The Social Cost of Coal: Implications for the World Bank

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Summary for Policymakers

The World Bank is considering adopting a new energy strategy that would define the institution's goals for energy sector lending and investments. Like other development assistance organizations, the World Bank needs to make sure that its energy portfolio helps advance a variety of goals, including economic growth, poverty alleviation, social justice and climate protection. The World Bank is considering what role coal projects should have in its lending strategy. This paper summarizes the state of knowledge on the social cost of coal-fired power plants in an effort to help inform ongoing policy discussions.

Although superficial analyses often find that coal-fired power is the cheapest source of energy, these analyses fail to account for the myriad costs of coal-fired electricity for society. Health impacts remove productive citizens from the work force and shift spending away from industries and education. Water pollution creates further health problems and makes agriculture more expensive, raising the cost of living and reducing international competitiveness. The adverse impacts of climate pollution from coal plants, such as floods, storms and droughts, carry significant economic and social costs.

Findings

The results of a number of independent economic studies confirm that these "external" costs (faced by society and not the facility owners) make coal-fired power one of the most expensive forms of electricity generation (see Table 1). As shown below, nuclear, natural gas, wind, and biomass cost between $52/MWh and $88/MWh, while pulverized coal costs roughly $100/MWh.

Table 1: Social costs of electricity generation (2010$/MWh)

	Coal		Lower Emissions		Renewables		
	PC	IGCC	Nuclear	Natural Gas	Wind	Solar	Biomass
Explicit Costs	$41	$77	$41	$53	$70	$154	$78
External Costs	$58	$57	$11	$30	$2	$6	$11
Total	$99	$134	$52	$83	$72	$160	$88

The external costs of coal-fired power, including pulmonary disease, mercury poising, and premature death, have a significant effect on the countries that bear them. The choice to build a 4,000 MW coal power plant instead of a comparable nuclear, natural gas, wind, or biomass plant, even taking into account the coal plant's lower construction and operations costs, results in $319 to $1,414 million additional social costs (see Table 2). For this hypothetical single coal plant, additional expected costs would include approximately $370 million in health costs in mining communities, $940 million in air pollution costs, and $108 to $320 million in climate change costs.

Table 2: Social cost tradeoffs of Pulverized Coal versus other generation sources (Million 2010$)

	Coal	Nuclear	Natural Gas	Wind	Biomass
Explicit Costs	$1,221	$1,221	$1,592	$2,089	$2,315
External Cost					
Health in Mining Communities	$374	-	-	-	-
Air Pollutants from Combustion	$937	-	-	-	-
Effects of Mercury	$28	-	-	-	-
Climate Change Impacts	$320	-	$211	-	-
Other Externalities	$69	$314	$668	$63	$314
Total	$1,728	$314	$880	$63	$314
Social Costs	$2,949	$1,535	$2,472	$2,152	$2,629
Additional Social Costs of PC		+$1,414	+$477	+$797	+$319

Implications for the World Bank

The implication of this analysis is that the World Bank's choice to fund a new coal power plant over an equivalent cleaner nuclear, natural gas, wind, or biomass power plant significantly burdens recipient countries and the poor. The World Bank should redirect its funding to cleaner generation sources that avoid such great costs for the recipient countries.

The World Bank's own operational policies require it, before financing any project, to determine whether a given investment opportunity "creates more net benefits to the economy than other mutually exclusive options for the use of the resources in question."[1] The research summarized here demonstrates that a pulverized coal power plant, the most common type of new coal generation facility, does not meet this standard.

[1] World Bank. Operational Policy 10.04.

Technical Background Note

The World Bank is considering adopting a new energy strategy, including determining what role coal projects should have in its lending strategy. Although superficial analyses often find that coal-fired power is the cheapest source of energy, these analyses fail to account for the myriad costs of coal-fired electricity for society. This technical note draws on other independent economic studies to estimate the social cost of electricity generation from a new coal-fired power plant in comparison to other potential sources of generation in various countries around the world.

Introduction

The World Bank is a major financier of power plants and other vital infrastructure around the world. In determining which projects to finance, the World Bank follows Operational Policy (OP) 10.04, which requires economic evaluation of investment projects to "determine whether the project creates more net benefits to the economy than other mutually exclusive options for the use of the resources in question" (World Bank 1994). This language echoes the standard economic logic, that the social welfare maximizing option should achieve more positive social benefits than any other options. The mandate ensures that the World Bank only finances the most socially beneficial projects.

In determining the net benefits to the economy created by each option, OP 10.04 directs the World Bank to calculate, to the extent possible, both the explicit costs (the monetary cost paid by the owner of the project) and the external costs (costs not paid by the owner of the project but borne by society). In the case of a coal power plant, the explicit costs would include, for example, the cost of physical materials and fuel for the plant, while the external costs would include among many things the health effects of air emissions and water pollution by the plant. The sum of these two costs represents the full social cost of the generation source. As the benefits of electricity are uniform between sources, meaning a unit of electricity creates the same amount of social benefits regardless the fuel from which it is generated, the generation source with the least social cost has the greatest social benefits.

This study draws together available data from the medical and economic literatures to calculate the social cost of electricity generation from coal and other potential generation sources. We review the seven most common sources of generation, including two forms of coal generation (pulverized coal (PC) and integrated gasification combined cycle (IGCC)), two forms of lower emissions generation (natural gas combined cycle and a nuclear pressurized water reactor), and three forms of renewable generation (onshore wind turbines, solar thermal, and solid biomass).[1]

[1] We did not examine a natural gas combustion turbine as it is generally a source of peak load generation (a "peaker") and thus is not a viable substitute for a base load pulverized coal power plant.

The study finds that generation from a pulverized coal (PC) power plant, the most common form of coal generation, is often among the cheapest in terms of explicit costs but the most expensive in terms of external costs and, as a result, not the least expensive in terms of social cost. The results of this study suggest that the World Bank should not finance pulverized coal power plants.

Explicit Costs

The explicit costs of electricity generation, as mentioned above, represent the costs paid by the power plant owner to build the facility and generate electricity. The major sources of costs include capital costs (the cost of building the plant itself), fixed and variable operations and maintenance (O&M) costs, and the cost of fuel (which is zero for renewable power plants). Costs are generally calculated on a per Megawatt-hour (MWh) or "levelized" basis in order to enable comparison between sources of generation. The resulting per MWh cost is known as the levelized cost of energy (LCOE).

Table 1: Explicit costs of Electricity Generation (LCOE, 2010$/MWh)[2]

	Coal		Lower Emissions		Renewables		
Data Source	**PC**	**IGCC**	**Nuclear**	**Natural Gas**	**Wind**	**Solar**	**Biomass**
IEA 2010							
OECD	$81	$75	$57	$89	$108	$211	$54
Non-OECD	$41	-	$41	$53	$70	-	$78
Industry	$62	-	$54	$75	$69	$154	-
EIA 2010	$96	$112	$116	$64	$99	$317	$114
MIT 2003	$52	-	$82	$50	-	-	-
CERI 2004	$50	-	$68	$63	-	-	-
RAE 2004	$56	$69	$49	$48	$115	-	$145
University of Chicago 2004	$44	-	$71	$48	-	-	-
IEA/NEA 2005	$57	$55	$59	$62	$114	$161	$90
OK DTI 2006	$58	$62	$79	$73	$170	-	-
MIT 2007	$55	$59	-	-	-	-	-
CBO 2008	$62	-	$81	$64	-	-	-
EC 2008	$65	$71	$97	$79	$132	$301	$197
EPRI 2008	$71	$77	$81	$88	$101	$194	$88
House of Lords 2008	$91	-	$100	$86	$161	-	$199
MIT 2009	$69	-	$93	$72	-	-	-

In our study, we examine many estimates of the explicit LCOEs for new generation. The first source, labeled as International Energy Agency (IEA 2010), represents an average calculated by the author of costs in OECD and non-OECD countries and from industry estimates con-

[2] All costs converted into 2010$ using the Consumer Price Index for All Urban Consumers published by the US Bureau of Labor Statistics (BLS 2011). IEA estimates assume a 5% cost of capital. Other estimates assume various costs of capital.

tained in the IEA report. The second source, the Energy Information Agency (EIA 2010), applies only to the United States. The remaining sources are taken from a literature review of other external cost estimates prepared by the IEA (IEA 2010). The results of the first two sources and the various studies from the literature review are shown in Table 1.

We prefer the non-OECD estimates within the first source as the calculated averages are based on non-OECD data, which is relevant because the World Bank does not fund as many projects in OECD countries as in non-OECD countries and we do not believe that OECD cost estimates are representative of explicit costs in non-OECD countries (as demonstrated by comparing the OECD and non-OECD estimates). We also prefer the non-OECD costs because they do not contain any assumed carbon cost (the IEA adds a carbon cost to all OECD and industrial estimates from OECD countries which cannot be factored out).[3] The two exceptions to this rule are the estimate for solar, taken from the industry estimate in IEA 2010 as no non-OECD estimate is available, and IGCC, taken from the EPRI 2008 study as no non-OECD estimate is available and the other IEA 2010 estimates include the price of carbon.

Table 1 shows that generation from a pulverized coal plant is among the most cost-effective in terms of explicit costs.

External Costs

The external costs of power generation, also discussed above, represent the costs not paid by the owner of the generation facility but borne by society. By definition, these costs are not taken into account by the owner in deciding whether to build a new power plant. The major external costs from power generation include negative health impacts from air emissions, water pollution from coal mining and oil and gas extraction, and climate change impacts from greenhouse gas emissions.

The external cost of power generation must include all external costs attributable to generating electricity from the given generation source. Economists refer to this as the "lifecycle" external costs, or the external costs resulting from all stages of the production process. In the case of electricity generation from coal power plants, the full lifecycle includes coal mining, transportation of coal to the power plant, construction of the power plant and related infrastructure, generation of electricity from the power plant, and disposal of waste products, such as coal ash. The idea is to capture all external costs attributable to generating electricity from a given source.

In this study, we examined the widely-considered best estimates of the lifecycle external cost estimates for generation from a new power plant (Burtraw et al Forthcoming). The results of these studies, converted to 2010$/MWh, are shown in Table 2. Results for RFF/ORNL 1995, Rowe et al 1995, ExternE 2005, and NRC 2010 taken from Burtraw et al (Forthcoming). The results for RFF/ORNL 1995, Rowe et al 1995, and ExternE 2005 do not include climate change impacts, which are estimate to be $21/mt CO2e or about $18 /MWh for a pulverized coal power plant (with a heat rate of 9,200 btu/kwh) or about $7/MWh for a natural gas

[3] For IGCC, we use the explicit costs from EPRI 2008 as the IEA 2010 OECD estimate includes the cost of carbon and as the EIA cost estimate falls at the upper end of the range of estimates.

combined cycle (with a heat rate of 6,700 btu/kwh) (Greenstone et al 2010).

The studies provide a broad range of estimates of the social cost of coal generation. We prefer the estimates of Rafaj and Kypreos 2007 for a variety of reasons. First, the results are highly credible. The estimates are based on the ExternE project (whose results are also included in the table), a large, multi-year, peer-reviewed study of lifecycle impacts of electricity generation. Further, the results are used in the MARKAL model, a computable general equilibrium model of the world economy managed by the IEA. Second, the results are globally applicable. Rafaj and Kypreos adjust the ExternE results to create a global estimate, for use in the MARKAL model. Third, the results include estimates for all the potential generation sources we review, ensuring a common methodological approach with the coal social cost estimate.

Table 2: External costs of electricity generation (2010$/MWh)[4]

	Coal		Lower Emissions		Renewables		
Data Source	**PC**	**IGCC**	**Nuclear**	**Natural Gas**	**Wind**	**Solar**	**Biomass**
RFF / ORNL 1995	$2.3	-	$0.5	$0.4	-	-	$3.0
Rowe et al 1995	$1.3-$4.1	-	$0.2	$0.3	$0.0	-	$4.8
ExternE 2005	$27-$202	-	$3.4-$9.4	$13.4-$53.8	$0-$3.4	-	$0-$67
NRC 2010	$2-$126	-	-	$0-$5.8	-	-	-
Epstein et al 2011	$180.7	-	-	-	-	-	-
Rafaj and Kypreos 2007	$58.0	$57.0	$10.5	$29.5	$2.1	$6.3	$10.5

As shown in Table 2, electricity generation from a pulverized cost power plant is the most costly in terms of external costs. We specifically use the Rafaj and Kypreos estimate for the social cost of a coal plant with emissions controls for criterion pollutants, such as scrubbers for SO2 and selective catalytic reduction (SCR) for NOx. This is a conservative assumption that likely biases downwards the social cost of coal as many coal plants do not have such emissions controls and the Rafaj and Kypreos estimate for the social cost of a coal plant without such controls is significantly higher ($222 / MWh).

Social Costs

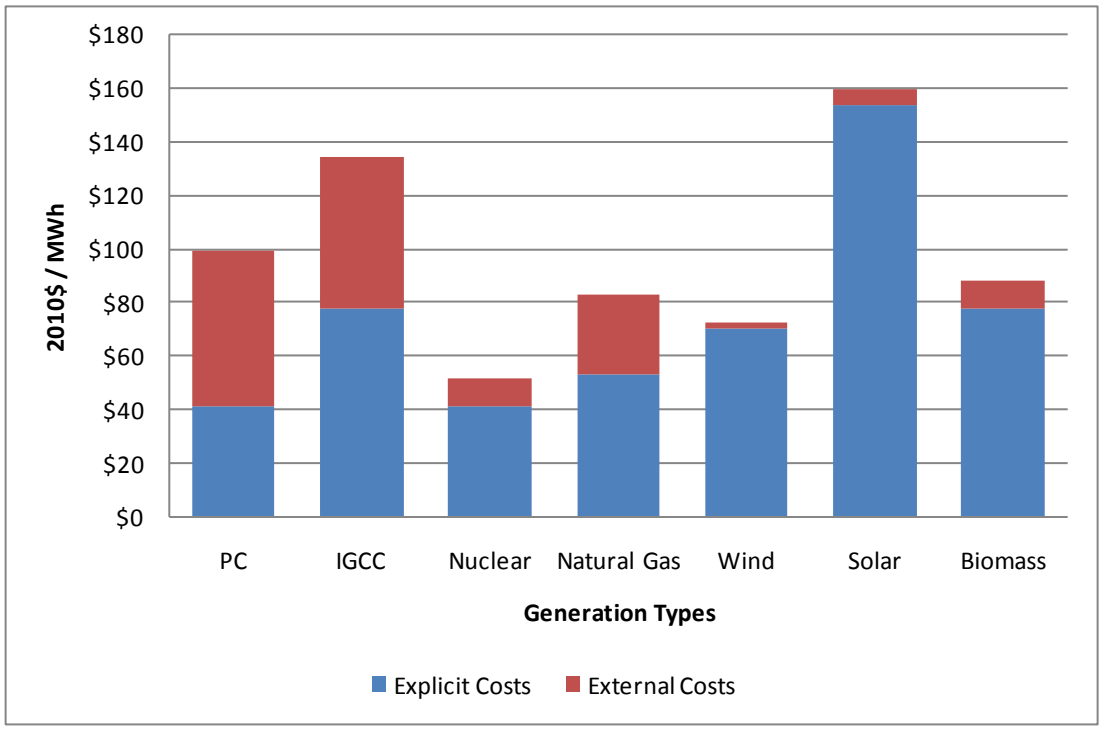
Using our preferred estimates for explicit and external costs, we calculate the social cost of electricity generation from our set of generation sources, including a pulverized coal power plant. The results of this calculation are shown in Table 3 and Figure 1.

Table 3: Social costs of electricity generation (2010$/MWh)

	Coal		Lower Emissions		Renewables		
	PC	**IGCC**	**Nuclear**	**Natural Gas**	**Wind**	**Solar**	**Biomass**
Explicit Costs	$41	$77	$41	$53	$70	$154	$78
External Costs	$58	$57	$11	$30	$2	$6	$11
Total	$99	$134	$52	$83	$72	$160	$88

[4] All costs converted from local currencies to US dollars using prevailing exchange rates at the time of the calculation, namely 0.1549 RMB to USD and 1.4521 EUR to USD (Google 2011a and Google 2011b). Foreign currents converted into 2010 equivalents using historical inflation rates for from the International Monetary Fund (IMF), World Economic Outlook Database (IMF 2011).

Figure 1: Social costs of electricity generation (2010$/MWh)



As Table 3 and Figure 1 demonstrate, electricity generation from a pulverized coal power plant is not the most cost-effective in terms of social cost.

Sensitivity Analysis

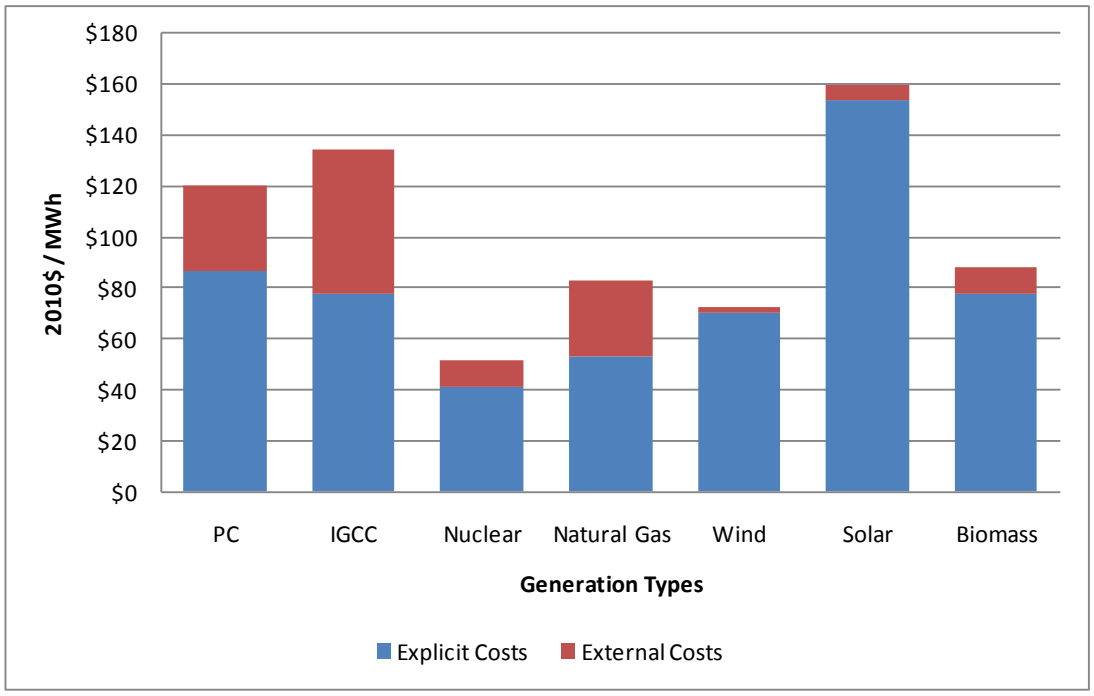
We conduct one sensitivity analysis to demonstrate the robustness of our results to alternative coal plant configurations. Specifically, we replace the previous estimate for the social cost of a Pulverized Coal plant with one for the most efficient pulverized coal plant (ultra-supercritical) with the addition of carbon capture and Sequestration (CCS). The purpose of this sensitivity analysis is to demonstrate that even with high efficiency and social cost of coal, the pulverized coal plant does not have the lowest social cost.

For explicit costs, we use the IEA 2010 estimate for an ultra-supercritical Pulverized Coal Plant with Carbon Capture and Sequestration. For external costs, we use the external cost estimate for a Pulverized Coal plant with a CCS system from Rafaj and Kypreos 2007. The sensitivity case social cost results are shown in Figure 2 and Table 5.

Table 5: Social Costs of Electricity Generation – all available coal emissions controls for Pulverized Coal (2010$/MWh)

	Coal		Lower Emissions		Renewables		
	PC	IGCC	Nuclear	Natural Gas	Wind	Solar	Biomass
Explicit Costs	$87	$77	$41	$53	$70	$154	$78
External Costs	$34	$57	$11	$30	$2	$6	$11
Total	$121	$134	$52	$83	$72	$160	$88

Figure 2: Social costs of Electricity Generation – all available coal emissions controls for Pulverized Coal (2010$/MWh)



Although the addition of the controls reduces external costs, it drastically increases explicit costs. As a result, pulverized coal is still not the most cost-effective source of electricity.

Disaggregation of External Costs

We also disaggregate the external costs of a coal plant and compare the disaggregated external costs to the external costs of other possible generation sources. We disaggregate and compare the external costs to contextualize and provide more clarity on the external costs.

We start with the same external costs used in the base case provided by Rafaj and Kypreos 2007. This estimate, however, does not provide a disaggregation of the components of the external costs. As such, we take the disaggregated external costs provided by Epstein et al 2011 to calculate the share of total external costs represented by each component. Although the Epstein et al estimate is calculated for the U.S. only, we assumed that the shares of external cost components should be similar across countries. We then apply these shares to the Rafaj and Kypreos 2007 external cost estimate, generating the coal results shown in Table 6.

Table 6: Disaggregation and comparison of the external cost of electricity generation for Pulverized Coal versus other generation sources (Million 2010$)

	Coal	Nuclear	Natural Gas	Wind	Biomass
Explicit Costs	$1,221	$1,221	$1,592	$2,089	$2,315
External Cost					
Health in Mining Communities	$374	-	-	-	-
Air Pollutants from Combustion	$937	-	-	-	-
Effects of Mercury	$28	-	-	-	-
Climate Change Impacts	$320	-	$211	-	-
Other Externalities	$69	$314	$668	$63	$314
Total	$1,728	$314	$880	$63	$314
Social Costs	$2,949	$1,535	$2,472	$2,152	$2,629
Additional Social Costs of PC		+$1,414	+$477	+$797	+$319

For the purposes of this table, we specifically calculate disaggregated external costs for the four most important components according to Epstein et al and group all other components under the "Other" category. As no source we found provides a comparable disaggregation of external costs for the other sources (nuclear, natural gas, wind, and biomass), we could not disaggregate the external costs for the other generation sources and included all of their external costs except for climate change impacts within the other category. For climate change impacts from natural gas (nuclear plants, wind, and biomass are assumed to generate no net direct CO2 emissions), we calculated the emissions rate of a natural gas combined cycle and multiplied it by the social cost of coal calculated by Greenstone et al 2010. To calculate total costs of a representative plant, we multiply all the $/MWh external costs by 4,000 MW, the approximate capacity of a recent coal power plant partially funded by the World Bank in South Africa (World Bank 2010).

References

Bureau of Labor Statistics (BLS) (2011). "CPI Detailed Report: Data for May 2011." http://www.bls.gov/cpi/cpid1105.pdf. Accessed on July 4, 2011.

Burtraw, Dallas, Alan Krupnick, and Gabriel Sampson. "True Cost of Electric Power." Forthcoming.

Energy Information Agency (EIA) (2010). "Assumptions to America's Energy Outlook 2010." 92. http://www.eia.gov/oiaf/aeo/assumption/index.html

European Commission (ExternE) (2005). Externalitites of Energy: Methodology 2—5 Update. P Bickel and R. Friedrich, Luxembourg.

Epstein, Pual R., Jonathan J. Buonocore, Kevin Eckerle, Michael Hendryx, Benjamin M. Stout III, Richard Heinberg, Richard W. Clapp, Beverly May, Nancy L. Reinhart, Melissa M. Ahern, Samir K. Doshi, Leslie Glustrom. (2011). "Fully cost accounting for the life cycle of coal." Annals of the New York Academy of Sciences 1219: 73-98.

Google (2011a). Search of term "convert RMB to USD." Accessed on July 4, 2011.

Google (2011b). Search of term "convert EUR to USD." Accessed on July 4, 2011.

Greenstone, Michael, Elizabeth Kopits, and Ann Wolverton (2011). "Estimation the Social Cost of Carbon for Use in U.S. Federal Rulemakings: A Summary and Interpretation." NBER Working Paper Series. Working Paper 16913. http://www.nber.org/papers/w16913

International Energy Agency (IEA) (2010). "Projected Costs of Generating Electricity 2010 Edition." http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=2207

International Monetary Fund (IMF) (2011). World Economic Outlook Database. April 2011. Accessed on June 26, 2010. http://www.imf.org/external/pubs/ft/weo/2011/01/weodata/index.aspx

National Research Council. (2010). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. Washington: National Academies Press.

Rafaj, Peter and Socrates Kypreos (2007). "Internalisation of external cost in the power generation sector: Analysis with Global Multi-regional MARKAL Model." Energy Policy. 35. 2. February. 828-843. ftp://124.42.15.59/ck/2011-02/165/009/226/759/Internalisation%20of%20external%20cost%20in%20the%20power%20generation%20sector%20Analysis%20with%20Global%20Multi-regional%20MARKAL%20model.pdf

World Bank 1994. "Operational Policy 10.04, Economic Evaluation of Investment Operations." September 1994. http://web.worldbank.org/WBSITE/EXTERNAL/PROJECTS/EXTPOLICIES/ EXTOP-MANUAL/0,,contentMDK:20064625~menuPK:4564185~pagePK:64709096~piPK:64709108~theSitePK:502184,00.html.