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ESTIMATION OF EXTERNALITIES: A REVIEW FROM THE POINT OF VIEW OF ENERGY PLANNING IN BRAZIL

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ABSTRACT

Electricity generation and transportation are two of the leading sources of environmental impact around the world. For developing countries, the problem is exacerbated by a lack of funding, which inevitably prevents industry leaders from choosing the economically best available technologies considering the total cost picture. For a full cost assessment, the external damages and costs must be first quantified and then integrated into the decision making process. Externalities include lifetime (construction, operational, and decommissioning) plant costs, and environmental (human and ecological) risk for local, regional and global scales, and social (demographic and lifestyle) changes. In most cases, estimating the externalities is the greatest challenge to planning and policy decisions, in part due to the current limits in working knowledge, and the large amounts of data needed to carry out the analysis. Since the early 1990s, several high level studies on external costs of energy have established a methodological framework to quantify both health and environmental impacts from electricity generation, and to quantify in monetary terms the damage resulting from these physical impacts. In order to incorporate economic, social and environmental aspects in the decision process of energy planning in Brazil, a joint research project sponsored by the International Atomic Energy Agency has been carried out, the primary objective of which is to perform a comparative risk assessment of alternative energy systems. This project includes not only the quantification of the physical impacts and damage costs associated with airborne emissions from the traditional fossil fuels (coal, gas and oil) and nuclear energy, but also those from renewable resources, most specifically from hydroelectric, which is the major source for electricity generation in Brazil. The main objective of the this paper is to present the main challenges in estimating damage costs from the point of view of energy planning in Brazil. A brief analysis of the potential environmental *impacts from different energy sources is also performed. The methodology used to evaluate monetary costs (externalities) of technology using damage cost estimation is also discussed. Site-specific data bases for Brazilian sites are being assembled and applied.*

KEYWORDS: Externalities, Environmental Risk, Energy Planning

1. INTRODUCTION

Guiding principles and standards for evaluation of industrialized and developing economies around the world have long been founded on the assumption of the desirability and possibility of continuing growth in energy demand and distribution, and of management of natural resources through proper allocation and optimization (efficiency). It is clear that the use of energy in all forms and applications can provide an enormous benefit to society. However, energy generation and distribution can also be associated with numerous environmental and social challenges, such as the health effects from pollution of air, water and soil, ecological disturbance and species loss, and landscape damage. According to the World Bank (1998) if they are to be conducive to sustainable development, energy systems should meet the following criteria:

a) consistent with environmental sustainability. The related pollutants should not exceed the absorptive capacity of environmental media (air, water, and land) as determined by scientific standards. The environmental costs for maintaining the total functions of the relevant energy resource or functions of other natural assets affected by the development and use of energy should be accounted for, collected from the producer/user (polluter pay principle) and reinvested within the environmental sector.

b) consistent with economic sustainability. User costs of energy must be accounted for to determine the feasibility of projects; if projects do go ahead, such costs must be collected and invested by or through the public sector in any asset (particularly in renewable energy sources) or in a combination of assets that lead to a constant level of income originated from the relevant energy resource.

c) consistent with social sustainability. The development and use of energy should not harm people's health according to established international standards (WHO), nor involve involuntary resettlement. It should contribute to poverty alleviation and social equity. Where human impacts do occur, health impacts can and should be included in the cost of energy development and use, and reallocated to human health protection.

Since the early 1990s, several high level studies on external costs of energy have established a methodological framework to quantify both health and environmental impacts from electricity generation, and have quantified in monetary terms the damage resulting from these physical impacts. In order to incorporate economic, social and environmental aspects in the decision process of energy planning in Brazil, a joint research project sponsored by the International Atomic Energy Agency has been carried out, the primary objective of which is to perform a comparative risk assessment of alternative energy systems. This project includes not only the quantification of the physical impacts and damage costs associated with airborne emissions from the traditional fossil fuels (coal, gas and oil) and nuclear energy, but also those from renewable resources, most specifically from hydroelectric, which is the major source for electricity generation in Brazil. The main objective of the this paper is to present the main challenges in estimating damage costs from the point of view of energy planning in

Brazil. A brief analysis of the potential environmental impacts from different energy sources is performed. The methodology used to evaluate monetary costs (externalities) of technology using damage cost estimation is also discussed.

2. ENVIRONMENTAL IMPACTS OF ELECTRICITY PRODUCTION

Electricity generation from fossil, nuclear, or renewable sources may cause an increased level of environment air concentration of pollutants or an increased level of ionizing radiation due to activities on the various process steps of the energy systems, resulting in increased risks of adverse effects within general public, ecosystems and materials. When discussing and assessing environmental impacts from electricity production, it is necessary to compile a list of all possible impacts and to make an initial estimation of their relative importance. Because of the complexity, generally it is not possible to deal with all potential burdens, pathways and types of impacts in a single environmental impact study. The approach usually taken is to focus on identifying and analyzing those that appear, on a first review, to have the largest potential impacts on specific situations.

The level of awareness of health and environmental impacts of energy systems, as well as the technical and economic capability to mitigate impacts, is not the same in all counties and regions of the world (EC, 1998). In some countries, protection to human health and the environment is given high priority, and sophisticated technical, regulatory and management systems have been implemented to mitigate impacts. In other countries, in particular those with a shortage of money for capital investment, protection of health and environment, although recognized as being needed, may be given a lower priority than, for example, overcoming a shortage of electricity supply. One of the main objectives of a integrated approach to electricity system analysis, which take in account economic, social an environmental aspects, is to promote the use of comparative analysis studies aiming towards identifying strategies for achieving both adequate electricity supply, and protection of attempts to highlight the overall impacts and to provide if information of the types and approximate magnitudes of impacts associated with different energy sources and chains for electricity generation. This analysis includes all the operations that are carried out in connection with electricity generation including extraction, transportation, use and final disposal of the fuel residues. The emissions or burdens arising from the cycle result in physical impacts, which in turn imply certain environmental impacts. Examples of mapping the burdens onto the environmental impacts are showed in Table 1, and of mapping the impacts into the environmental externalities are presented in Table 2.

Table 1. Mapping of Burdens into Impacts

BURDENS	IMPACTS
human health	mortality morbidity
ecological	crops forests commercial fishing recreational fishing other water use recreational forests and parks other land use biodiversity
non-ecological	building materials land water visibility

Table 2. Mapping of Impacts into Externalities

IMPACTS	EXTERNALITIES
mortality morbidity	willingness to pay to reduce risk of death willingness to pay to avoid illness
crops forests commercial fishing recreational fishing other water use recreational forests and parks other land use biodiversity	market value of damages market value of damages market value of damages market value of damages willingness to pay for facility willingness to pay for use willingness to pay for use willingness to pay
building materials land water visibility	market value of damages lost use value in market and non market terms lost use value in market and non market terms willingness to pay

3. METHODOLOGY FOR QUANTIFICATION OF ENVIRONMENTAL DAMAGE COSTS

The quantification of environmental impacts and resulting damage costs basically follows the methodology approach developed in ExternE project (EC, 1995 and ORNL/RFF, 1992) to quantify marginal costs for a specific power plant at a specific site. The ExternE damage function analysis is a *bottom-up* impact assessment approach, consisting of four steps as showed in Figure 1. For this example, it will be assumed that the releases are to the atmosphere, and that the primary impacts are through the airborne exposure pathway. In general, other pathways may be of equal or greater importance.

Source characterization

The damage function analysis begins by identifying the source location (urban or rural surroundings), quantifying the physical characteristics of the source and preparing a detailed inventory of airborne releases. The source parameters include the effluent composition, particle size, emission rates, emission velocity, and temperature and stack height at which the different pollutants are emitted to the atmosphere. Emissions are technology and fuel dependent. Each fuel cycle is evaluated in a location-specific context, so that it refers to the impacts arising from the use of coal, or gas or whatever fuel is being considered at an actual plant that is operating. This provides the analyst with an ecological footprint of the plant that is being studies (Spadaro, 1999).

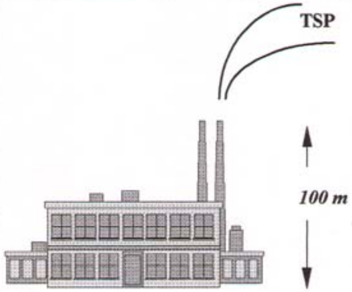
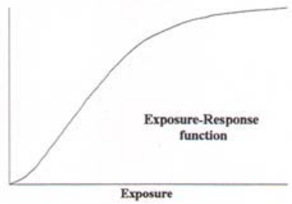
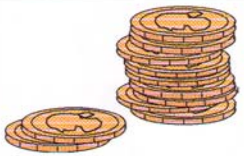
1. Source characteristics ⇨ *source location* (rural or urban site) ⇨ *source type* (point or line source) ⇨ *stack parameters* (height, exhaust flow and temperature of gases) ⇨ *emitted pollutants*	
2. Air dispersal of pollutants ⇨ *local dispersion* (near source) ⇨ *regional transport* (up to 1000's of km away)	
3. Impact evaluation ⇨ human health ⇨ agricultural crops ⇨ building materials ⇨ ecosystems	
4. Monetary evaluation ⇨ external costs	

Figure 1: Steps in the ExternE *Impact Pathways* methodology [EC, 1995]

Pollutant concentration levels

The next step of the damage function approach consists in estimating the marginal or incremental increase in pollutant concentration level (that is, above the existing background value). Atmospheric dispersion can be subdivided into *local scale* dispersion, extending up to 50 kilometers in all directions of the emission source, and *regional* scale dispersion beyond that. The regional domain extends to several thousand kilometers. Depending on the scale, different air transport algorithms (models) are employed in estimating the concentration field. For the local scale, the degree of pollutant dispersion is dependent primarily on meteorological parameters. Of these, certainly, the most important are wind speed, wind direction, ambient temperature, Pasquill dispersion classes (atmospheric stability categories) and mixing layer heights (lower portion of atmosphere within which turbulent transport takes place). For the regional domain, on the other hand, chemical interactions between source and normal airborne species, pollutant removal or disappearance via dry (gravitational settling, for example) and wet deposition (precipitation) mechanisms are as important as meteorological data in determining the fate of pollutants (air-water, air-soil, air-vegetation interactions) and their concentration levels in the air.

Impact evaluation

Next, the physical impacts are calculated. These include, for example, the number of asthma attacks, hospital visits or admissions and mortality impacts, such as the number of Years of Life Lost (YOLL) (Ponce de Leon, 1996 and Pope, 1995). Impacts to health, agricultural crops, ecosystems and *man-made* structures (damages to building surfaces, bridges, etc.) are quantified through the use of the *exposure-response* (ER) relationships. These functions relate the incremental change in pollutant concentration level (exposure) to the anticipated damage or benefit (response) to a particular receptor.

Economic evaluation

Finally, the last step in the analysis is the economic evaluation or estimation of the *external* or *social* costs of air pollution. This involves multiplying the number of cases (responses) by the monetary unit cost per incidence. For health effects, the unit costs are often determined via contingency valuation studies, such as an individual's *Willingness To Pay* (WTP) to achieve an environmental benefit or an individual's *Willingness To Accept* (WTA) payment in lieu of an incurred environmental harm (Spadaro, 1999). Other valuation techniques include the use of *hedonic* pricing schemes, which are *indirect* methods used to quantify the value (worth), of one good through variation in the price of another. For example, using the variation of house prices to determine people's aversion to transport noise and/or reduced visibility.

4. MODELING APPROACH

Taking into account the mechanism of action outlined above, a reliable estimate of impacts needs to consider site specific conditions, since receptor distribution, meteorological conditions, the composition of the pollutant mix in the atmosphere might have a significant influence on resulting effects. To support a standardized implementation of impact pathway approach, a number of models have been developed, which include complex models as the EcoSense and approximate solutions to the impact assessment function as the Uniform World

Models (Simple and Robust models, identified, respectively as SUWM and RUWM). EcoSense provides harmonized air quality and impact assessment models together with a comprehensive set of relevant input data (Krewitt et al, 1995). Nevertheless, the actual version of this model only permits the estimation of damage costs for EU countries. Studies are being carried out in order to implement a new version of EcoSense to be used in Brazil and some other countries of South America.

In the Simple version of the Uniform World Model (UWM), the population density, atmospheric dispersion parameters (in particular, the rate at which a pollutant is removed from the air) and the exposure-response relationships are all treated as constants and independent of the actual source parameters and location. In the Robust version, site dependence (characterized by the actual local population distribution) and real source parameters (in particular, stack height and exhaust flow values) are accounted in a more rigorous, yet simplified, mathematical treatment. Both models permit a rough estimation of health impacts under certain simplifying assumptions regarding demographic distributions, atmospheric dispersion and functional form of the ER relationship. The UWM estimates are accurate to within an order of magnitude for densely populated urban sites and a factor of two for rural areas. The main hypotheses of the UWM are summarized as follows (Spadaro, 1999):

- The receptors at risk are uniformly distributed about the emission source. This implies that the result is site independent.
- The atmospheric dispersion parameters are treated as constant throughout the impact domain. That is, the dispersion variables are geographically independent of both source and receptor locations.
- All pollutants are assumed to be vertically well mixed inside a vertically-limited atmospheric mixing zone. This implies that the emission source parameters have no significant effect on dispersion.
- The surface removal flux (mass of pollutant depleted per unit horizontal area) is proportional to the local pollutant concentration level (first order rate relationship).
- The exposure-response function is a straight line extending from zero at zero concentration to monotonically higher values at higher concentrations. That is, the ER function is linear without a threshold value, which implies that any change in background concentration always has a positive impact on the exposed receptor.
- The degree of the impact depends solely on the magnitude of the slope of the ER function, which is independent of the absolute value of the ambient concentration.
- The emission or creation rates for a given pollutant are identically equal to its removal rate (chemical transformation plus dry/wet deposition). In other words, the atmospheric concentrations are constant (steady state regime).

By invoking the above assumptions, the UWM estimate is expressed as:

$$UWM = \frac{Q \times f_{ER} \times \rho}{k}$$

Where,

Q emission rate of pollutant,
ρ uniform receptor density throughout impact domain (within 1500 km of source),
f_{ER} exposure-response function applied to population at risk, ex., children or adults,
k depletion velocity, accounts for pollutant removal from atmosphere.

5. EXTERNAL COSTS OF ELECTRICITY: PRELIMINARY STUDIES IN BRAZIL

The damage costs estimations were performed for old power plants which are still operating throughout Brazil, and which are in the process of being examined for environmental licensing. Three different scenarios were analyzed. The first one considered an old oil-fired power with an installed capacity of 250 MW and a load factor of 80% (7000 hours per year). The results of this analysis were compared with those corresponding to the assumption that the fuel could be replaced by coal. In this case, two situations were considered, one using domestic and the other imported coal.

The power plants are located in a rural zone. The local receptor density (ρ_L) is (within 25 km, which corresponds to the radius R_o of the local domain), the local population density is 72 people/km^2, and the regional density (ρ_{UNI}) within a 1000 kilometer radius is 28.3 people/km^2. The annual externalities are calculated just for health impacts, since in this preliminary phase of the project, specific data about impacts in agriculture, building material and ecosystem for Brazil are not available. In this case, the human health effects considered are "Years of Life Lost" (YOLL), restricted activity days and respiratory hospital admissions.

Approximate estimates of monetary unit costs for Brazil are obtained *indirectly* by using unit cost values taken from Contingent Valuation (CV) studies carried out in the US or Europe (ExternE, 1998). Transfer of these costs to Brazil involves scaling the Western values by the ratio of GDP per capita of Brazil (5400 US$ per person) and of the reference case study (European Union value, which corresponds to 17900 U$). The ratio of incomes is raised to a power (income elasticity factor, $\beta \leq 1$), which accounts for the fact that someone's willingness to pay for better air quality is likely to be lower in a low income country, but not necessarily in proportion to one's personal spending income (Spadaro, 1999). In the present study, all the calculations were performed assuming a β value of 1.

All externality estimations are performed using real data, which are specific for each plant analyzed. These include source characteristics and meteorological data (wind speed, wind direction, temperature, height of the mix layer, etc.) from the region where the plants are located. The dose-response curves are adjusted in order to take into account the age distribution in Brazil.

The results of the externalities calculations with the associated uncertainties are presented in Table 3. As can be seen, it is that health costs are dominated by the chronic mortality impact, which accounts in average for 60 % of the total externality. Taken together with acute mortality, mortality costs about 97% of the aggregate impact. It can also be observed that the best option is the use of an imported coal-fired plant, since this is the option that has the lowest PM_{10} emission rate.

Table 3. Health cost estimates for each scenario analyzed. Annual costs are expressed in millions of US $ (1995) for an elasticity factor β= 1.0

Endpoint	PM_{10} Value	PM_{10} 68% CI	SO_2 Value	SO_2 68% CI	Total Value	Total %
Oil						
Restricted Activity Days	0.079	0.016-0.40			0.079	2.5
Respiratory Hospital Admissions	0.001	0.0003-0.003	0.012	$(0.4\text{-}3.6)\times10^{-2}$	0.013	0.4
Chronic Mortality	2.51	0.50-12.6			2.51	78.4
Acute Mortality			0.60	0.08-4.8	0.60	18.7
All illness (σ_g=4)	**2.59**	**0.65-10.4**	**0.61**	**0.15-2.4**	**3.20**	**100**
Domestic Coal						
Restricted Activity Days	0.310	0.062-1.55			0.31	1.9
Respiratory Hospital Admissions	0.004	0.0013-0.012	0.11	0.037-0.33	0.11	0.7
Chronic Mortality	9.86	1.97-49.3			9.86	61.5
Acute Mortality			5.75	0.72-46	5.75	35.9
All illness (σ_g=4)	**10.18**	**2.5-40.7**	**5.86**	**1.5-23.4**	**16.03**	**100**
Imported Coal						
Restricted Activity Days	0.032	0.0064-0.16			0.032	1.7
Respiratory Hospital Admissions	4.2×10^{-4}	$(0.14\text{-}1.3)\times10^{-3}$	0.017	0.0057-0.051	1.74×10^{-2}	0.9
Chronic Mortality	1.01	0.20-5.1			1.01	52.9
Acute Mortality			0.85	0.11-6.8	0.85	44.5
All illness (σ_g=4)	**1.04**	**0.26-4.2**	**0.87**	**0.22-3.5**	**1.91**	**100**

6. CONCLUSIONS

In order to incorporate economic, social and environmental aspects in the decision process of energy planning in Brazil, a joint research project sponsored by the International Atomic Energy Agency has been carried out, the primary objective of which is to perform a comparative risk assessment of alternative energy systems. This project includes not only the quantification of the physical impacts and damage costs associated with airborne emissions from the traditional fossil fuels (coal, gas and oil) and nuclear energy, but also those from renewable resources, most specifically from hydroelectric. The results showed in the present paper cover just old power plants which are still operating throughout in Brazil, and that are passing through environmental licensing process.

The main objective of the first phase of the project is to become familiar with the damage function methodology. It is important to mention that the results presented in Table 3 are best estimates, and must be considered together with an uncertainty label. The quantification and valuation of environmental damage is still linked to partly large uncertainties (data and model uncertainty), and the results also depend on basic framing assumptions that are based on ethical and political value choices (Rabl, 1998). The dose-response models used in the analysis are based on results from epidemiological studies, which have established a statistical relationship between the mass concentration of particles and various health effects. The uncertainty resulting from this lack of knowledge is difficult to estimate (Krewitt et al, 1999). All externalities estimations were performed based on dose-response models used in the ExternE project, since until now specific data for Brazil are not available.

The main challenge of this project is to estimate the externalities associated with environmental impacts arising from hydroelectric power plants. Very few studies have been done in this area, mainly due to the difficulty in performing monetary valuation of impacts on socio-economic and cultural systems. Examples of impacts that must be considered include effects on indigenous and ethnic peoples, and effects on ecosystems (both aquatic and terrestrial flora and fauna). These latter considerations are especially challenging, since in all cases data must be acquired and interpreted for systems very different than those Northern Hemisphere situations heretofore studied.

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