Non-Monetary Costs of Generating Electricity: Where Does Hydro Stand?

A recent study in Québec, Canada, used monetization techniques to place social and environmental costs, known as externalities, on an equal footing with traditional economic costs. The results? Hydro is still a winning alternative.

By Jean-François Lefebvre, Yves Guérard, and Jean-Pierre Drapeau

One primary objective of most power producers is to generate electricity at the lowest possible cost. This cost is viewed foremost as an economic cost, and often excludes or minimizes social and environmental externalities. These externalities are "...costs to society (human health and other environmental damages) resulting from provision of electric services, which costs are not already incorporated in the price of electric services. They are those costs which occur after all government-imposed environmental standards and regulations are met."[1] In the interests of sustainable development and fairness to future generations, producers and consumers should consider the externalities related to their energy choices, so that these choices will be less costly for all of society.

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This article has been evaluated and edited in accordance with reviews conducted by two or more professionals who have relevant expertise. These peer reviewers judge manuscripts for technical accuracy, usefulness, and overall importance within the hydroelectric industry.

The Québec, Canada,-based Group for Research in Applied MacroEcology has developed a model for evaluating the costs of externalities for various electricity generation options. With variables representing 35 internal and external costs and benefits, this model offers a wide range of possibilities for analyzing the sensitivity of externality costs. The externalities considered include atmospheric emissions, loss of natural habitats, mercury problems, and many others.[2] Because of the many and variable assumptions in the model, it does not yield absolute cost figures. Rather, it provides information useful for assessing how options rank under different assumptions.

We used the model to compare six electricity generating options: hydropower, wind power coupled to hydropower, nuclear, forest biomass, and coal- and gas-fired thermal plants. Data used in the model were drawn primarily from existing and proposed generating stations in Québec. The model simulation period was 120 years, to ensure that externalities experienced by future populations were adequately considered.

An Overview of the Model

The model, known as GRAME (Gestion des Ressources par Actualisation et Monétisation des Externalités), consists of a spreadsheet program that calculates the internal costs and externalities of the following options:

— Hydropower stations with reservoirs;
— Wind turbines coupled to the hydroelectric grid;
— Nuclear generating stations;
— Coal-fired stations;
— Combined-cycle gas-turbine (CCGT) stations; and
— Forest biomass stations.

The model essentially consists of a database and a trend chart. Results are generated in the form of tables and charts. The database contains 35 indicators for evaluating the internal and external costs and benefits of electricity production. These indicators are divided into internal and external costs, including positive and negative externalities.

Internal costs, or financial costs assumed by producers and investors, are readily available as monetary figures. We drew internal cost data from real (for hydro) and hypothetical projects in Québec. Costs were expressed for an output of 1 terawatt-hour (TWh) per year for all generating options. We did not adjust costs and benefits for quality of service, although a TWh generated by an intermittent source, such as a wind turbine, actually has less value than a TWh generated by a highly reliable source, such as hydropower with storage.

We assumed service lives of 50 years for a hydropower station, 30 years for coal-fired and nuclear facilities, 25 years for wind turbines, and 20 years for gas-turbine and forest biomass stations.

Evaluating Externalities

Economists use several different approaches to assign monetary value to (monetize) the effects of environmental externalities. Some of these approaches are as follows:

— Damage value estimates, or the monetary value of the damage caused by externalities;
— Estimates of the costs incurred to control or to prevent the externality (for example, the cost of eliminating emissions of pollutants);
— Compensation value estimates, such

Table 1: Atmospheric Emissions Caused by Six Electricity Generating Options (In Tons per TWh)

Generating Option	Greenhouse Gases CO_2+CH_4 (equivalent tons O_2)	Gases Associated With Acid Rain And Smog		Other Emissions		
		SO_2	NO_x	CO	Particles	Others
Biomass (25% efficiency)	-414,500	157	1,531	2,147	266	0
Coal (35% efficiency)	1,028,500	2,880	2,597	491	100	0.019 Hg; 0.335 U
Hydroelectricity	31,000	11	0	0	0	0
Natural Gas (45% efficiency)	719,350	713	800	300	10	0
Nuclear	60,100	0	100	0	0	0
Wind Power	48,300	0	0	0	0	0

as the expenditures required to replace a damaged ecosystem; and

— Contingent evaluations, which are measurements of the public's willingness to pay to avoid an impact, or the damages claimed as compensation for a nuisance.

Setting values for externalities is subject to considerable uncertainties. Some values are especially difficult to quantify because they involve long time periods, wide geographical areas, or a broad range of impacts. Externality cost estimates also must take into account the entire life cycle of a generating option, including the effects of construction work, fuel extraction and transportation, and waste management.

Applying Monetary Principles To Externalities

A basic problem in impact studies is the lack of a universal unit of measurement that can be used to accurately compare effects related to economics, social effects, and environmental issues. The monetization of externalities is one way to obtain such a universal unit.

The concept of sustainable development provides a framework for the principle of monetization. Sustainable development is, by definition, a form of development that could be generalized and perpetuated without destroying its resource base. "Perpetuation" implies that future generations would not bear negative externalities; and "generalization" means that cumulative effects of the project or practice are considered. Thus, in a project following the principles of sustainable development, costs normally associated with externalities would be internalized and the net environmental loss would be nil.

The introduction of money as a unit of measurement creates a major difficulty. A discount rate is applied to monetary values analyzed over an extended time period to account for inflation and interest. Discounting, however, is often criticized for devaluing ecological and social costs. One response to this concern is to use a very low discounting rate—for example, 3 percent or even less. However, this approach arbitrarily distorts the true cost of obtaining funds to finance a project. If externalities are regarded as real costs that have to be assumed and financed, we should use a discounting rate that reflects the true cost of capital.

Our model addresses the issue of discounting by simulating a 120-year time period as well as various rate and discounting options. The very long analysis period lets us apply the financial analysis procedures for calculating the infinite replacement costs of facilities (which are needed to ensure equitable comparison of facilities with unequal service lives) while taking future generations into account.

We used two discounting methods, each with constraints and limitations that affect the interpretation of results. The first method was a traditional approach in which we assumed infinite replacement of facilities with a continuous, realistic discount rate of 7 percent. Even if externalities can be adequately monetized, this procedure will devalue the cost of externalities occurring in the future unless they can be internalized, or included in the upfront cost of the project. Failure to set up an internalization fund as of Year 0 leads to an "actuarial" deficit that becomes almost total after one generation (30 years). The second generation, from its standpoint at Year 30, is faced with the full value of external costs.

In cases where external costs are not financially internalized, they can be studied using discontinuous discounting. We included such a procedure in our model, in which the 120-year period is divided into four successive 30-year horizons, each constituting a discounting period. This procedure allows us to consider the viewpoints of both the promoters and society in each successive generation. The discontinuous discounting procedure also takes into account the effect of legacies, positive or negative, handed down from one generation to the next.

Nevertheless, the result must be interpreted with caution. It does not represent the net present value of future costs, but the sum of four net present values corresponding to the viewpoints of four successive generations.

Quantifying External Costs

To integrate external costs and benefits into the model, we must first assess quantitative impacts of the project. Such quantities might include tons of pollutants, land areas affected in hectares or square kilometers, or hunting days gained or lost. These quantities, expressed per TWh produced, are multiplied by a corresponding monetary cost per unit of impact.

Our evaluation for hydropower was based on the impact study for Hydro-Québec's 882-MW Sainte-Marguerite-3 project, now under construction in the North Shore region of Québec. For our study, we assumed that the reservoir would cause the same mercury contamination problems that have been documented in hydroelectric reservoirs in the James Bay region, even though it now appears that mercury contamination is almost non-existent on the North Shore.

Atmospheric Emission

Table 1 lists the atmospheric emissions caused by the six generating options

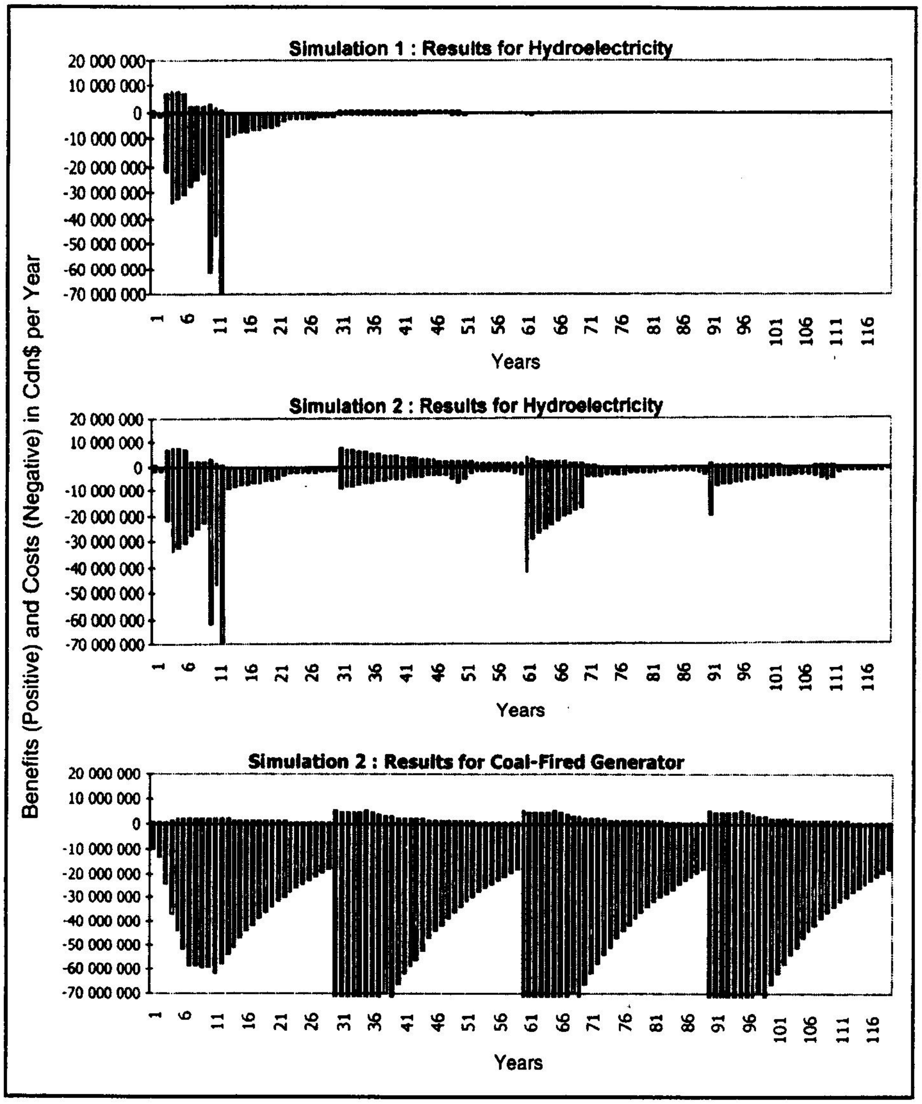

Figure 1: These samples of the temporal distribution of costs and benefits of various generating options provide a sense of the model output under the different discounting and generation scenarios. Simulation 1 (shown for hydroelectricity only) uses continuous discounting at a rate of 7 percent. In this approach, both costs and benefits of hydropower become negligible (from today's perspective) after about 50 years of operation. However, renewing the discounting period every 30 years (Simulation 2, shown for both hydroelectricity and coal) shows that even from the perspective of future generations, externality costs related to hydropower diminish over time, while those related to coal are felt equally by each successive generation.

studied. These emission estimates, based on values presented in scientific literature, are associated with the entire life cycle of the project. We tested several different monetary values for atmospheric emission in the model. (Except where indicated otherwise, the monetary values used in the study are expressed in 1994 Canadian dollars. The average 1994 exchange rate for U.S. dollars was US$0.73 to Cdn$1.)

Our literature review suggested values for one ton of CO_2 ranging from a low of $11 to a high of $36. The high value is similar to that adopted by the World Bank, which is US$25 (Cdn$34) per ton of CO_2. According to the U.S. Department of Agriculture, the average cost of achieving 10 and 30 percent offsets for CO_2 through tree planting and forest management in the U.S. would be US$12 (Cdn$19) and US$18 (Cdn$28) per ton, respectively.[3] We also considered higher values based on the emissions taxes already in effect in five countries, which range on average from $42 per ton to $115 per ton.

For hydroelectricity, the emission rate of gases such as CO_2 and CH_4 ("greenhouse" gases that are potentially associated with global warming) decreases by half in the first 50 years after impounding.

For SO_2 emissions, based on control costs, we retained a value of $612 for the low hypothesis and $6,122 for the high hypothesis. The value of one ton of NO_x emissions ranges from $3,061 to $11,223, while the value of one ton of particle emissions ranges from $1,020 to $13,264, based on control costs. The value of one ton of CO emissions ranges from $583 to $1,354, based on damage value.

We assumed a control cost for one ton of atmospheric mercury emissions ranging from $42,000 to $11.2 million per ton, based on a 1995 study by the Tellus Institute.[4] We also provisionally adopted a value of $1 million per ton for atmospheric uranium emissions, on the basis of the value used for mercury.

Ecosystem-Related Externalities

To estimate the value of one hectare of natural habitat, we employed the concept of replacement cost. According to a 1991 Ducks Unlimited study in the U.S., creating one acre of wetlands costs between US$30,000 and US$70,000. Because wetland creation has only a 50 percent success rate, we doubled these costs.[5] We used this value while assuming that all flooded habitats represented a loss of wetlands, whatever the actual habitat classification. We also very conservatively estimated the cost of stabilizing one kilometer of newly-formed shoreline at $300,000 to $649,000.

We used a contingent evaluation study from Washington State to estimate the value of rapids.[6] Residents of the Seattle area were asked how much they would be willing to spend to preserve a 10-mile stretch of rapids heavily used for recreation. We adjusted the resulting estimates of value for the much lower population density in Québec, arriving at a range of values from $10,920 to $109,200 per kilometer per year. (The high value is based on the possibility that Québec residents place ten times the value on river recreation than Seattle-area residents do.)

We derived a financial cost associated with mercury contamination from the amount set in a 1986 agreement between Cree groups, provincial government, Hydro-Québec, and the James Bay Development Society. We took the amount paid out (per TWh) as a measurement of Québec society's willingness to pay for the externalities caused by dissolved mercury in hydroelectric reservoirs. We assumed that mercury would be released into the hydroelectric reservoirs at the time of impounding, and that concentrations would return to normal after 20 to 30 years. This

Table 2: External and Total Costs of Six Electricity Generating Options[1]

	"Macroecologic" Perspective (Emphasizes Regional/Global Environmental Quality)				*"Microecologic" Perspective (Emphasizes Land Values)*			
	Discounting Method[2]				*Discounting Method[2]*			
	Simulation 1: Continuous		*Simulation 2: Discontinuous*		*Simulation 3: Continuous*		*Simulation 4: Discontinuous*	
Option	*External*	*Total*	*External*	*Total*	*External*	*Total*	*External*	*Total*
Biomass	1.8	6.8	1.0	4.8	4.9	9.9	1.0	4.7
Coal	8.2	15.3	8.4	14.5	1.7	8.8	1.9	8.0
Hydropower	1.3	5.3	-0.2	1.4	2.8	6.6	0.5	2.1
Natural Gas	3.3	8.8	3.5	8.3	0.6	6.1	0.8	5.6
Nuclear	2.0	8.1	2.3	7.3	1.8	7.9	2.1	7.1
Wind Power	0.4	6.4	0.5	4.3	-0.1	5.9	0.2	4.0

[1] "Total" cost refers to sum of external and internal costs. All costs are given in Canadian cents per kilowatt-hour.

[2] Discounting rate is 7 percent for all cases.

hypothesis was representative of James Bay projects, where inundated soils had been previously contaminated by atmospheric emissions of mercury, but, as stated previously, was not actually true for the Sainte-Marguerite-3 project.

The value of the land area occupied by a project, in dollars per square kilometer, is basically intended to reflect the "sacredness" of the land, or its integral value to society. It is neither a market value nor the value of the ecosystems or natural resources affected. Instead, it is the value attributed by society to preservation of the land in its original condition. This value may seem abstract, but it is a prominent issue in the current energy debate in Canada and throughout the world. Much of the opposition to hydroelectric development is related to the large areas occupied by such developments, regardless of the fact that these areas (specifically the reservoirs) still can be used for purposes other than electricity production.

A very high value for land preservation would lead to the disqualification of all renewable, low-pollution energy sources, including not only hydropower but also wind power, biomass, and solar energy. We used values ranging from $1,000 to $100,000 annually for each square kilometer of land occupied. Although the range was somewhat arbitrary, it provided a good basis for analyzing the model's sensitivity to this important value.

In Québec, wind power is highly dependent on hydroelectric reservoirs for achieving reliability. In fact, massive development of wind power, if coupled with hydropower, would be expected to lead to more erratic and unforeseeable management of reservoir levels and river flows, with accompanying ecological consequences. Therefore, in addition to the externalities commonly associated with wind power (such as danger to birds, aesthetic issues, and land requirements), other externalities associated with hydropower must be attributed to wind power as well. We used a 1998 study of proposed wind farms in Québec to establish the level of dependence between wind power and hydroelectricity in the model.[7]

Comparing Generating Options

The model is not designed to determine categorically which generating option is best. Ranking of the options will vary according to the values assigned to the variables and to the discounting rates and methods used. These choices are partly methodological in nature, but also partly determined by individual or collective values such as the relative importance accorded to future generations.

Table 2 summarizes the results of several simulations. For each generating option, the external costs and the sum of internal and external costs are expressed in cents per kilowatt-hour (kWh).

The first two simulations take the "macroecological" perspective, meaning that most regional environmental effects (such as effects on air quality) were assigned relatively high costs (for example, $36 per ton of CO^2.) Less importance was placed on the "sacredness" of the land occupied (less than $1,000 per square kilometer). We considered this approach to be compatible with the principles of sustainable development, in that it emphasizes long-term and geographically widespread effects.

The second two simulations represented a "microecological" approach, in which we placed a very low value on CO_2 ($10/ton) and other atmospheric pollutants but a very high value on the "sacredness" of land ($100,000 per square kilometer).

For each of the two approaches, one simulation was made with continuous discounting and the second with four 30-year discounting periods. The discount rate for all cases was 7 percent.

The simulation least favorable to hydropower was the one using continuous discounting and the microecological perspective (Simulation 3). Under these assumptions, hydroelectricity has higher external costs than coal or even natural gas. However, even for the most unfavorable hypothesis, total hydroelectricity costs are only slightly higher than wind and gas-turbine costs, and lower than total costs for nuclear, biomass, and coal.

The model results were quite different for the final simulation, which retained the same externality values as Simulation 3 but used four 30-year discounting periods, giving weight to the viewpoint of future generations. For this case, hydro's external cost of 0.5 cent per kWh was close to the external costs of wind power and natural gas, and its total cost of 2.1 cents/kWh was well below any of the alternatives.

Figure 1 provides a look at temporal distribution of costs and benefits for hydropower.

Assessing Hydro's Strengths

This study confirms that hydroelectricity generates most of its externality costs locally and over a short period of time, while fossil and nuclear plants tend to spread these costs over a wider geographic area and a longer period of time (based on data from Québec).

Hydropower shows strong advantages over other generating options, given certain approaches to valuing externalities. In particular, hydropower has relatively low external and total costs when assessed from a perspective that gives weight to upcoming generations or assigns the greatest environmental significance to global pollution impacts such as climate change, acid rain, and stratospheric ozone depletion.

Hydroelectricity appears to be the energy source that makes the best showing in any analysis that places significant importance on sustainable development, including global pollution and long-term impacts. This poses a paradox for the hydroelectric industry: the burden of hydroelectric development (including external and internal costs) is borne primarily by the current generation for the benefit of future generations. Because its externalities tend to be local and immediate, hydroelectricity is particularly vulnerable to public opposition when, according to our study, a long-term view reveals hydro as a positive legacy to future generations. ■

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Notes:

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