Title
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Journal
The Electricity Journal, 24(9)

ISSN
1040-6190

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Publication Date
2011-11-01

DOI
10.1016/j.tej.2011.09.020

Peer reviewed

Volume 24, Issue 9, November 2011 ISSN 1040–6190

ELSEVIER

the Electricity JOURNAL

www.elsevier.com/locate/tej

Is '2nd-Best Theory' 2nd-Rate? A Debate

Costs of Environmental and Performance Attributes of the Colorado Electricity Sector

This study offers a practical example of how environmental and performance adders might be calculated for environmental and performance attributes. The study reviews secondary data and provides marginal damage estimates of environmental and performance attributes associated with electricity generation in the state of Colorado. Low, mid-point, and high values are calculated for five environmental pollutants: mercury, carbon dioxide, nitrogen oxide, sulfur dioxide, and fine particulate matter. Marginal damages are also calculated for intermittent electricity.

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The author extends acknowledgement and appreciation to the Colorado Governor's Energy Office for funding this project (Grant No. 10-136).

I. Introduction

Along with a handful of other states, Colorado has recently enacted legislation requiring publicly owned utilities to consider environmental and performance targets in electricity generation. In the case of Colorado, recent legislation now mandates environmental targets for electricity power production, and requires publicly owned utilities to implement a renewable portfolio standard. Respectively, Colorado House Bill 10-1365 (''Clean Air, Clean Jobs Act'') tasks regulated utilities to develop plans that reduce nitrogen oxides by at least 70 percent below 2008 baseline levels by calendar year end 2017. The Clean Air, Clean Jobs Act also covers a minimum retirement or retrofitting of over 900 MW of coal-fired generation (or 50 percent of Colorado utility's coal-fired generation). The other landmark energy bill is Colorado House Bill 10-10-1001 (''The Renewable Portfolio Standard''). The Renewable Portfolio Standard mandates that by 2020, 30 percent of retail sales generated or purchased by regulated utilities come from eligible renewable energy resources such as wind, solar, and small hydro power, as defined by C.R.S. §7, 40-2-124(1) (d). There is also a carve-out for distributed generation, such as solar PV for 3 percent of the 30 percent threshold.

Policymakers have stated that these policies are intended to jump start innovation for new energy generation technologies that reduce negative impacts on the environment through a legislative approach.[1] However, the blunt force of regulatory policy does not necessarily lead to a more efficient use of resources.[2] This has prompted Colorado regulators to consider pricing externalities from electricity generation as a means to encourage technological advancement, while meeting environmental and performance targets.[3]

An externality-pricing approach is somewhat reflective of an ''adder,'' which incorporates environmental costs by ''adding'' or ''subtracting'' external costs to utility prices. Interest in adders policies began in the late 1980s, and by the mid-1990s, over half of all states had either implemented an adders policy or were considering doing so. Many economists were critical of the concept,[4] though a respectable minority of policy-oriented economists saw a constructive role for adders' policies.[5] However, with energy deregulation in the late 1990s and beginning of the new century, the majority of adders policies were never implemented. While these authors laid the groundwork for adders theory and how to calculate external costs of electricity generation, confounding the matter has been the absence of a practical illustration of what the external costs of electricity generation might look like.

Secondary data can be utilized to determine shadow prices for the external costs of electricity generation in a marginal damage function.

In addition to regulatory reform, Colorado has also explored a modified adders policy that could co-exist with its renewable portfolio standard. While the interaction of such policies would undoubtedly yield implementation complexities, a major appeal of an adders policy is that it applies to all technologies neutrally. The exercise of determining external costs of environmental and performance attributes might guide future electricity life cycle analyses, and energy policies, including but not limited to a modified adders policy.

The objective of this article is to provide a practical illustration of how external prices can be calculated for environmental and performance attributes of electricity generation, using Colorado as an example. This article demonstrates how secondary data can be utilized to determine shadow prices for the external costs of electricity generation in a marginal damage function. This article is intended to expand upon the work of previous authors to illustrate how min, mid-line, and high values can be calculated for environmental and performance attributes of electricity generation.

II. Study Background

Increasingly stringent national standards are on the horizon for EPA criteria pollutants, such as carbon dioxide and nitrogen oxide, tied to the electricity sector.[6] The EPA is in the process of reviewing the NAAQS for fine particulate matter, and is considering a strengthening of that federal standard.[7] The need to balance economic and

  doi:/10.1016/j.tej.2011.09.020

environmental targets should provide electricity generators with incentive to reduce energy production costs and negative environmental impacts. An argument could be made for implementing a total-cost, social-accounting approach that rewards low costs and low pollution (e.g., avoided externalities). By placing a price on all costs, including environmental attributes, the lowest-cost technology is inclusive, market-based, and technology-neutral, meaning it does not give preferential treatment to any particular generation technology. Generators with low operating costs are still financially rewarded. However, financial incentives are also provided for generators to achieve environmental (e.g., low nitrogen oxide emissions) and performance (e.g., consistently available power) targets. In other words, externalities are considered in the cost of electricity generation, but this approach does not diminish electricity providers' market incentives to reduce total costs.

In contrast to emissions taxes, adders policies do not directly impose costs upon already established energy generation sources. Instead, the adder is applied to new generation sources or power generation expansions, thereby forcing utilities to account for what would otherwise be external costs when considering new sources of energy. By imposing ''shadow prices'' (i.e., marginal costs) upon the new sourcing emissions that exceed certain targets, the utilities are required to evaluate alternatives on the basis of total social cost, equal to the bid price plus the appropriate adder. What follows is a practical example of how environmental and performance adders might be calculated for environmental and performance attributes.

Marginal values are used to measure the environmental cost to society of the last unit of environmental pollutant ''out'' of the stack.

III. Calculating the Costs of Desired Environmental Attributes of Electricity Generation: The Example of Colorado

This section presents a calculation of the social costs for five environmental attributes that are pending federal/state regulation: mercury, carbon dioxide, nitrogen oxide, sulfur dioxide, and fine particulate matter. Mercury, carbon dioxide, nitrogen oxide, and sulfur dioxide are primary pollutants that can result from electricity generation. Fine particulate matter, $PM_{2.5}$, is a secondary pollutant caused by complex chemical reactions in addition to the identified primary pollutants. $PM_{2.5}$ was disaggregated from the primary pollutants because specific damages can be separated from other pollutants and attributed to $PM_{2.5}$. A marginal damage cost model was chosen to measure the external costs of these environmental attributes. Marginal values are used to measure the environmental cost to society of the last unit of environmental pollutant ''out'' of the stack, which reflects the value of the first unit controlled. Although this article uses secondary, rather than primary data, it has been shown that use of secondary data and benefit transfer studies present cost-effective means to estimate environmental damages.[8]

A. Mercury

Mercury occurs naturally in soil and rock. It does not environmentally degrade, and its presence is bio-accumulative and long-term. Coal fired electric plants, zinc/copper mining, and medical products have been identified as leading sources of mercury pollution.[9] When mercury drifts into water it is transformed into methylmercury (MeHg), a highly toxic substance that accumulates in aquatic species and animals that consume them, including humans. Mercury toxicity can cause organ and immune system damage to people of any age. MeHg has been most

 1040-6190/$–see front matter doi:/10.1016/j.tej.2011.09.020

highly correlated with fetal nervous system damage and IQ loss stemming from maternal ingestion of contaminated fish. States may issue warnings against fish consumption from lakes and streams that are known to be contaminated; however, far-reaching international fish trade can yield contamination beyond regional boundaries. Due to atmospheric transport, chemical transformations, and deposition into lakes, rivers and aquifers, the effects from mercury fate and transport are far-reaching.[10]

At this writing, the EPA is developing mercury emissions standards for power plants under §112 of the Clean Air Act. Several states, including Colorado, have already enacted state legislation to reduce Mercury emissions.[11] As much as 40 percent of mercury in the U.S. actually originates from outside the country.[12] Accumulation of mercury in U.S. waterways from international sources will likely continue to be a source of concern and require international cooperation.[13] Thus, Colorado marginal damage estimates must account for worldwide damages.

Marginal damage function estimates are based on work of Spadaro and Rabl.[14] MeHg is estimated by applying damage from a dose response model to the statistical value of human life in the United States. The authors cite literature that U.S. ingestion of MeHg is statistically similar to the world average. Using the EPA damage dose threshold of 6.7 μg/day, the authors estimate damages as the sum of the impact per person exceeding the threshold (as measured by social costs resulting from loss of IQ) averaged over the entire population. Loss of IQ has been used in modeling damages from pollutants (including lead) that cause a decrease in cognitive skills and whose effects are cumulative over a lifetime.[15]

The financial impact and social costs of carbon emissions have been the source of diverse opinions and spirited debate.

Through meta-analysis of prior studies, Spadaro and Rabl assign a value of $18,000 per loss of IQ point for a U.S. resident, as a baseline. The authors apply a time lag of 15 years because the effects of MeMg contamination are cumulative and damages are often not realized for some time. Using a 3 percent discount rate over 15 years yields a discount factor of 0.64. With an average per person IQ point loss of 0.02, accounting for the population that is above the threshold on a given day, the mercury marginal damage estimate equates to an average of $1,663/kg. A Monte Carlo simulation to calculate 68 percent confidence intervals in cost/kg yields low and high estimates of $141/kg and $2,494/kg, respectively. The authors also vary the interest rate in the uncertainty analysis.

B. Carbon dioxide

While carbon dioxide (CO_2) emissions have been linked to global climate change,[16] the financial impact and social costs of carbon emissions have been the source of diverse opinions and spirited debate. Nonetheless, national carbon reduction policies are under consideration by legislatures and regulators.

Proposed carbon social costs vary widely because the social costs are highly uncertain and the effects may be geographically diffuse. For purposes of this project, marginal damage estimates have been derived from the 2010 Interagency Workgroup on Social Cost of Carbon (SCC).[17] The Interagency Workgroup consists of 12 agencies, including Department of Energy, Department of Agriculture, and the Office of Management and Budgeting. The estimates reflect annual monetized damages associated with an incremental increase in carbon emissions in a given year. The values include changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change. Uncertainties are present with the estimation and it is important to periodically update the values.

 1040-6190/$–see front matter , doi:/10.1016/j.tej.2011.09.020

The Interagency Workgroup values are based upon different climate scenarios of three scientifically accepted integrated assessment models: FUND,[18] DICE[19] and PAGE.[20] These respective models reflect the median, lower-bound, and higher-bound estimates of \$22.12, \$5.27, and \$8.48 per metric tonne, respectively, when adjusted for inflation. The median and lower bound estimate are based upon the climate change damage estimates at the 3 and 5 percent discount rates, respectively. The max value (\$68.48) represents higher than expected impacts from temperature change for the 95th percentile at a 3 percent discount rate.

C. Nitrogen oxide

Nitrogen oxides (NO_2 and NO_3, or collectively, NO_x) are major pollutants contributing to elevated tropospheric ozone (O_3) levels and regional haze. Burning fossil fuels like gasoline, oil or coal comprises approximately 7 percent of NO_x emissions in Colorado.[21] NO_x damages are associated with respiratory and cardiovascular morbidity, particularly in asthmatics, children, and older adults.[22] NO_x has also been linked with poor visibility and long-term O_3 concentration in national parks such as Rocky Mountain and Mesa Verde, as well as wilderness and natural areas.[23]

Several authors have estimated marginal damage functions from NO_x emissions; however, these studies combine impacts from NO_x, sulfur dioxide (SO_2), O_3 and $PM_{2.5}$ into a single marginal damage estimate.[24] Although SO_2 has also been identified as a pollutant contributing to regional haze and ozone, the case can be made for disaggregating NO_x, SO_2, and $PM_{2.5}$ damage estimates. The chief rationale is that the complex chemical reactions cause health and environmental impacts to vary across time and space. Furthermore, damages that result from these pollutants vary in intensity and origin.[25] It is also important to assign damage values to the primary pollutant from which the pollution is formed.[26] Compared to SO_2, NO_x has been shown to have a disproportionately large effect on agriculture, forestry, and recreation.[27] Separating the impacts of the individual pollutants may yield a more precise marginal damage value.[28] Furthermore, the effect of NO_x emissions on generating secondary pollutants such as O_3 and $PM_{2.5}$ varies depending on relative concentrations of NO_x, volatile organic compounds (VOCs), sunlight, temperature, and other factors.[29] Due to atmospheric chemistry, NO_x and SO_2 emissions in urbanized areas leads to higher exposures and damages from both compared to rural areas.[30] This implies that damage estimates from these emissions should be weighted higher for urbanized areas. The authors' computations are based upon changes in emissions as a result of the 1990 amended Clean Air Act, and apply U.S. EPA standards reflecting the statistical value of a life and dose–response functions.

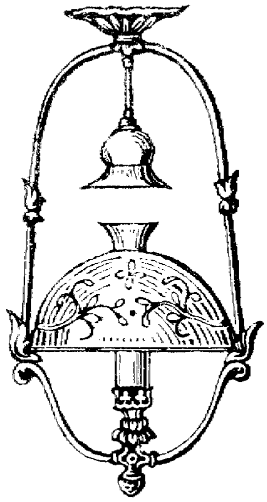
Compared to SO_2, NO_x has been shown to have a disproportionately large effect on agriculture, forestry, and recreation.

Muller and Mendelsohn[31] calculate the mid-line damage estimates for NO_x emissions at \$381/ton/year for urban regions and \$254/ton/year for rural areas, adjusted for inflation to 2010 levels. Weighting the damages higher to areas within the urban nine-county Denver-Metro non-attainment areas is not unreasonable. After reviewing a series of comparisons between urban and rural regions in the Mueller and Mendelsohn studies, the typical difference between urban and rural regions yields NO_x emissions at a level of 0.75 lower than urban regions. With this approximation, the lower bound threshold for rural regions is \$191. The lower threshold for urban areas is \$254, which reflects an un-weighted average estimate that does not differentiate between damages to urban and rural areas. Muller and Mendelsohn's upper bound estimate for urban areas is $2,261 per ton/year. Thus, the upper threshold for rural areas is $2,261 * 0.75, or $1,696.

Marginal damage functions do not appear to have been adequately calculated for NO_x as damage estimates in the literature have been limited to health effects. Thus, a ''true'' estimate of marginal damage from NO_x should probably be skewed towards the higher range. In summary, it appears that the economic effect of NO_x on the environment and recreation presents a gap in the literature and under-represents the level of economic damages. To elaborate upon this, poor visibility in natural areas including Rocky Mountain National Park and Mesa Verde has the potential to diminish both cultural and economic value of the region.[32] Damage effects are particularly noteworthy because mountain ecosystems are vulnerable to ecosystem damage and recreators at high mountain summits such as Long's Peak in Rocky Mountain National Park attach a much higher economic value to their experience compared to typical hiking or recreational experience.[33] It is therefore conceivable that the upper bound estimate for NO_x emissions could be even higher, with the inclusion of recreational damages.

D. Sulfur dioxide

SO_2 has been highly correlated with morbidity and mortality in humans. Muller and Mendelsohn's Colorado-specific median value is $1,232 per ton, with the upper and low and high estimates at $635-$1,270 per ton, statewide.[34] Estimates are skewed towards the high end of the distribution, and all values have been adjusted for inflation. While health damages from SO_2 have been established, the relative impact of SO_2 on Colorado and



the rural western United States is less than the eastern United States.[35] For example, Muller and Mendelsohn project that emissions of sulfur dioxide in large eastern cities cause damages that are 50 times larger than equivalent emissions produced in rural western locations.[36]

E. Fine particulate matter

Fine particulate matter ($PM_{2.5}$) refers to particles that are less than 2.5 micrometers in aerodynamic diameter. $PM_{2.5}$ is a secondary pollutant that is formed by a convergence of anthropogenic pollutants, as well as naturally occurring elements from dust and vegetation. Anthropogenic sources include gasoline, open burning, and coal-based power production. The effect of SO_2 and NO_x on ambient concentrations of $PM_{2.5}$ has led some scientists to aggregate the damage functions for SO_2 and NO_x on $PM_{2.5}$.[37] However, the complexity of this multi-source pollutant, as well as linkages $PM_{2.5}$ between high adult mortality rates levels necessitates further delineation.[38]

Of course, the challenge is to avoid double-counting the marginal damages from primary pollutants such as nitrogen oxide. For this reason, the estimates used rely on county-level marginal damage estimates from Muller and Mendelsohn[39] that only reflect the damages of $PM_{2.5}$ on human health. $PM_{2.5}$ concentrations and subsequent damage functions vary considerably across the state. Marginal damage estimates for Denver and Jefferson Counties are $12,701-$25,402 per ton, placing the estimates in the second highest category of severity. Three nearby counties also reach the damage threshold of $12,701. Probably due to their low population densities, the far northwest and southeast corners of the state present $0-$635 per ton of damages, the lowest category of damages. Putting this into perspective and remaining consistent with the prior regional marginal damage estimates, different marginal damage estimates should be applied to the Front Range compared to other regions in the state. Front Range

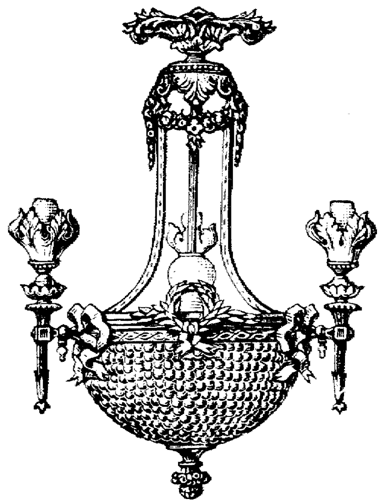
 1040-6190/$–see front matter , doi:/10.1016/j.tej.2011.09.020

min, mean, and maximum values should reflect $12,701, $19,051, and $25,402, respectively. Facilities outside of the nine-state out of compliance area present values between $635-$953, yielding min, mean, and max values of $635, $794, and $953, respectively.

IV. Calculating the Costs of Desired Performance Attributes of Electricity Generation

Firm or ''dispatchable'' power is a desirable performance target for the electric power utilities. Production from variable power sources often cannot be relied upon during peak demand, thus requiring utilities to employ expensive, short-run generation options as a stopgap.[40] Social costs may reflect the expected marginal increases in operational costs that are a consequence of producing energy from intermittent sources.

A recent Colorado-specific study modeled the additional cost of wind integration between $3.51 and $5.13 MWh, depending upon the penetration rate of wind integration (10 percent through 30 percent, respectively).[41] This assumes a geographically diverse location of wind generation facilities (i.e., beyond where wind is currently concentrated, primarily in the northeastern corner of the state), and accurate forecasting technology. This range uses the assumption that variable energy production displaces electricity produced by natural gas, running at $5 MMBTU. The authors adjust their assumptions to allow for less geographical diversity, different gas prices, smoothing adjustments to accommodate differences in wind speeds, and forecasting. Most of the values for the $5 MMBTU model hover



around $5 per MWh wind integration cost. Not surprisingly, higher natural gas prices yield higher integration cost prices (roughly around $8 MWh). Given the complexity of the modeling process, an adder of $5 MWh is applied to variable power technologies. In a manner similar to the environmental targets, the performance adder should be reevaluated frequently to reflect technological advancements within the field, and within the state.

V. Summary

This article describes how externalities from electricity generation may be calculated using secondary data. The values used reflect marginal damage estimates, which are more conservative compared to marginal abatement costs. The data are state-specific and have been adapted to reflect urban density. These environmental and performance adders could be used either as an alternative to, or in conjunction with, legislative policies such as Colorado HB-10-1001 and HB-1365. When combined with private costs external costs could yield a ''total cost accounting approach.'' Depending upon how it is implemented, a total cost pricing mechanism could create incentives to continually improve upon the environmental and performance characteristics of electricity generation, integration, and even conservation technologies. Policymakers may benefit from the experience of Colorado and from understanding how marginal damages from electricity generation may be calculated.

This article is intended to expand upon the work of previous authors to illustrate how min, mid-line and high values can be calculated for environmental and performance attributes of electricity generation. As for areas of future analysis, time-of-delivery benefits associated with daily and seasonal peaks in demand could be calculated. A full lifecycle assessment (LCA) of particular generation technology could be conducted in order to reflect different steps in the energy extraction and supply process. When the scope of analysis is expanded to include exploration, drilling, and expansion, the costs of the criteria pollutants will almost certainly increase.■

Endnotes:

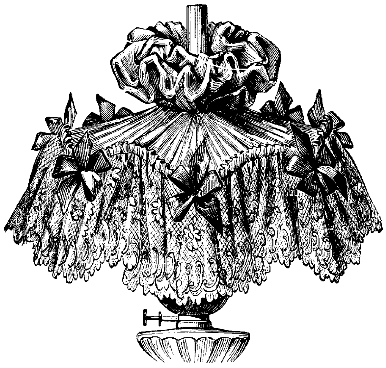
1. In the words of Gov. John Hickenlooper during his gubernatorial acceptance speech in November 2010, Colorado policymakers envision Colorado to be the ''center of the Clean Energy Economy.'' Mark Jaffe, *Nation Watching Xcel's Plans for Aging Coal-Fired Power Plants*, Denver Post, Nov. 7, 2010, at A-1, *at* http://www.denverpost.com/business/ci_16539428. The outgoing governor, Bill Ritter, Jr., has also declared energy reform as his legacy. See Bill Ritter, Jr., *A Blueprint for a New Energy Economy*, Jan. 2011 at http://rechargecolorado.com/images/uploads/pdfs/Ritter_Energy_Book_F_ForWeb.pdf.Thus, Colorado might serve as a case example for progressive electricity generation policy.

2. Peter Z. Grossman, When Is Command-and-Control Efficient? Institutions, Technology and the Comparative Efficiency of Alternative Regulatory Regimes for Environmental Protection (with Daniel H. Cole), Wisconsin Law Rev., Nov. 1999. Reprinted in Land Use & Environmental Law Rev., 31, 2001, at http://digitalcommons.butler.edu/cgi/viewcontent.cgi?article=1028&context=cob_papers&sei-redir=1#search="the+blunt+force+of+regulatory+policy+does+not+necessarily+lead+to+more+a+more+efficient+use+of+resources.

3. Catherine M.H. Keske, Terrence Iverson, Samuel Evans and Gregory Graff, *Designing a Technology-Neutral, Benefit Pricing Policy for the Electric Power Sector in Colorado*, Technical Report Submitted to Colorado Governor's Energy Office, Dec. 10, 2010, at http://soilcrop.colostate.edu/keske/index.html.

4. Paul L. Joskow, *Weighing Environmental Externalities: Let's Do It Right!* 5 Elec. J., June 1992, at 53–67.

5. See Dallas Burtraw, W. Harrington, *et al.*, *Optimal 'Adders' for Environmental Damage by Public Utilities*, 29(3) J. Environmental Econ. & Mgmt., 1995, at S1–S19, and M.A. Freeman, Dallas Burtraw, W. Harringon and A. Krupnick, (1992) *Weighing Environmental Externalities: How to Do It Right*, Elec. J., June 1992, at 18–25.



6. See Dallas Burtraw, Arthur G. Fraas and Nathan Richardson, *Green House Gas Regulation Under the Clean Air Act: A Guide for Economists*, Resources for the Future, Document No. 11-08, 2011, at http://www.rff.org/documents/RFF-DP-11-08.pdf.

7. See U.S. Environmental Protection Agency, *Policy Assessment for the Review of the Particulate Matter National Ambient Air Quality Standards*, Second External Review Draft, June 2010.

8. See Dana L. Hoag, Randall Boone and Catherine M.H. Keske, *The Agricultural Cost to Coexist with Wildlife in Colorado*, Human Dimensions of Wildlife 16(5) 2011 at 319–329. Methodologies for calculating marginal damage functions may include the statistical value of a life, a dose-response function, damages that may be incurred by regulatory action, or opportunity cost of a resource relative to highest and best use. Readers desiring a more in-depth description behind the respective methodologies can review J. Lesser, D. Dodds and R. Zerbe, *Environmental Economics and Policy* (1997); and J.M. Fang and P.S. Galen *Issues and Methods in Incorporating Environmental Externalities into the Integrated Resource Planning Process*, National Renewable Energy Laboratory Technical Report No. 461-6684, Golden, CO (1994). The calculations in this report do not reflect the social value of energy security or global climate change, although a case can be made to include these respective measures. For information on how to include the latter, see O. Hohmeyer, *Renewables and the Full Costs of Energy*, 20(4) Energy Policy (1992) at 365–375; or D.M. Kammen and S. Pacca, *Assessing the Costs of Electricity* 29(1) Annual Rev. of Environment & Resources (2004) at 301–344.

9. V.V. Lissianski, P.M. Maly, *et al.* (2009) *Mercury Reduction System and Method in Combustion Flue Gas Using Staging*, U.S. Patent Office, General Electric Company, US 7,600,479 B2.

10. N. Pirrone and R. Mason, *Mercury Fate and Transport in the Global Atmosphere: Emissions, Measurements, and Models* (2009).

11. Colorado Mercury Reduction Regulation for EGUs 2012, 2014, 2018, summarized at http://www.dora.state.co.us/puc/presentations/InformationMeetings/CleanAir/04-26-10CIM_RH_HB1365-AirQuality.pdf.

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15. Massimo Pizzol, Marianne Thomsen, Lise M. Frohm and Mikael S. Andersen, *External Costs of Atmospheric Pb Emissions: Valuation of Neurotoxic Impacts Due to Inhalation* 9(1) Environmental Health (2010) at 1–9.

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16. Interested readers should review A. Scott Denning, Melville Nicholls, Lara Prihodko, Ian Baker, Pier-Luigi Vidale, Kenneth Davis and Peter Bakwin, *Simulated Variations in Atmospheric CO_2 over a Wisconsin Forest Using a Coupled Ecosystem–Atmosphere Model* 9 (9) 2010 Global Change Biology, at 1241–1250.

17. United States Government Interagency Workgroup on Social Cost of Carbon, *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, Feb. 2010, at http://www.epa.gov/otaq/climate/regulations/scc-tsd.pdf.

18. The FUND model is based upon the work and papers published by R. Tol, *The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties* 33 (16) 2005 Energy Policy 2064–2074; R. Tol, *The Economic Effects of Climate Change* 23 (2) 2009, J. Econ. Perspectives, at 29–51; R. Tol, *Estimates of the Damage Costs of Climate Change, Part I: Benchmark Estimates* 21 (1) 2002, Env. & Resource Econ., at 47–73; and R. Tol, *Estimates of the Damage Costs of Climate Change, Part II, Dynamic Estimates* 21 (2) 2002 Env. & Resource Econ. at 135–160.

19. The DICE model is based upon the work and papers published by W. Nordhaus and J. Boyer, *Warming the World: Economics Models of Global Warming* (2000) and W. Nordhaus, *A Question of Balance: Weighing the Options on Global Warming Policies* (2008).

20. The PAGE model is based upon the work and papers published by C. Hope, *The Marginal Impact of CO_2 from An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern* 6 (1) 2006 Integ. Assessment, at 19–56; and C. Hope, *Optimal Carbon Emissions and the Social Cost of Carbon over Time Under Uncertainty* 8 (1) 2008 Integ. Assessment, at 107–122.

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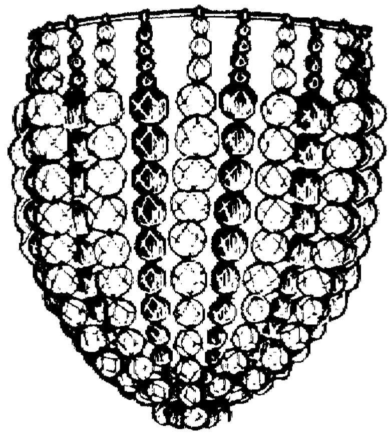
22. Lisa Ann Miller, Acting Chief Medical Officer, Colorado Dept. of Public Health & Environment. *Docket No. 10M-245E In the Matter of Commission Consideration of Public Service Company of Colorado Plan in Compliance with House Bill 10-1365, 'Clean Air-Clean Jobs Act,'* Sept. 17, 2010.

23. Paulette Middleton, Air Quality Analyst, Western Resource Advocates, *Docket No. 10M-245E In the Matter of Commission Consideration of Public Service Company of Colorado Plan in Compliance with House Bill 10-1365,*



'Clean Air-Clean Jobs Act,' Sept. 17, 2010.

24. Examples include:Dallas Burtraw, R. Bharvirkar, *et al.*, Uncertainty and the Net Benefits of Emissions Reductions of Nitrogen Oxides from Electricity Generation 79 (3) 2003 Land Econ. at 382–401, and S. Kumar and S. Managi, Sulfur Dioxide Allowances: Trading and Technological Progress, 69 (3) 2010 Ecological Econ. at 623–631.

25. *Id.* at xxi.

26. N.A. Muller and R. Mendelsohn, *Weighing the Value of a Ton of Pollution* 33 (2) 2010 Regulation, at 20–24.

27. N.Z. Muller and R. Mendelsohn, *Measuring the Damages of Air Pollution in the United States* 54 (1) 2007 J. Environmental Econ. & Mgmt., at 1–14.

28. N. Muller, D. Tong and R. Mendelsohn, *Regulating NO_x and SO_2 Emissions in Atlanta* 9 (2) 2009 The B.E. J. Econ. & Policy, at 1–30.

29. *Id.* at xxi.

30. *Id.* at xxvi.

31. *Id.* at xxvii.

32. Readers interested in better understanding the science behind nitrogen cycling and deposition process along Colorado's Front Range are encouraged to review IMPROVE (Interagency Monitoring of Protected Visual Environments) educational materials (2009). Adverse impacts of NO_x in natural areas are echoed in the Rocky Mountain National Park Nitrogen Deposition Reduction Plan, a joint effort between the CDPHE, the NPS, and the EPA (2007).

33. John B. Loomis and Catherine M. Keske, *Peak Load Pricing of Colorado's Peaks:Influence of Substitutes on Valuation and Use of Price as a Management Tool* 90 (2009) J. Environmental Mgmt., at 1751–1760.

34. *Id.* at xxvii.

35. *Id.* at xxvii.

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