hohmeyer	1988	Olav Hohmeyer Fraunhofer-Institute for Systems and Innovation Research, Federal Republic of Germany	Commission of the European Communities	Specific to the former Federal Republic of Germany.
Bonneville Power Administration (BPA)	1983-1987	ECO Northwest Biosystems Analysis Nero and Associates	Bonneville Power Administration; U.S. Department of Energy	Seven studies, each on a different source (e.g., coal, nuclear).
Shuman and Cavanagh	1982	Michael Shuman and Ralph Cavanagh, Natural Resources Defense Council	Northwest Conservation Act Coalition	Specific to Northwest U.S.

NOTE' Names reflect terms commonly used to refer to the study in subsequent literature. Sponsors do not necessarily endorse or agree with a study's findings, particularly in the case of government agencies Studies were selected based their comprehensiveness, influence, and methodological discussion. Several other studies exist that do not meet one or more of OTA'S selection criteria. See box 2-3 for recent studies not reviewed in this report.

SOURCE. Office of Technology Assessment ,1994

TABLE 2–3: Characteristics of Selected Studie

	DOE-EC *(unfinlshed)*	New York State *(unfinished)*	Pace	Tellus	Chernick and Caverhill	Hohmeyer	BPA	Shuman and Cavanagh
Sources monetized	coal oil natural gas nuclear solar (PV) wind hydroelectric biomass conservation	coal (4) oil **(3)** natural gas **(3)** nuclear **(2)** biomass MSW hydroelectric (2) wind solar (2)	coal (4) oil (4) natural gas **(3)** nuclear solar wind biomass efficiency	coal (4) oil (7) natural gas (3)	coal (4) oil (4) natural gas (4)	fossil fuels nuclear solar (PV) wind	coal **(2)** oil natural gas nuclear biomass MSW geothermal solar (central) wind hydroelectric	coal nuclear wind solar (hot water) efficiency
Sources discussed, but not monetized	—	demand-side management	waste-to-energy hydroelectric geothermal	—	—	—	—	—
Emissions with monetized impacts	(not **available)**	**SO_2** NO_x particulate nitrates lead mercury ozone acid aerosols air toxics water pollution radiation solid waste	**SO_x** NO_x **CO_2** particulate radiation nuclear accidents noise	**SO_2** **NO_x** **N_2O** **CO_2** **CO** particulate volatile organics	**SO_2** NO_x **CO_2** CH_4 marine oil spills	**air pollutants** **CO_2** nuclear accidents indust. accidents noise	(varies)	air pollutants **CO_2** radiation nuclear accidents indust. accidents transp. accidents
Monetized impacts	(not available)	human health property damage crop damage fisheries damage land use visibility	human health property damage global warming crop damage land use visibility	(not applicable)	human health property damage global warming ecosystem damage crop damage livestock timber visibility	human health property damage global warming ecosystem damage land use	(varies)	human health property damage global warming proliferation

TABLE 2–3 (cont'd.): Characteristics of Selected Studies

	DOE-EC *(unfinished)*	New York State *(unfinished)*	Pace	Tellus	Chernick and Caverhill	Hohmeyar	BPA	Shurnan and Cavanagh
Effects quantified but not monetized	(not available)	energy security	acid rain; water use and pollution; thermal pollution; land use; solid waste; methane;	—	particulate;	—	(varies)	—
Effects noted but not quantified	(not available)	CO_2	ecosystem effects; non-routine nuclear emissions; damage to historical monuments; livestock; forestry; electro-magnetic fields	water pollution, noise, traffic	air toxics; carbon monoxide; ozone; electro-magnetic fields; herbicide use on transmission rights-of-way; land use; waste disposal; water pollution; thermal pollution; N_20; indoor air pollution	species loss; routine nuclear emissions; damage to historical monuments; production of intermediate goods used in energy generation; impacts of stages of fuel cycle besides generation	(varies)	water consumption; recreation losses; fish and wildlife mortality; aesthetic damage; transmission and distribution
Stages or activities monetized	emphasis on generation	mining fuel processing transportation generation	generation decommissioning	generation (air emissions)	**generation**	generation	(varies)	extraction transportation generation
Valuation methods	(damage cost)	(damage cost)	market contingent hedonic mitigation cost	control cost mitigation cost	market control cost mitigation cost	market hedonic mitigation cost	(varies)	market hedonic control cost

NOTES: Numbers in parentheses in "Sources" indicate the number of different systems within the general source category that were considered (e.g., "Coal (3)" indicates that the study estimated environmental costs for three different types of coal plants). When effects are listed as "quantified but not monetized, " monetization may have been discussed, but the study produced no specific monetization estimate. Not all emissions, impacts, or effects were necessarily estimated for all energy sources, The Pace study discusses hydroelectric, but does not estimate monetized environmental costs for this source. Information in some studies had to be adapted to fit the structure of this chart. Valuation techniques based on damage costs include market, contingent, and hedonic valuation. Human health includes both public and occupational impacts. Some studies estimate nonenvironmental costs such as subsidies and macroeconomic effects; these are not included in this chart. The source listed as "efficiency" denotes several different approaches; Pace evaluated demand-side management; Shuman and Cavanaugh evaluated household weatherization. Valuation methods are discussed in greater detail in chapter 3.

SOURCE: Office of Technology Assessment, 1994.

BOX 2-3: Recent and Ongoing Studies Not Reviewed in This Report

The following studies were identified in the course of OTA'S analysis but are not extensively reviewed in the body of this report Each is briefly discussed below and its Implications for the report are explored

Studies

Nevada: These two studies were prepared by National Economic Research Associates, Inc. (NERA) for two Nevada utilities (Sierra Pacific Power Co, and Nevada Power Co),[1] The studies estimate environmental costs for five conventional air pollutants (PM-1 O, NO_x, SO_x, VOC, CO). In addition, estimates are made for environmental costs associated with four greenhouse gases (CO_2, CO, methane, and N_20) These latter estimates are based on estimates made by other studies and the reports note they are highly speculative. All estimates are given in terms of dollars per pound of pollutant. The study does not derive overall environmental costs associated with particular power or plant types. In this way, the Nevada studies differ from the studies reviewed in the body of the report.

Australia: This study was prepared by RCG/Hagler, Bailly, Inc. and SRC Australia Pty Ltd. as part of a larger project to evaluate and develop externalities policy for Victoria, a province in Australia.[2] The project was commissioned by the Victorian Department of Energy and Minerals and also sponsored by the Commonwealth Department of Environment, Sport and Territories, the State Electricity Commission of Victoria, the Gas and Fuel Corp. of Victoria, and the Renewable Energy Authority Victoria. Environmental cost estimates were made for particulate, nitrogen oxides, sulfur dioxide, ozone, air toxics, wastewater discharge, solid waste, and greenhouse gases. Estimates also were made of the socioeconomic benefits. The estimates are specific to the Latrobe Valley, a particular geographic region in Victoria, Although the report focuses on estimates in terms of dollars per pound of pollutant, the costs of one specific power plant are provided.

Wisconsin/Minnesota: These two studies have been prepared by RTI and NERA for U.S. utilities in Wisconsin and Minnesota. In both cases, the studies have not been made public by their sponsors, due to their use in pending rate cases before state regulatory commissions. They will be released by the end of 1994.

California Energy Commission: For several years, the California Energy Commission (CEC) has sought to quantify environmental costs of constructing new generating facilities. These analyses have been part of the Energy Report process, a formal process that includes adopting environmental cost estimates to be used for energy planning. The 1992 Energy Report process used values based on estimates made by Regional Economic Research, Inc. This research recently has been compiled into a single document.[3]

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1 National Economic Research Associates, *Final Report. External Costs of Electric Utility Resource Selection m Nevada,* report prepared for the Nevada Power Co (Cambridge, MA March 1993), National Economic Research Associates, *Final Report External Costs of Electric Utility Resource Selection m Northern* Nevada, report prepared for Sierra Pacific Power Co (Cambridge, MA December 1993)

2 RCG/Hagler, Bailly, Inc and SRC Australia Pty Ltd., *Externality Policy Development Project: Energy Sector, Consultants' Summary Report for the Victorian Study* (East Melbourne, Victoria Department of Energy and Minerals, October 1993)

3 Mark A Thayer et al , Regional Economic Research, "The Air Quality Valuation Model, " draft report, Apr 21, 1994

(continued)

BOX 2-3 (cont'd.): Recent and Ongoing Studies Not Reviewed in This Report

Implications

The Nevada, Australia, Wisconsin, Minnesota, and CEC studies are not discussed elsewhere in this report. In the case of the Wisconsin and Minnesota studies, they could not be discussed because sufficient information was not available, In the case of the Nevada, Australia, and CEC studies, they provide only limited results. The Nevada studies provide cost estimates for air emissions only, and do not provide comparative figures for different types of power plants. The Australia study provides estimates for a more comprehensive set of effects, but only applies those figures to evaluating the overall costs of a single type of plant (a coal-fired power plant). The CEC study provides estimates only for air emissions and only for a limited number of generating technologies that are being considered in California.

Results from these newer studies do not alter OTA'S overall findings, The estimates of environmental cost studies still vary widely, depending on the values and assumptions embedded within the studies. Differences in these values and assumptions are unlikely to be resolved by technical studies, Accepting the results of a particular study involves the implicit or explicit acceptance of a large set of assumptions about what effects to include and how to value those effects,

Results of these newer studies confirm several of OTA'S findings. First, their cost estimates are generally far lower than many previous studies. The two Nevada studies make cost estimates associated with different air emissions that are between 30 percent and less than 1 percent of similar cost estimates of the Tellus and Pace studies. Similarly, the Australia study estimates the environmental cost of an existing coal plant as between 0.0013 and 2.3 cents/kWh, with a central estimate of 0.0020 cents/kWh. By comparison, the Tellus and Pace studies make estimates ranging between 3 and 10 cents/kWh. These results reinforce the conclusion that cost estimates are extremely variable. Second, results of these newer studies differ from results of other studies in ways discussed in chapter 4. In comparison with many other studies, these newer studies are more restrictive in the categories of costs that are included and in how those costs are valued. Consequently, their cost estimates are lower than those of many earlier studies,

SOURCE. Office of Technology Assessment, 1994,

sions of fossil fuels, others include emissions such as oil spills and impacts such as nuclear war.[7]

- *Categorization of effects:* Several of the studies categorize environmental effects by emissions, presenting results for SO_2, CO_2, NO_X, and other emissions and then adding them to obtain overall estimates of environmental costs (e.g., Pace, Tellus, and Chernick and Caverhill). Other studies categorize effects by type of impact such as flora, fauna, human, and climate impacts (e.g., Hohmeyer).
- *Technology specificity:* Some studies group a number of different technologies into a single category. For example, Hohmeyer's study produces only a single estimate of environmental costs for all fossil fuels. In contrast, other studies (e.g., Pace, Chernick and Caverhill) differentiate estimates based on generation tech-

7 One study (Shuman and Cavanagh) includes the risk of nuclear war in its high-end estimates of environmental costs associated with nuclear power. They contend that use of nuclear power increases the proliferation of nuclear weapons, and proliferation increases the risk of nuclear war. Michael Shuman and Ralph Cavanagh, *A Model Conservation and Electric Power Plan for the Pacific Northwest, Appendix 2: Environmental Costs* (Seattle, WA: Northwest Conservation Act Coalition, November 1982).

nology (e.g., oil combustion turbine) and by the sulfur content of fuels.

- *Location specificity:* Some studies are specific to a particular region of the country, whereas others are intended to be more general. Highly specific studies calculate impacts based on assumptions about population densities, particularly sensitive or resistant ecosystems, or transport or deposition of pollutants. Several studies have chosen specific sites to evaluate, in order to be able to make specific assumptions about the exposed population and the surrounding ecological conditions.[8,9]

Despite these differences, it is tempting to look for common conclusions, or to average numerical results, in an effort to obtain conclusions with greater validity than those of a single study. However, the differences among the studies make it difficult to compare their results in a meaningful way. Taken together, these studies point more toward the diversity of approaches to evaluating environmental costs than toward common conclusions.

Each study is discussed briefly below. Each completed study is accompanied by a table presenting its quantitative results. The results are presented first in a way that is as close to the original study as possible—the cost figures have not been rounded or recalculated. 10 In addition to the original figures, a set of adjusted figures in 1990 dollars is given for each study to facilitate inflation-adjusted comparisons.

Additional discussion of methodological issues is presented in chapters 3 and 4. The studies reviewed below are used to illustrate that discussion.

Department of Energy/Commission of the European Communities

The DOE/EC study is a major ongoing study initiated in February 1991 by the U.S. Department of Energy (DOE) and the Commission of the European Communities (EC). The two organizations agreed to support a study to develop a comparative analytical methodology and the best range of estimates of external costs for eight fuel cycles and four conservation options.[11] The eight fuel cycles are coal, oil, natural gas, uranium, biomass, hydroelectric, photovoltaic, and wind. The study is expected to conclude in late 1994.

Responsibilities for the analytical work have been split between U.S. and European research teams. The teams share lead responsibilities for the nuclear study. The U.S. leads the coal, oil, natural gas, biomass, and hydroelectric studies. The EC leads the conservation, photovoltaic, and wind studies. DOE's portion of the study was contracted to Oak Ridge National Laboratory (ORNL) and Resources for the Future (RFF).[12,13] The EC organized a similar study team.

In November 1992, the U.S. contractors issued a report that summarized progress to date and detailed modifications made to the initial DOE/EC agreement.[14] The 1992 report remains the only

8 For example, the studies by DOE/EC and BPA.

9 For an extensive discussion of this issue, and approaches to extending findings from one location to other locations, see Alan J. Krupnick, "Benefit Transfer and Valuation of Environmental Improvements," *Resources,* vol. 110, winter 1993, pp. 1-7.

10 Some analysts have recalculated cost estimates so that they refer to a set of standard power plants. No such recalculation was attempted here. For an example of such recalculation, see Jonathan Koomey, *Comparative Analysis of Monetary Estimates of External Environmental Costs Associated With Combustion of Fossil* Fuels, LBL-28313 (Berkeley, CA: Lawrence Berkeley Laboratory, July 1990).

11 The Federal Energy Regulatory Commission is also a sponsor of the U.S. portion of the study.

12 Oak Ridge National Laboratory is a federally owned, contractor-operated laboratory. Resources for the Future is an independent nonprofit organization that conducts research on the development, conservation, and use of natural resources and on the quality of the environment.

13 As with most reports contracted for by DOE, the study's conclusions will not necessarily represent the views of its sponsors.

14 Oak Ridge National Laboratory and Resources for the Future, op.cit., footnote 3.

publicly available document on the DOE/EC study. However, in January 1993, DOE circulated a draft report for peer review. In August 1993, peer review was complete and the report was returned to ORNL and RFF for modifications. The coal-specific report is expected to be issued in September 1994, with the remaining reports (on oil, natural gas, hydroelectric, biomass, and nuclear) to be completed by the end of 1994.[15]

The DOE/EC study is not completed, but many details of its methodology are available. The study is using damage cost approaches (see chapter 3)-one of the first times damage costing has been used exclusively in a major study of the environmental costs of electricity. Its component reports plan to cover a broad range of fuel cycles and stages of energy production (e.g., mining, transportation, use, and waste disposal). Each fuel cycle report will focus on one or two actual plants, in an effort to produce specific and defensible results.

New York State

The New York State study is a major ongoing study that began in December 1991. It was undertaken in response to an order from New York Public Service Commission, and its goal is to develop a methodology and computer model that will permit estimation of environmental costs. The model will apply to new electricity generating plants, relicensed plants, and electricity demand management options in the state of New York.

The study is a joint effort of four organizations: the New York State Department of Public Service, the New York State Energy Research and Development Authority, the New York State electric utilities through the Empire State Electric Energy Research Corp. (ESEERCO), and the Electric Power Research Institute (EPRI).[16] The latter three organizations are funding the $1.75-million project.

The project is managed by a five-member board of representatives from the four organizations and one representative from Resources for the Future, an independent expert selected by the four other members. The management board directs the work of two contractors: the research contractor (RCG/Hagler, Bailly, Inc.) and the coordinating contractor (Industrial Economics, Inc.).

The project will produce four separate reports: 1) a critical review of existing research that screens a large number of possible emissions and impacts, 2) a recommended methodology, 3) a computer model and manual, and 4) case studies that represent applications of the model. The first report was completed in December 1993 and became available to the public in May 1994.[17] The other reports are expected to be finished by the end of 1994.

The first report screens different possible environmental effects for inclusion in the final computer model. The report reviews a large number of emissions and impacts, and it categorizes them based on initial judgments of the size of their associated damages and their ability to be accurately quantified. Later reports will concentrate on the emissions and impacts judged to be both large and amenable to quantification.

Among the studies reviewed by OTA, the New York State study is unique because of its intended output. The study will produce a software-based model that runs on personal computers. The software will permit users to modify the values of model parameters (e.g., levels of emissions and costs per unit of emission) and will produce estimates based on those values. All other studies reviewed in this report provide only a printed

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[15] Paul Carrier, Department of Energy, personal communications, January, April, May, and July 1994.

[16] EPRI's participation is limited to the first phase of the study (see below).

[17] RCG/Hagler, Bailly, Inc., "New York State Environmental Externalities Cost Study Report 1: Externalities Screening and Recommendaions," ESEERCO Project EP91-50, December 1993.

report with environmental cost estimates based on a single, or at least limited, set of parameter values. [18]

Pace

The Pace study is one of the best known and most frequently cited studies of environmental costs. The study was prepared for the New York State Energy Research and Development Authority and the U.S. Department of Energy, and it was published in 1990.[19] The study is wide-ranging, covering different energy sources (e.g., coal, oil, natural gas, nuclear, renewable, waste-to-energy systems, demand-side management) and environmental effects (e.g., air and water pollution, global warming, acid rain, land use). The report also includes a brief discussion of policy tools on both the state and federal levels.

Quantitative results of the study are summarized in table 2-4. The study concludes that environmental costs associated with coal, oil, and nuclear are highest, costs associated with natural gas are somewhat lower, and costs associated with renewable sources (solar, wind, and biomass) and demand-side management are substantially lower.

The Pace study explicitly notes several classes of environmental costs excluded from the analysis, generally due to uncertainty or lack of data. For fossil fuels, it excludes greenhouse gases such as methane and N_20; air toxics; water use, land use, and solid waste disposal; and environmental costs associated with fuel extraction, transportation, and processing. For nuclear power, it excludes extraction and transportation of uranium. Due to the exclusion of these environmental costs, the authors believe their estimates are more likely to be underestimates than overestimates.

The Pace study summarizes, critiques, and evaluates much of the existing literature. These estimates are then combined to produce illustrative estimates. However, the authors note that some of the studies they reviewed were inadequately documented and substantively deficient. The authors caution that the quantitative results of the study should not be cited as definitive estimates, but rather indicate the order-of-magnitude of results and should be a useful starting point for further research.

Tellus

The Tellus study represents work published in 1990 and 1991 by Stephen Bernow, Donald Marron, and Bruce Biewald of the Tellus Institute, an independent, nonprofit research and consulting organization. The Tellus work is not a single study, but instead is comprised of several estimates produced for state regulatory commissions and state energy agencies. A 1990 report summarizes this previous work and describes the estimates and methodology concisely. In addition, a 1991 journal article applies the results of the 1990 report to estimate overall environmental costs for several combinations of generating technologies and fuels.[20]

The study differs from other environmental cost studies in two important respects. First, the Tellus study only provides estimates of the costs of air emissions. Costs of other types of emissions (e.g., radiation), and impacts (e.g., industrial and transportation accidents) are not estimated. Air emissions are relevant only to the burning of fossil

18 One study not reviewed in this report does include a computer model: Mark A. Thayer et al., *The Air Quality Valuation Model (San* Diego, CA: Regional Economic Research, Inc., Apr. 21, 1994).

19 Ottinger et al., op. cit., footnote 2.

20 Stephen Bernow and Donald Marron, *Valuation of Environmental Externalities for Energy Planning and Operations, May 1990 Update* (Boston, MA: Tellus Institute, May 18, 1990); and Stephen Bemow et al., "Full-Cost Dispatch: Incorporating Environmental Externalities in Electric System Operation," *The Electricity Journal,* March 1991, pp. 20-33.

TABLE 2-4: Pace's Estimates of Environmental Costs

Type	cost, $/lb (1989)	Cost, $/lb (1990)
By emission type		
SO_2	2.03	2.13
Particulate	1.19	1.25
NO_x	0.82	0.86
CO_2	0.0068	0.0071
By plant type		
Plant	**Cost, $/kWh (1989)**	**Cost, ¢/kWh (1990)**
Coal		
Existing boiler (1 .2% S)	6.8	7.1
AFBC (1 .1% S)	3.3	3.5
IGCC (0.45% S)	2.8	2.9
NSPS	4.5	4.7
Oil		
Boiler (0.5% S)	3.2	3.3
Boiler (1% S)	4.5	4.7
Boiler (2.2% S)	7.9	8.3
Combustion turbine (1% S)	3.0	3.1
Natural Gas		
Existing steam plant	1.2	1.3
Combined cycle	1.1	1.1
BACT	0.8	0.8
Nuclear	2.91	3.05
Renewab/es		
Solar	0-0,4	0-0.4
Wind	0-0.1	0-0.1
Biomass	0-0.7	0-0.7
Demand-side Management	0.0	0.0

NOTE: Values in 1989 dollars and cents are reported in the study. Values in 1990 dollars and cents are adjusted using the consumer price index The values reported above for various emission types are listed by Ottinger et al. as "rough starting points"; in several cases (SO_2, NO_x, and particulate), the authors contend that the damages "could be much higher."' Values for acid deposition, electromagnetic fields, and land and water use impacts were not estimated due to inadequate data. Most plant types for fossil fuels list the sulfur content of the fuel (e.g., 1,2% S).

The study derived values for various plant types from thevaluesfor emission types Thestudyfoundthat waste-to-energy plants were likely to have fairly large environmental impacts, but they concluded that more research was needed before a quantified estimate could be made,

KEY: NSPS = New source performance standards: IGCC = Integrated gas combined cycle: AFBC = Atmospheric fluidized bed combustion BACT = Best available control technology

SOURCE: Richard L. Ottinger et al., Pace University Center for Environmental Legal Studies, *Environmental Costs of Electricity (New* York, NY: Oceana Publications, 1990).

fuels (coal, oil, and natural gas) and these are the only sources for which Tellus generates estimates.[21] A summary of the Tellus estimates is provided in table 2-5.

Second, the Tellus study is unique because of its exclusive reliance on a valuation method known as *control costing.*[22] It derives all esti-

21 Despite these limitations, the Tellus study is an important one to consider. It strongly defends the use of control cost approaches, and its results have influenced the actions of several state regulatory commissions.

22 Other studies make occasional use of control cost valuation. Tellus is the only study to rely exclusively on control costing.

TABLE 2-5: Tellus' Estimates of Environmental ^

By emission type				
Type	Northeast U.S. cost, $/lb (1989)	southern California cost, $/lb (1989)	Northeast U.S. cost, $/lb (1990)	Southern California cost, $/lb (1990)
NO_x	3.50	131.00	3.7	137.29
SO_x	0.75	37.50	0.79	39.30
Volatile organic gases	2,65	14.50	2.78	15.20
Particulate	2.00	24.00	2.10	25.15
CO	0.43	0.43	0.45	0.45
CO_2	0.011	0.011	0.012	0.012
CH_4	0.11	0.11	0.12	0.12
N_2O	1.98	1.98	2.08	2.08

By plant type

Plant	Cost, ¢/kWh (1990)
coal	
FGD	4.47
2.37°A sulfur	7.00
1.83°A sulfur	9.97
0.82% sulfur	6.05
Oil	
Steam, 1 .5% sulfur	5.55
Steam, 1 .3% sulfur	3.92
Steam, 1 .0% sulfur	4.08
Steam, 0.75% sulfur	3.54
Steam, 0.70% sulfur	3.86
Steam, 0.30% sulfur	4.44
Combustion turbine	6.04
Natural Gas	
Steam	2.37
Combustion turbine	4.22
Combined cycle	1.68

NOTE: Values by emission are from Bernow and Marron, 1990. Differences in cost estimates between the Northest United States and Southern California result from differences in applicable state laws. Estimates for NO_x and CO include both ambient air quality and greenhouse warming impacts; volatile organic gases include both volatile organic compounds and reactive organic gases; particulate include both total suspended particulates and PM1O. Values by plant type are from Bernowet al., 1991 (table 5) and are based on power plants operating in the Northeastern United States. FGD = flue-gas desulfurization.

SOURCES. Stephen S. Bernow and Donald B. Marron, *Valuation of Environment/ Externalities for EnergyP/arming and Operations, May 1990 Update* (Boston, MA. Tellus Institute, May 18, 1990); and Stephen Bernow et al., "Full-Cost Dispatch' Incorporating Environmental Externalities in Electric System Operation," *The Electricity Journal*, March 1991, pp. 20-33.

mates of environmental costs from the costs imposed by existing legislation.[23] It estimates the costs of compliance with existing regulations, and then uses these values to indicate a "revealed preference" of regulators—a cost that regulators are willing to impose on utility customers to control emissions. Control costing is covered in more detail in chapter 3.

[23] There is one exception. Environmental costs associated with c@ emissions were estimated using the cost of mitigating the damages from global warming.

The control costing approach used in the Tellus study results in varying estimates for the environmental costs of emissions in different areas of the country. In several cases, estimates of the environmental costs associated with air emissions in the Northeast are substantially lower than estimates for the costs associated with air emissions in Southern California. This difference results from California's more stringent emission standards. California's standards impose higher costs on utilities and their customers, thus resulting in a higher estimate of environmental costs associated with particular emissions.

Chernick and Caverhill

The Chernick and Caverhill study was produced in 1989 by Paul Chernick and Emily Caverhill of PLC, Inc.,[24] a consulting firm in Boston, Massachusetts.[25] The study was sponsored by the Boston Gas Co. and filed with the Massachusetts Department of Public Utilities. It targets issues important to New England and the northeastern United States, and is not intended to provide results applicable to the entire United States. It estimates environmental costs for coal, oil, and gas-fired generators. It makes no estimates of the environmental costs associated with other sources, such as nuclear, hydroelectric, solar, and wind power.

Chernick and Caverhill make estimates by combining several sources of information. They examine estimates from previous environmental cost studies (e.g., for $S0_2$ and NO_x),26 from information about the costs mandated by various environmental regulations (e.g., for $S0_2$ and NO_x), and from the costs of mitigation (e.g., for $C0_2$, CH_4, and marine oil spills). For each emission, they examine the range of estimates offered by each method, and then choose what they feel to be a plausible value.

The study estimates values for two general categories of environmental effects: air emissions ($S0_2$, NO_x, $C0_2$, and CH_4) and marine oil spills. In addition, estimates are made of the environmental costs associated with the macroeconomic effects of oil imports. The report also lists a set of other environmental costs as identified, but not quantified: additional air emissions (air toxics, CO, particulate, and ozone) and a variety of noncombustion-related environmental costs (e.g., electromagnetic radiation, pesticide use on transmission rights-of-way, water and thermal pollution, indoor air pollution, and accidental injuries and deaths in extraction and transportation).

Table 2-6 presents a summary of the study's results on environmental costs. The report contends that estimates of environmental costs are more likely to be underestimates than overestimates. Overall, the study estimates the environmental costs associated with natural gas to be somewhat lower than those associated with coal and oil.

Hohmeyer

The Hohmeyer study was published in 1988 by Olav Hohmeyer, then an economist and deputy head of the Department of Technical Change at the Fraunhofer-Institute for Systems and Innovation Research in the Federal Republic of Germany.[27] It was sponsored by the Commission of the European Communities.

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24 The company is now named Resource Insight, Inc.

25 Paul Chernick and Emily Caverhill, PLC, Inc., "The Valuation of Externalities From Energy Production, Delivery, and Use: Fall 1989 Update," A Report to the Boston Gas Co., Dec. 22, 1989. Although entitled an "update," this report is the primary document referred to by other studies and analysts in the area, and appears to contain the primary methodological content.

26 In particular, Chernick and Caverhill use several studies conducted for the Bonneville Power Administration (BPA) (see below). In many cases, the authors adapt the BPA calculations to add effects they feel were left out of the original calculations.

27 Olav Hohmeyer, *Social Costs of Energy Consumption: External Effects of Electricity Generation in the Federal Republic of* Germany (Berlin, Germany: Springer-Verlag, 1988).

[redacted] [redacted]

By emission type		
Type	**Cost, $/lb (1988)**	**Cost, $/lb (1990)**
SO_2	0.88	0.96
NOx	1.50	1.64
CO_2	0.011	0.012
CH_4	0.35	0.38
Marine 011 spills	o.20/MMBTU	o.22/MMBTU
By plant type		
Plant	**Cost, ¢/kwh (1988)**	Cost¢ **¢/kWh (1990)**
Coal		
Existing (1 .2% S)	5.7	6.2
AFBC	3.8	4.1
IGCC	3.2	3.5
NSPS	4.9	5.3
Oil		
Existing steam plant (0.5% S)	3.6	3.9
Existing steam plant (1% S)	4.3	4.7
Existing steam plant (2.2% S)	5.8	6.3
Combustion turbine (0.3% S)	5.0	5.5
Natural Gas		
Existing steam plant	1.9	2.1
Combined cycle	1.9	2.1
NSPS	1.6	1.7
BACT	1.28	1.40

NOTE MBTU = 1,000 BTU Values in 1988 dollars and cents are reported in the study. Values in 1990 dollars and cents are adjusted using the consumer price index Values are specific to the Northeast. The authors felt that the values reported above are "more likely to be understated than overstated " (p 96) Values for many other classes of costs were not estimated, due to their inability to quantify them with any certainty

Valuesforod-fired generators were adjusted to *exclude* an oil import premium that was included in the report's final estimates This premium reflects the national economic cost of oil imports It includes costs associated with vulnerabilities to interruptions and price swings, increases in inflation, and deterioration of the balance of payments In contrast to every other effect estimated, the 011 import premium is nonenvironmental.

The study derives values for for various plant types from the values for emission types. In addition to the combustion-related emissions, 00007 pounds of NO_x were included for each source to account for emissions during transportation No cost estimates were made for some combustion emissions (air toxics, CO, particulates, and ozone) and for some noncombustion related effects (e g., electromagnetic radiation, solid waste generation, water and thermal pollution, and accidental deaths and injuries).

Values for new coal and gas plants (NSPS, IGCC, AFBC, and BACT) are specific to New England

KEY. NSPS = New source performance standards, IGCC = Integrated gas combined cycle; AFBC = Atmospheric fluidized bed combustion, BACT = Best available control technology.

SOURCE Paul Chernick and Emily Caverhill, PLC, Inc , "The Valuation of Externalities from Energy Productlon, Delivery, and Use: Fall 1989 Update, " A Report to the Boston Gas Co , Dec. 22, 1989.

The study is specific to the Federal Republic of Germany. However, it is worth considering because it is widely cited and generated substantial interest in the United States when it was released. Its methodology is explained fairly carefully in the text of the study, and Hohmeyer maintains the general approach is valid for any market-based economy.

The study explicitly compares renewable energy resources, such as solar and wind, with conventional energy sources, such as coal and nuclear. It focuses on costs in the following categories: environmental effects, subsidies, depletion of nonrenewable resources, and public expenditures (R&D support, induced expenditures, and subsidies).

TABLE 2-7: Hohmeyer's Estimates of Environmental Costs

	Envirwwnental effects by plant type	
Plant	Cost, DM/kWh (1982)	Cost, ¢/kWh (1990)
Fossil fuels	0.0114-0.0609	0.78-4.153
Nuclear	0.0120-0.1200	0.82-8.18
Solar	**0.0044**	**0.30**
Wind	O.0001	**0.007**

NOTE: Values in 1982 Deutsche Marks are reported in the study. Values in 1982 cents were converted using a conversion rate of 2DMn — a rough value suggested by Hohmeyer during presentations on the study. Values m 1990 dollars are adjusted using the consumer price index. Values are specific to the Federal Republic of Germany. Values for some classes of effects were not estimated. Estimates for nuclear reactors excludes breeder reactors.

Values presented here are for environmental costs only, Estimates of public expenditures and resource depletion costs that are included m the study are not included in this table.

SOURCE: Olav Hohmeyer, Social *Costs of Energy Consumption: External Effects of Electricity Generation in the Federal Republic of Germany* (Berlin, Germany: Springer-Verlag, 1988).

Its cost estimates are based on several sources. Some estimates come directly from other studies that value specific categories of effects (e.g., human health effects of air pollution). Other estimates involve direct calculations based on damages (e.g., estimating the probability of, and health effects from, a nuclear accident and multiplying by the monetary value of a life). Finally, a few estimates involve the costs of mitigating environmental damages (e.g., the costs of avoiding the effects of sea level rise brought on by global warming).

The study explicitly notes several classes of environmental costs are not quantified. These include "psycho-social" costs of deaths and illness, health care costs, species loss, environmental effects of intermediate goods used to produce and operate energy systems, some costs of climatic changes, environmental costs of routine operation of nuclear plants, and aesthetic and land-use effects of renewable energy. The author contends that data gaps and uncertainties (which prevented some effects from being quantified or monetized) placed renewable energy sources at a disadvantage.

Table 2-7 summarizes the quantitative results of Hohmeyer's study. Overall, the study estimates that the environmental costs of coal and nuclear power are substantially larger than those of solar and wind power. The report notes that the quantitative results should be interpreted as a first approximation that can be useful for policy. Further, the report claims that where uncertainty existed, the assumptions were least favorable to the report's eventual conclusion (that the environmental costs of renewable sources are considerably lower than those of conventional sources).

I Bonneville Power Administration

The Bonneville Power Administration (BPA) study was undertaken to comply with the provisions of the Pacific Northwest Electric Power Planning and Conservation Act, passed in 1980. The act requires the Bonneville Power Administration and the Northwest Power Planning Council to pursue a planning process that gives priority to cost-effective energy options when planning new energy generation capacity. The act requires that evaluations of cost-effectiveness include quantifiable environmental costs that are directly attributable to energy conservation measures or new energy resources.[28]

zs~is same act motivated a coalition of environmental, labor, ratepayer, and citizens' groups to produce a separate study (see Shuman and Cavanagh, below).

TABLE 2-8: BPA's Estimates of Environmental Costs

	By plant type	
Plant	**Cost (¢/kWh)**	**Cost (1990 ¢/kWh)**
Coal	0.064-0.956	0.072-1.081
Oil		
Combustion turbine	**0.03**	0.04
Natural Gas		
Combustion turbine	**0.087**	0.108
Nuclear	**0.000837-0.0126**	0.001142-0.0172
Hydroelectric	**0.769-1.074**	1,049-1,465
Biomass	-0.011-0.49	-0.013-0.56
Municipal Solid Waste	-3,18-41.664	-3.66-47.9852
Geothermal	0-0.0188	0-0,0217
Solar	0	0
Wind	0	0

NOTE: The separate BPA studies differ substantially, so the estimates for different energy sources are not strictly comparable. Years of the estimates vary: coal=1987, oil and natural gas = 1984, nuclear and hydroelectric = 1982, biomass, MSW, geothermal, solar, and wind = 1986. The coal estimates are drawn from the generic, rather than the site-specific, study. Range of coal estimates reflects a range of possible plant locations; range of nuclear estimates reflects a range of possible valuation techniques; range of hydroelectric estimates reflects a range of possible valuation techniques and discount rates; range of biomass, municipal solid waste, and geothermal estimates represents uncertainty in effects and valuation. Negative values indicate a net environmental benefit. Estimates reported here only include the studies' estimates of environmental costs and benefits, not estimates of socioeconomic and infrastructure costs and benefits that are included in some of the studies. In addition, the damages associated with the consumptive use of water are not included in the nuclear estimates.

SOURCES: ECO Northwest et al., "Generic Coal Study: Quantification and Valuation of Environmental Impacts," report commissioned by Bonneville Power Administration, Jan. 31, 1987; ECO Northwest et al., "Final Report: Economic Analysis of the Environmental Effects of the Coal-Fired Electric Generator at Boardman, Oregon," report commissioned by the Bonneville Power Administration, Dec. 29, 1983; ECO Northwest et al., "Estimating Environmental Costs and Benefits for Five Generating Resources," report commissioned by the Bonneville Power Administration, March 1986; Biosystems Analysis, Inc., "Final Report: Methods for Valuation of Environmental Costs and Benefits of Hydroelectric Facilities, A Case Study of the Sultan River Project," report commissioned by Bonneville Power Administration, June 1984; ECO Northwest et al., "Economic Analysis of the Environmental Effects of a Combustion-Turbine Generating Station at Frederickson Industrial Park, Pierce County, Washington: Final Report," report commissioned by Bonneville Power Administration, Mar. 26, 1984; and Nero and Associates, Inc., "Environmental Costs and Benefits Case Study: Nuclear Power Plant, Quantification and Economic Valuation of Selected Environmental Impacts/Effects," report prepared for the Bonneville Power Administration, Feb. 8, 1984.

The study consists of a set of six semi-independent studies, completed over a period of five years by three different contractors: ECO Northwest, Nero and Associates, and Biosystems Analysis.[29] The studies covered 10 different energy sources: coal (both a generic and a site-specific analysis), oil and natural gas (fueling combustion turbines), nuclear, hydroelectric, solar, wind, geothermal, biomass, and municipal solid waste. The quantitative results of the study are given in table 2-8.

[29]ECO Northwest et al., "Generic Coal Study: Quantification and Valuation of Environmental Impacts," report commissioned by Bonneville Power Administration, Jan. 31, 1987; ECO Northwest et al., "Estimating Environmental Costs and Benefits for Five Generating Resources," report commissioned by the Bonneville Power Administration, March 1986; ECO Northwest et al., "Economic Analysis of the Environmental Effects of a Combustion-Turbine Generating Station at Frederickson Industrial Park, Pierce County, Washington: Final Report," report commissioned by Bonneville Power Administration, Mar. 26, 1984; ECO Northwest et al., "Final Report: Economic Analysis of the Environmental Effects of the Coal-Fired Electric Generator at Boardman, Oregon," report commissioned by the Bonneville Power Administration, Dec. 29, 1983; Nero and Associates, Inc., "Environmental Costs and Benefits Case Study: Nuclear Power Plant, Quantification and Economic Valuation of Selected Environmental Impacts/Effects," report prepared for the Bonneville Power Administration, Feb. 8, 1984; and Biosystems Analysis, Inc., "Final Report: Methods for Valuation of Environmental Costs and Benefits of Hydroelectric Facilities, A Case Study of the Sultan River Project," report commissioned by Bonneville Power Administration, June 1984.

Although the studies are similar in the broad outlines of their methodology, they vary substantially in a number of factors, including the emissions considered and the specific valuation approaches used. As a result, the cost estimates associated with the energy sources cannot be compared with each other in the same way as estimates made by other studies.

| Shuman and Cavanagh

The Shuman and Cavanagh study was prepared in 1982 by Michael Shuman and Ralph Cavanagh of the Natural Resources Defense Council. It was prepared as part of a larger report-a comprehensive proposal for future power development in the Pacific Northwest-sponsored by the Northwest Conservation Act Coalition, an umbrella organization for 38 environmental, labor, ratepayer, and citizens' groups in the Pacific Northwest.[30] The environmental cost estimates are contained in appendix 2 of the larger report.[31]

The study examines some of the most significant environmental impacts of five different energy options: coal, nuclear, wind, solar water heating, and household weatherization. It estimates costs for occupational and public exposure to emissions; property and crop damage from emissions; occupational and nonoccupational accidents in extraction, transportation, and generation (including catastrophic nuclear accidents); and nuclear proliferation. The study does not address a variety of potential environmental costs such as water consumption, recreation losses, fish and wildlife mortality, aesthetic damage, and impacts from transmission and distribution facilities.

A summary of the study's quantitative findings is shown in table 2-9. Overall, the study estimates that the environmental costs of solar, wind, and weatherization are less than one-tenth of those associated with coal and nuclear. The authors believe their analysis to be conservative-the assumptions made in the study are least favorable to the eventual conclusions of the study (that coal and nuclear have high environmental costs relative to solar, wind, and conservation).

The study's explicit aim is to compare renewable sources of energy, such as solar and wind, with conventional sources such as coal and nuclear. The study's estimates of solar and wind were done largely in a relative way. For example, the health impacts of solar and wind were estimated by using the estimate for nuclear (excluding accidents, radon emissions, and proliferation). This decision reflected the authors' belief that the primary environmental costs of solar and wind were due to the construction of a large energy-producing facility and that those risks were similar for nuclear, solar, and wind. The study assumes that few environmental impacts are reflected in the economic costs of energy use, and that most environmental costs should be treated as economic externalities.

In their analysis, Shuman and Cavanagh felt it was best to preserve uncertainties in the range of estimates offered, rather than in what classes of environmental costs were included. As a result, they quantify environmental costs some other studies typically leave out. For example, estimates of coal environmental costs include the health effects and property damage resulting from climate change. These effects account for more than half of the total costs at the high end of the range that Shuman and Cavanagh give for coal power. Similarly, estimates of nuclear environmental costs include the health effects and property damage resulting from nuclear accidents, radon release, and weapons proliferation. These effects account for more than 99 percent of the high end of the range given for environmental costs associated with nuclear power.

SoRalph Cavmagh et ~]., A M~el Electric power and Consemation plan *for the Pacijc Northwest (Seattle,* WA: Northwest Conse!_vation Act Coalition, November 1982).

31 Shumm and Cavmagh, op. Cit., foomote 7.

TABLE 2-9: Shuman and Cavanagh's Estimates of Environmental Costs

By plant type

	Cost, ¢/kWh (1980)		Cost, ¢/kWh (1990)	
~Plant	Midpoint range	Full range	Midpoint range	Full range
Coal	2-3	0.03-20.68	3-5	0.05-35.31
Nuclear	*2-3*	*0.05-30.24*	*3-5*	*0.09-51.64*
Solar and Wind	0-0.12	—	0-0.20	—
Weatherization	0	—	0	—

NOTE: Values in 1980 dollars are reported in the study. Values in 1990 dollars are adjusted using the consumer price index. Values are specific to the Pacific Northwest. Values for some classes of costs were not estimated.

SOURCE: Michael Shuman and Ralph Cavanagh, *A Model Conservation and Electric Power Plan for the Pacific Northwest, Appendix 2: Environmental Costs* (Seattle, WA: Northwest Conservation Act Coalition, November 1982).

COMPARING STUDIES

The final results of environmental cost studies cannot be validated, in the sense of being able to compare them with some objective reality. Other types of studies can, at least in principle, be compared with measurements of actual phenomena. For example, energy demand forecasts can be compared with actual demand experienced at a later date; models that estimate environmental transport of pollutants can be compared with measured concentrations of those pollutants. In contrast, environmental cost studies produce final results that cannot be compared with anything except results of other studies.

The difficulty with validating environmental cost studies places special importance on the ability to compare the results of several studies. This section discusses several conclusions based on a comparison of the studies reviewed in this chapter.

Estimates are Not Independent

None of the studies summarized above contain only original research. All of the studies assemble smaller studies of individual components such as the health impacts of particulate, the value attached to a human life, and the willingness to pay for pollution-free wilderness.[32] In addition, some analysts adapt calculations used in other studies to suit their own purposes. Studies nonetheless require substantial work on the part of their authors: they must develop an overall structure for the study; they must locate, critique, and select original studies; and they must combine those studies in a rigorous and defensible way.

This prevailing approach of assembling smaller pieces means that each study does not represent an independent estimate of environmental costs. The estimates, assumptions, and methods of one study are often used in subsequent studies, albeit in modified form. The body of literature on environmental costs thus represents an evolving set of related estimates rather than a set of completely independent ones.[33]

In addition, environmental cost studies are not always estimating the same thing. Each study has its own definition of what constitutes an environmental cost and its own assumptions about how the cost should be estimated. As a result, any two studies may actually be estimating quantities whose definitions only partially overlap.

These features of environmental cost studies have important implications for how the studies' quantitative estimates are used. When viewing a set of quantitative estimates, there is a temptation

[32] In a few cases, the studies conducted original research to supplement the other, smaller studies that they assembled to estimate environmental cost. For example, the BPA site-specific hydroelectric study conducted original valuation research.

[33] This should not be construed to mean, necessarily, that the externalities literature is converging on a single set of estimates or that more recent studies are always superior to older ones.

TABLE 2-10: Methods of Categorizing Environmental C

Method	Examples	Studies using as a major categorization method
Energy source	Coal, oil, nuclear, photovoltaics	Pace, Tellus, Chernick and Caverhill; Hohmeyer, BPA, Shuman and Cavanagh
Activity	Mining, transportation, fuel processing, generation, waste disposal, energy use	BPA (coal), Shuman and Cavanagh
Emission	$S0_2$, $C0_2$, NO_x, particulate, heat, noise	Pace, Tellus, Chernick and Caverhill
Impact	Human health, quality of life, climate, flora, fauna	Hohmeyer, BPA (coal and hydro), Shuman and Cavanagh
Manifestation	Species extinction, global warming, cancer	Shuman and Cavanagh

NOTE: It maybe possible to retrospectively apply different categorization schemes to published studies based on data they contain. However, for a study to be listed in the rightmost column, the method must be used explicitly in the study to organize the reported results, The DOE/EC and New York State studies are excluded because they are not yet completed,

SOURCE: Office of Technology Assessment, 1994.

simply to average the values, assuming that each value is an independent estimate of the same quantity. These conditions do not hold for the environmental cost estimates discussed in this chapter, and the estimates should not be averaged. Instead, individual studies need to be examined and their estimates compared.

| Studies Categorize Costs Differently

Unfortunately, interstudy comparisons are often problematic. Environmental cost studies employ a wide variety of methods for categorizing environmental costs (see table 2-10). Each method provides a different view of environmental costs. A single activity, such as the emission of carbon dioxide from a coal plant, can be categorized by many different characteristics, including the medium of the emission (air), the phase of the fuel cycle (generation), and the energy source (coal).

The differing categorization schemes employed by different studies make comparisons difficult. Nearly all studies categorize results by energy source (e.g., coal, nuclear, and hydroelectric). However, the components that make up these overall estimates are important to examine, and this is made substantially more difficult when the components are reported using different categorization schemes.

For example, the Pace study reports environmental costs associated with particular emissions (e.g., CO_2, SO_2, NO_x particulate) and then combines these with quantity estimates to estimate the environmental costs associated with each fossil fuel energy source (e.g., coal, oil, natural gas). In contrast, the BPA generic coal study categorizes effects by impact (e.g., human health, crops, livestock, timber, materials, ecosystems, and visibility).

If studies use a common framework, comparisons are easier. Analysts and readers could compare several studies side by side to understand their similarities and differences. In addition, a consistent framework allows researchers to alter an existing study to incorporate new data or assumptions. However, no categorization of environmental costs fits perfectly for all environmental effects and all technologies.[34]

Differences in categorization are understandable, given the diverse conditions and purposes under which the studies were assembled. How-

[34] Stirling, op. cit., footnote 4.

ever, the differences force policy makers to view existing studies as independent units of analysis, rather than flexible tools whose assumptions and numeric values can be interchanged to fit the policy makers' particular circumstances or interests. In contrast, the results of at least one pending study (New York State) will be embodied in computer software, which will allow many parameters of the study to be changed easily, although its basic structure will remain fixed.

One Effect Category Often Dominates

Although studies categorize environmental effects quite differently, a single category dominates most estimates of environmental cost. Specifically, in the eight studies reviewed by OTA, 55 quantitative estimates were produced that were broken down into several categories of effects. Of these, 46 (84 percent) had single categories that accounted for the majority (i.e., 50 percent or more) of the total estimate.[35]

For example, Pace makes estimates for 15 different generating technology and fuel combinations. Within each estimate, the study categorizes effects by emission (e.g., $S0_2$, NO_x, particulate, and $C0_2$). Pace produced an estimate of 4.72 cents/kWh for the environmental cost associated with coal plants meeting the new source performance standards (NSPS). In the case of this estimate, the effects associated with $S0_2$ accounted for 2.95 cents/kWh, or more than 60 percent of the total estimate.

There is some consistency in the effects that dominate. Three studies (Pace, Tellus, and Chernick and Caverhill) estimate costs for fossil fuels and categorize effects by emission. When a single category dominates in an estimate from these studies, the category is either $S0_2$ or $C0_2$. Similar conclusions are difficult to draw for nuclear and renewable energy sources because the studies are often less specific about how they categorize effects for these energy sources.

This dominance of single effects has important implications for policy makers. It points to the potential for environmental cost studies to be used for setting priorities. Although studies with different frameworks of assumptions may differ in their quantitative estimates of environmental costs, if there is agreement on dominant effects then the studies may provide valuable guidance for where legislative and regulatory efforts should be focused. Important questions of priorities would still remain, of course, including how to balance environmental programs against other important federal priorities, but focusing environmental efforts effectively is still an important victory.

Cost Estimates are Highly Variable

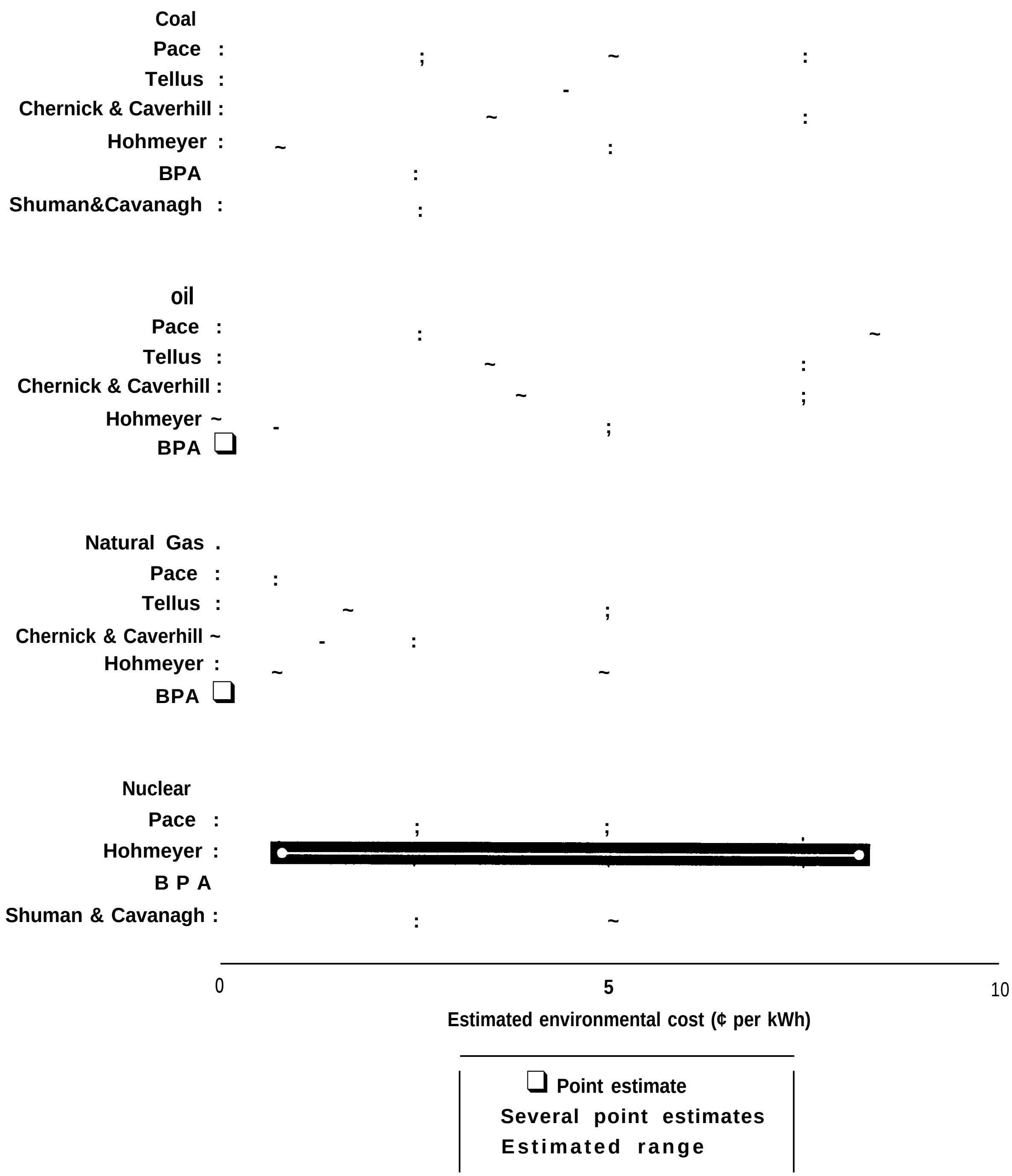
In some cases it is possible to compare results of different environmental cost studies .[36],[37] Despite these differences in categorization, rough comparison of results is still possible (see figures 2-2 and 2-3). Comparing these results indicates wide variation in cost estimates. Some estimates of environmental costs are nearly zero. In other cases, estimates are as high as 10 cents/kWh-costs that are larger than the electricity rates that average consumers currently pay. The wide variation in

[35] None of the studies actually make this calculation. The OTA numbers are derived by employing the primary categorization method used by each study. In some cases, not all of the estimates in the particular study were counted. For example, the BPA hydro study contained a wide range of estimates, but only two (the high and low estimates) were included in the 55 estimates used for this calculation. Similarly, estimates that include only a single category of effects were not counted. For example, Hohmeyer's estimate of nuclear environmental costs is based solely on accidents. This estimate was excluded from the 55 estimates used in the calculation.

[36] Nearly all studies produce results categorized by energy source (e.g., coal, nuclear, and solar). Even these results are categorized and reported indifferent ways. Hohmeyer presents one overall estimate for "fossil fuels," three studies (BPA, Shuman and Cavanagh, and Chernick and Caverhill) make distinct cost estimates for each fossil fuel source (coal, gas, and oil), and the remaining completed studies (Pace and Tellus) produce further distinctions among several different combinations of combustion technology and fuel.

[37] As noted earlier, some analyses have attempted to adjust for differences among the studies attributable to different technical assumptions, such as the heat rates and emission factors of power plants. For example, see Koomey, op. cit., footnote 10.

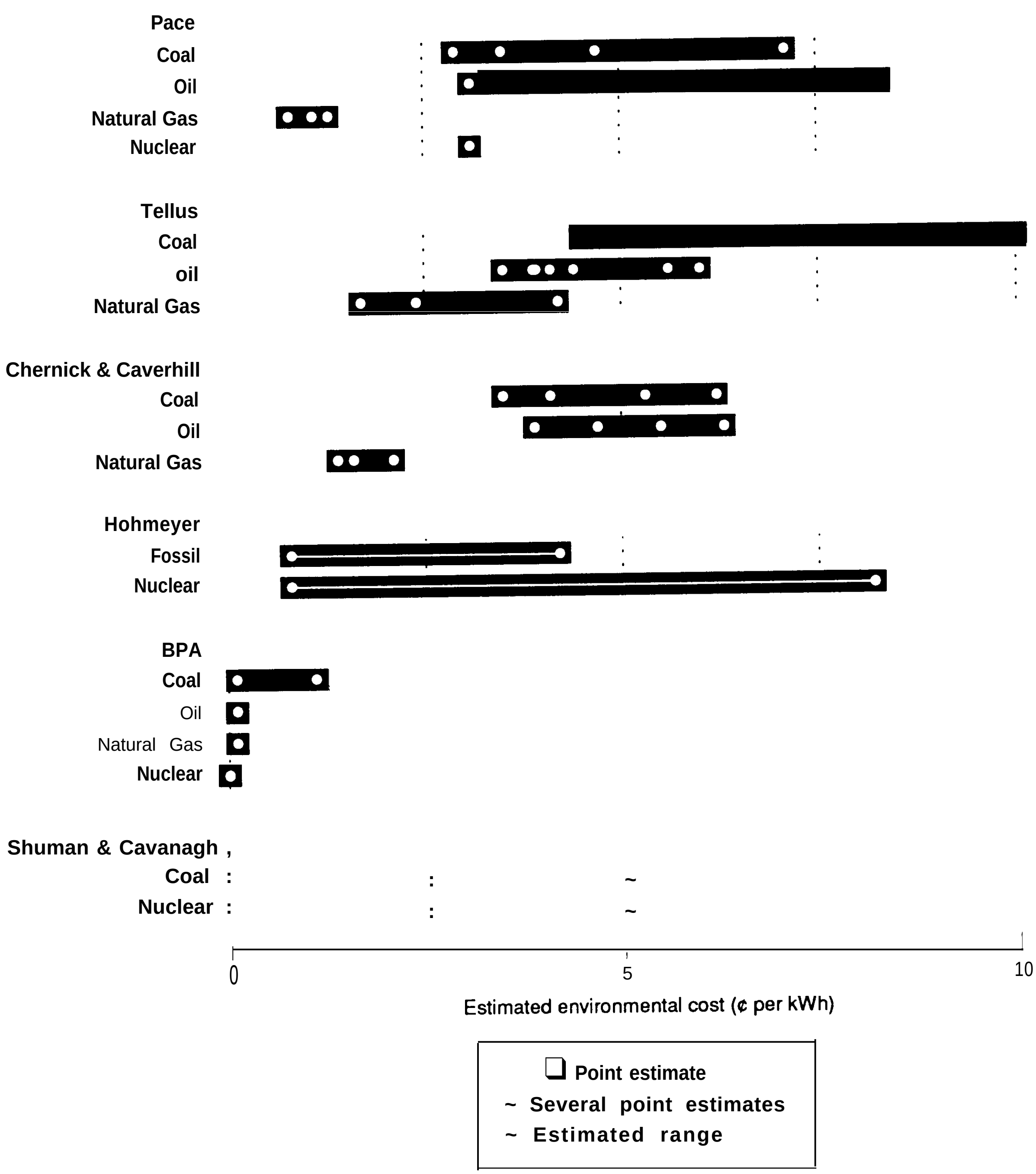
FIGURE 2-2: Results of Environmental Cost Studies Vary Widely (listed by generating technology)



NOTES: See text for full description of the difficulty of comparing environmental cost estimates, When several point estimates are given, each estimate is for a different specific generating technology (e.g., combustion turbine) or specific fuel (e g., oil with 1 % sulfur content). Hohmeyer gives only one estimated range for all fossil fuels (coal, oil, and gas). The Shuman and Cavanagh estimates are the "best estimate" ranges, Costs are given in 1990 cents per kilowatt-hour. Not all results are shown for each study.

SOURCE: Office of Technology Assessment, 1994

FIGURE 2-3: Results of Environmental Cost Studies Vary Widely (listed by study)



NOTES See text for full description of the difficulty of comparing environmental cost estimates When several point estimates are given, each estimate is for a different specific generating technology (e g , combustion turbine) or specific fuel (e g., 011 with 1 % sulfur content). Hohmeyer gives only one estimated range for all fossil fuels (coal, 011, and gas) The BPA estimates should not be directly compared because the individual studies used different methods and assumptions. The Shuman and Cavanagh estimates are the "best estimate" ranges. Costs are given in 1990 cents per kilowatt-hour Not all results are shown for each study quantitative estimates demonstrates there is no consensus about cost estimates among currently published environmental cost studies.

I Cost Estimates are Highly Uncertain

Due to a variety of analytical difficulties and unknowns, all of the studies are cautious in their presentation of numerical estimates. First, some studies present broad ranges of possible values rather than specific numeric estimates (often called "point estimates"). For example, Hohmeyer, BPA, and Shuman and Cavanagh all use this method. Shuman and Cavanagh even go so far as to produce a "midpoint range" indicating values they think are most likely, and a "full range" for coal and nuclear indicating values they think are possible. Where ranges are presented, they are often quite large. The Hohmeyer high and low estimates vary by a factor of about five in the case of fossil fuels and 10 in the case of nuclear. Shuman and Cavanagh's full range high and low estimates differ by more than a factor of 500.

Second, some studies produce a point estimate and then attempt to evaluate the uncertainty associated with that estimate. Where uncertainty is evaluated, it is often quite large. For example, several of the BPA studies evaluate the uncertainty to be as large or larger than the estimate itself, indicating that the actual cost could be nearly zero or as much as twice the point estimate.[38]

Finally, most studies are careful to label their results "preliminary." This is due to various data gaps, uncertainties, methodological disputes, and the early stage of development of environmental cost analysis. Based on uncertainty estimates and cautions contained in the studies, and based on the large differences in the results of different studies, prospective users of environmental cost studies should assume that all estimates are highly uncertain and preliminary.

| Conclusion

Many of these issues—independence, categorization, variability, and uncertainty-are closely related to the valuation phase of environmental cost studies. This phase takes quantitative estimates of environmental impacts and attempts to value them in monetary terms. Other study phases also bear on the issues discussed above, but valuation introduces additional dimensions and complications. The different methods of valuation are discussed the next chapter.

38 Swcifjcally, the cost estimates for coal, oil, and natural gas are accompanied by uncertainty estimates. For coal, the standard deviation is estimated to be equal to the estimate itself. For oil and gas, the two standard deviations are estimated to be equal to the estimate itself. The standard deviation is a statistical quantity indicating the variability of an estimate. For a normal (or "bell shaped") distribution, approximately 95 percent of the possible values lie within two standard deviations of the mean value (the center of the distribution).