Introduction to Environmental Externality Costs

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INTRODUCTION

According to Griffin and Steele (1986), external costs exist when "the private calculation of benefits or costs differs from society's valuation of benefits or costs". Pollution represents an external cost because damages associated with it are borne by society as a whole and are not reflected in market transactions.

The goals of this article are modest. It does not attempt a systematic review of the current state of externalities analysis, because such reviews have been recently completed by other authors (CEC 1994, CECA 1993, ECO Northwest 1993, OTA 1994, Weil 1991). Instead, it serves as an introduction for the interested but uninformed reader to some of the key issues in assessing environmental externality costs, and gives references for those readers wishing to investigate further.

Many analysts have attempted to quantify societal costs of pollution and other externalities associated with fossil fuel combustion, and some regulatory bodies have even attempted to crudely incorporate externality costs into investment decisions (Cohen et al. 1990, Hashem and Haites 1993). Efforts to incorporate externalities have generally been confined to the regulated sectors of the energy system (electricity, and to a lesser extent, natural gas),. Unfortunately, estimates of externality costs are often based on quite different assumptions, making comparisons difficult. Uncertainties in such estimates are large, and can even span orders of magnitude.

FRAMEWORK FOR UNDERSTANDING EXTERNALITIES

Exploitation of any energy source generates externalities, defined as societal costs that are not reflected in market transactions. Figure 1 (Holdren 1981) shows a detailed listing of stages of energy sources, from exploration to end-use. It also shows phases of each stage, from research to dismantling. A comprehensive analysis of external costs must treat each and every stage in the process, which makes any such calculation inherently difficult.

Figure 2 (Holdren 1981) presents insults, pathways, stresses, and costs. Insults are humankind's physical and chemical intrusions into the natural world. Pathways are those mechanisms by which insults are converted to stresses. Stresses, defined as changes in ambient conditions (social, political, or environmental), then lead directly to societal costs.

Table 1 lists environmental and social insults attributable to fossil fuel combustion, and Table 2 shows those insults attributable to nuclear, hydro-electric, and wind generation. To understand how Figure 2 relates to such insults, consider the case of sulfur dioxide. SO_2 (the insult) is emitted from oil and coal combustion as a gas (this is the first pathway). Some of the SO_2 is converted, through chemical reactions in the atmosphere, to sulfuric acid, some of which then falls in rain into lakes and watersheds (another pathway). Some of this sulfuric acid is neutralized by buffering cations in the water and soil (a third pathway). The altered acidity of the lakes is the stress. The costs (social, economic, and environmental consequences) are the destruction of fish and other wildlife, mobilization of aluminum, damage to trees, and reduction in recreational value of the forest (Harte 1985).

While it is often possible to quantify the size of the insult, the pathways may be so numerous or complicated that only the crudest approximations are possible. Even if it is possible to confidently predict stresses from a given insult, translating those stresses into societal costs is problematic.

Stages of Energy Sources

Exploration/Evaluation
Harvesting
Processing/Refining
Transportation/Distribution
Storage
Conversion (Elect. Generation)
Marketing
End Use

Phases within a Stage

Research
Development/Demonstration
Commercial Construction
Operation and Maintenance
Dismantling
Management of Long-Lived Wastes
Environmental Controls*
Regulation and Monitoring*

Figure 1: Steps in Energy Production, Processing, and Use

*Occurs simultaneously with other phases but may have its own effects

Source: Holdren, John P. 1981. "Chapter V. Energy and Human Environment: The Generation and Definition of Environmental Problems." In *The European Transition from Oil: Societal Impacts and Constraints on Energy Policy*. Edited by G. T. Goodman, L. A. Kristoferson and J. M. Hollander. London: Academic Press.

TABLE 1: ENVIRONMENTAL INSULTS FROM FOSSIL FUELS

	All Fuels	Natural Gas	Oil	Coal
Exploration/ Harvesting	CO_2, CH_4, N_2O, NO_x, CO, ROG, HCs, particulates, trace metals, thermal pollution	drilling accidents, drilling sludge disposal	drilling accidents, SO_2, drilling sludge disposal	mining injuries, land degradation, SO_2
Processing/ Refining	CO_2, CH_4, N_2O, NO_x, CO, ROG, HCs, particulates, trace metals, thermal pollution	refinery accidents, refinery waste disposal	SO_2, refinery accidents, refinery waste disposal	SO_2
Transport/ Distribution	CO_2, CH_4, N_2O, NO_x, CO, ROG, HCs, particulates, trace metals, thermal pollution	pipeline accidents, LNG explosions	pipeline and tanker accidents, oil spills, SO_2	train accidents, SO_2
Conversion/ Marketing/ End Use	CO_2, CH_4, N_2O, NO_x, CO, ROG, HCs, particulates, trace metals, thermal pollution		ash disposal, SO_2	ash disposal, SO_2

ROG = Reactive Organic Gases, HC = hydrocarbons

TABLE 2. ENVIRONMENTAL INSULTS FROM EXISTING NUCLEAR POWER, HYDROELECTRIC, AND WIND GENERATION

	Nuclear Power	Hydro Electric	Wind
Exploration/ Harvesting	mining accidents, radioactive tailing disposal, land degradation, indirect fossil fuel emissions (from fuel used in harvesting)	N/A	
Processing/ Refining	processing accidents, indirect fossil fuel emissions	N/A	
Transport/ Distribution	truck accidents, risk of proliferation, indirect fossil fuel emissions	N/A	
Conversion/ Marketing/ End Use	Risk of catastrophic accidents, creation of low and high level radioactive wastes	may inhibit fish migration	may kill birds; noise pollution
Decommissioning	disposal of low and high level radioactive wastes*, indirect fossil fuel emissions	concrete disposal	

*All U.S. nuclear reactors are charged an annual fee to cover decommissioning and disposal of radioactive wastes. However, neither a disposal site or disposal method has yet been chosen, and no large reactor has ever been decommissioned. It is therefore unknown if the actual costs will correspond to the value of this fee.

Insults *to Physical and Human Environment*

Resources Used (land, water, energy)
Material Effluents (NOx, SO2, CO2)
Non-Material Effluents (noise, radiation, E&M)
Other Physical Transformations (dredging)
Socio-political Influences (politics, employment)

Pathways *(Convert Insults to Stresses)*

Media (air, water, ice, soil, rock, biota)
Processes (evaporation, diffusion, conduction)

Stresses *(Physical or Social Consequences of Insults)*

Altered ambient conditions (temperature, humidity, concentrations, EM fields)
Altered physical or social processes

Environmental and Social Costs *of Insults*

Magnitudes of Consequences
Temporal Distribution of Harm
Spatial Distribution of Harm
Coincidence of Risks and Benefits
Scaling (linear or nonlinear)
Resistance to Remedy
Irreversibility
Visibility of Harm
Quality of Evidence of Harm

Figure 2: Insults, Pathways, Stresses, and Environmental Costs

Source: Holdren, John P. 1981. "Chapter V. Energy and Human Environment: The Generation and Definition of Environmental Problems." In *The European Transition from Oil: Societal Impacts and Constraints on Energy Policy*. Edited by G. T. Goodman, L. A. Kristoferson and J. M. Hollander. London: Academic Press.

Calculating externality costs

In general, external costs can be crudely characterized by Equation 1:

$$\text{Externality Cost} = \text{Size of Insult} \times \text{Value of Environmental Damage per unit of insult} \qquad (1)$$

where

Externality Cost = total external cost to society, in dollars;

Size of Insult is expressed in physical units (lbs emitted or hectares degraded); and

Value of Environmental Damage (VED) is expressed in dollars per physical unit of insult.

Externality costs must be normalized to some common unit of service for consistent comparison. This unit is *delivered* kWh, which includes transmission and distribution losses. For direct fuel consumption, the unit of service is MMBtu.

Air pollution and climate effects tend to dominate most analyses of fossil fuel externalities. Such external costs, which vary with power plant fuel consumption, can be characterized by Equation 2 (which is a variation of Equation 1):

$$\text{Externality Cost}\left(\frac{¢}{\text{kwh}}\right) = \text{EF}\left(\frac{\text{lbs}}{\text{Btu}}\right) \times \text{HR}\left(\frac{\text{Btu}}{\text{kwh}}\right) \times \text{VED}\left(\frac{¢}{\text{lb}}\right) \qquad (2)$$

where

EF = Emission Factor, in lbs/Btu of fuel consumed;

HR = Heat Rate of power plant, in Btus/kWh;[1] and

VED = Value of Environmental Damage, in ¢/lb.

The emission factor relates the particular insult to the amount of fuel burned. The heat rate characterizes the first pathway by which the insult is converted from its fuel-related state to a form that impinges upon the natural environment. The marginal damage cost relates the insult to the social costs. It embodies a relationship between the insult and the stresses that depends on assumptions about geography, dose response, weather, biotic interactions, population density, post-combustion pathways, and myriad other factors.

[1] for direct fuel use, this term becomes the inverse of combustion efficiency.

EF and HR are physical parameters that can be measured, while VED can be calculated using direct cost estimation, abatement costs, or some combination of both. VED is an important parameter for regulatory policy analysis, but it is usually difficult to calculate. It should always be stated explicitly, along with the large number of assumptions needed to calculate such a value.

Environmental insults from energy efficiency and supply technologies

Consistent comparisons require that environmental insults from both energy efficiency and supply technologies must be included in externality assessments. Emissions from supply technologies are both direct (from the combustion of fossil fuels) and indirect (from the construction of the equipment and the extraction, processing, and the transport of the fuel). Emissions from efficiency technologies are generally only of the indirect type. On balance, increasing the efficiency of end-use reduces emissions and other externalities.

Energy supply technologies

Direct and indirect emissions for fossil fuels are calculated by DeLuchi et al. (1987b), Unnasch et al. (1989), Fritsche et al.(1989), Meridian Corp.(1989), and San Martin (1989). For a complete treatment of both direct and indirect emissions of carbon dioxide, NO_x and SO_2 associated with the latest fossil-fired cogeneration and district heating technologies, see Krause et al. (1994a). The net emissions from cogeneration vary by cogeneration fuel, cogeneration technology, and boiler fuel, and are rarely analyzed.

Indirect emissions for nuclear power are calculated by Meridian Corp.(1989), San Martin (1989), and Fritsche et al. (1989), while emissions and other environmental insults for nuclear are calculated by Ottinger et al. (1990) and Krause et al. (1994b). Meridian Corp.(1989), and San Martin (1989) also show indirect emissions for renewable power sources.

Efficiency technologies

Feist (1988) investigates eleven different insulating materials and wall compositions that are widely used in the FRG. He finds, based on process analyses for the manufacture and installation of alternative insulating systems by Marmé and Seeberger (1982), that for wall insulation thicknesses now typically applied in retrofits or new buildings in Europe (5-15 cm), indirect primary energy consumption can be neglected, since it amounts to less than five percent of the direct primary energy savings associated with installing the insulation. An analysis of efficiency technologies in the American context (Anderson 1987) came to a similar conclusion.

Methods of calculating the value of emissions reductions

There are two basic approaches to calculating the value of incremental emissions reductions: "direct damage estimation" and "cost of abatement". Direct damage estimation involves calculating damages that can be definitively linked to emissions of a particular pollutant, in dollar terms (Hohmeyer 1988, Ottinger et al. 1990). For instance, Cavanagh et al. (1982) monetize and tally the human health and environmental effects due to coal consumption in new power plants. These effects include premature human deaths, increased health costs, potential famine induced by global warming, and other effects. Direct estimation is extremely difficult, even when there are relatively few pathways. Some of the most important effects are impossible to quantify, while others depend on pathways that we do not fully understand.

Cost of abatement approaches typically use the cost of pollution controls imposed by regulatory decisions as a proxy for the true externality costs imposed by a pollutant (Chernick and Caverhill 1989, Marcus 1989). This approach (sometimes called "revealed preferences") assumes that regulators' choices embody society's preferences for pollution control, that the marginal costs of mitigation are known, and that these marginal mitigation costs are incurred solely to reduce emissions of a single pollutant (i.e., that there are no other benefits to a pollution reduction investment).

If society's preferences are changing rapidly, abatement cost calculations may be misleading, because society's previous preferences for pollution control may not accurately represent its present preferences. If mitigation measures have multiple or incommensurate benefits, revealed preference calculations become difficult. For instance, the cost of an energy conservation measure cannot be used to estimate the true value of mitigating SO_2 emissions, since the conservation measure avoids power plants, reduces fuel use, and eliminates other pollutants (Krause and Koomey 1989). In contrast, the cost of flue-gas desulfurization equipment or the price premium of low-sulfur oil over high-sulfur oil can be used without modification in abatement cost analysis, because the cost of these mitigation measures is incurred solely to reduce sulfur emissions.

Estimates from other studies

Table 3 shows the value of incremental emissions reductions from a variety of studies (in $/lb of pollutant). The difference in assessments of pollutant value reflect different geographic and environmental circumstances, as well as other factors. The assessments of the value of NO_X reductions in California are substantially higher than those estimated by Chernick for New England and implied by the NY PSC's bidding system. California has some of the strictest air pollution controls in the nation, which reflect its severe NO_X-related ozone problems. Chernick's, Schilberg's, and the CEC's estimates of the value of CO_2 reductions are based on proxy approaches, while the value implied in the Con Ed/NY PSC system (which is less than twelve percent of the other estimates) is based on cautious initial regulatory response to the global warming problem, and not on explicit analysis.

Damage costs vs. cost of abatement

California is arguably at the leading edge of externality policy. Table 4 shows a summary of the externality values calculated in the context of California's electricity planning process, as embodied in the *1992 Electricity Report* (CEC 1993). The table compares damage cost and control cost methods for estimating externalities in ten distinct regions of California. The estimates vary as a function of population density, geographic and meteorological conditions, stringency of emissions regulations, and other factors. Except for particulates with a diameter of less than ten microns (PM10) in six of the ten regions, control cost methods yield higher externality values than do damage cost methods.

TABLE 3: VALUE OF ENVIRONMENTAL DAMAGE (1989$/LB)

	SO_2 $/lb	NO_x $/lb	CO_2 $/lb C	ROG $/lb	CH_4 $/lb	N_2O $/lb	Particulates $/lb
EPRI (1987) rural PA, WV							
Low	0.21	0.02	--	--	--	--	--
High	0.85	0.23	--	--	--	--	--
Best Estimate	0.48	0.07	--	--	--	--	--
EPRI (1987) (Sub)urban*							
Low	0.48	0.02	--	--	--	--	--
High	2.31	0.23	--	--	--	--	--
Best Estimate	1.27	0.07	--	--	--	--	--
Hohmeyer (1988)							
Low	0.233	0.292	--**	0.233	--	--	0.233
High	1.244	1.555	--**	1.244	--	--	1.244
Chernick and Caverhill (1989)	0.92	1.58	0.042	--	0.37	--	>2.63
Schilberg et al (1989)							
Outside CA	0.50	1.35	0.027	0.33	0.19	1.85	--
CA Outside SCAQMD	0.90	9.40	0.027	0.57	0.19	1.85	--
CA Inside SCAQMD	9.15	12.25	0.027	8.75	0.19	1.85	--
CEC Staff (1989) in CA	5.75	5.80	0.013	1.65	--	--	3.9
Implied by NY PSC (1989)	0.48	0.94	0.0015	--	--	--	1.01
MA DPU (1990)	0.75	3.25	0.040	2.65	0.11	1.98	2.00
NV PSC	0.78	3.40	0.040	0.59	0.11	2.07	2.09
Pace University	2.03	0.82	0.026	--	--	--	1.19
Minnesota interim values							
Low	0.00	0.03	0.009	0.50	--	--	0.07
High	0.13	0.69	0.021	0.50	--	--	1.00

1) NV PSC and Pace University values taken from Weil (1991). Massachusetts Department of Public Utilities values taken from MA DPU (1990). Minnesota interim values are taken from MN PUC (1994), and are adjusted from 1994$ to 1989$ using the consumer price index, which increased 19% over this 5 year period. Other values as reported in Koomey (1990a).

2) Values for CO_2 are expressed in $ per lb of carbon.

TABLE 4: VALUE OF INCREMENTAL EMISSIONS REDUCTIONS IN CALIFORNIA (1989$/LB)

Air basin or district	*Valuation method*	*SOx*	*NOx*	*ROG*	*PM10*	*CO*
South Coast	Damage functions	3.71	7.24	3.46	23.81	0.00
	Control costs	9.90	13.20	9.45	2.85	4.65
Ventura County	Damage functions	0.75	0.82	0.14	2.05	0.00
	Control costs	3.10	8.25	10.55	0.90	Attainment
Bay Area	Damage functions	1.74	3.67	0.05	12.20	0.00
	Control costs	4.45	5.20	5.10	1.30	1.10
San Diego	Damage functions	1.34	2.78	0.05	7.11	0.00
	Control costs	1.80	9.15	8.75	0.50	0.55
San Joaquin Valley	Damage functions	0.75	3.24	1.86	1.88	0.00
	Control costs	8.90	4.55	4.55	2.60	1.60
Sacramento Valley	Damage functions	0.75	3.04	2.06	1.09	0.00
	Control costs	4.80	4.55	4.55	1.40	2.50
North Coast	Damage functions	0.75	0.40	0.23	0.28	0.00
	Control costs	1.50	3.00	1.75	0.45	Attainment
North Central Coast	Damage functions	0.75	0.98	0.40	1.43	0.00
	Control costs	1.50	4.55	4.55	0.45	Attainment
South Central Coast	Damage functions	0.75	0.82	0.14	2.05	0.00
	Control costs	1.50	4.55	4.55	0.45	Attainment
Southeast Desert	Damage functions	0.75	0.22	0.08	0.34	0.00
	Control costs	9.85	3.00	1.75	2.85	1.45

1) Taken from CEC (1993).

2) PM10 = particulates less than 10 microns in diameter.

PITFALLS IN EXTERNALITY ANALYSIS

Holdren (1980) identifies pitfalls in calculating total societal costs associated with energy technologies, which affect both direct estimation and cost of abatement approaches. These include: 1) inconsistent boundaries; 2) confusing average and marginal effects; 3) illusory precision; 4) environmental stochasticity; 5) "confusing things that are countable with things that count".

1) Inconsistent boundaries: boundaries must be drawn consistently to ensure that comparisons between estimates of external costs are fair. This principle implies that the service delivered by competing resources be identical, that all relevant stages of each resource be included in the comparison, and that geographic boundaries be drawn to include all external effects.

2) Average versus marginal comparisons: Hohmeyer (1988) calculates costs of externalities from the existing power supply mix in West Germany. While this calculation is useful to show total societal costs from power production, it will almost certainly be

misleading to use these embedded externality costs per kWh to calculate the cost of externalities from either *new* power plants or from *marginal existing capacity*, both of which may have characteristics quite different from average existing plants.

3) Illusory precision: there are often large uncertainties in specifying the size of insults, in translating insults through pathways to stresses, in converting stresses to consequences, and in valuing consequences. To ignore such uncertainty by specifying single point estimates to many significant figures can be quite misleading, since it creates the illusion that the estimates are certain. To avoid misunderstandings, externality cost estimates should be assigned appropriate error bounds. Such uncertainty creates a quandary for regulators, since most regulatory determinations *must* be in terms of point estimates. Analysts can best serve regulators by making the uncertainties explicit and understandable.

4) Stochasticity: Environmental and social systems are often characterized by *stochasticity*, or probabilistic variability about some mean value. The most interesting and important interactions between human societies and the natural world occur when one or both of these systems are far from their respective mean values. Overzealous averaging of important parameters may disguise damages that occur only under extreme conditions.

For instance, calculations of damages from ambient air pollutant concentrations may yield vastly different results depending on how the concentrations are averaged over time. Damages may not be linearly related to pollutant concentration, and may only occur if concentrations exceed some threshold value. Calculating damages based on the annual average pollutant concentration might be misleading for these reasons. Daily or hourly averages sorted by concentration would give a more accurate picture.

5) "What's countable versus what counts": Analysts often focus on those things that are amenable to quantitative treatment. Yet the probabilities, consequences, and risk-adjusted expected costs of many important external effects (like nuclear sabotage, nuclear proliferation, or global warming) may be difficult or impossible to quantify, and may also be irreversible once the damages are incurred. Since the "facts" are uncertain or nonexistent, and may not become certain before decisions need to be made, such costs can only be valued through the political process. In that circumstance, it is especially crucial that analysts' value judgements be made explicit.

USING EXTERNALITY COSTS IN THE CONTEXT OF POLICY

Some states have not explicitly monetized externality values, but have expressed their preferences for low polluting resources (such as efficiency and renewables) by increasing the cost of conventional resources by some fixed percentage (15% in Wisconsin, 10% in Iowa) for the purposes of resource planning. While such approximations push resource choices towards the less polluting resources, basing externalities on a percentage of the busbar cost of the resource can lead to perverse results (Koomey 1990a). Damages from pollutants are not, in general, correlated with resource costs, but are strongly related to pollutant emissions, local topography, population density, and other physical characteristics of the surrounding area.

There are huge uncertainties in assessing externality costs related to greenhouse gas emissions, and the exact values of these costs are probably unknowable. In spite of such uncertainties, it is clear that all emissions that contribute to global warming should be treated similarly. Carbon, which is the most important contributor to the global warming problem, is by no means the only one. Radiatively active trace gases like methane (CH_4), nitrous oxide (N_2O), and chloroflourocarbons (CFCs) should all be assigned the same externality cost per unit of global warming contribution. The appendices in Krause et al. (1989) explain how to convert concentrations of the other gases into *equivalent CO_2 concentrations*, which can then be used to assign these gases externality costs (once the appropriate cost for CO_2 has been determined). Others have also derived "warming factors" that can be used to achieve the same result (e.g., Unnasch et al. (1989) and DeLuchi et al. (1987a)).

An important consideration for policymakers in this area is that "getting prices right" is not the end of the story. Many market failures affecting energy use will still remain after external costs are incorporated (Fisher and Rothkopf 1989, Koomey 1990b, Levine et al. 1994, Sanstad et al. 1993). They are amenable to a variety of non-price policies, including efficiency standards, and incentive, information, and research & development programs. For more discussion of the policy issues surrounding energy tax and non-price policies, see Krause et al. (1993).

CONCLUSIONS

Estimates of the consequences of technological choices (including, but not limited to, estimates of externality costs) will always be inaccurate because many effects are spread geographically and chronologically, and the causal links are extremely complicated. Our understanding of these links will always lag behind our ability to alter them, as David Bella points out:

> ...changes can be accomplished one at a time as if they were essentially in isolation from each other. Moreover, only a small part of the environment and only a few environmental properties must be understood in order to produce a change. In contrast, to foresee the consequences of change requires that one examine the combined effect of many changes (Bella 1979).

As in all areas of life, externality policy must be made in the face of imperfect information. We can make action easier by looking for common ground and by undertaking policies that have multiple benefits. We must be prepared to experiment, to change course in response to new information, and to learn from our mistakes. To not incorporate externalities in prices is to implicitly assign a value of zero, a number that is demonstrably wrong.

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