Title

Total Cost Electricity Pricing: A Market Solution for Increasingly Rigorous Environmental Standards

Journal

The Electricity Journal, 25(2)

ISSN

1040-6190

Authors

Keske, Catherine MH
Evans, Samuel G
Iverson, Terrence

Publication Date

2012-03-01

DOI

10.1016/j.tej.2012.02.004

Total Cost Electricity Pricing: A Market Solution for Increasingly Rigorous Environmental Standards

This technology-neutral marginal cost pricing approach can integrate the private and social costs of electricity generation. The pricing methodology borrows from the adders and value-based feed-in tariff literature. When both social and private costs are considered, the lowest-cost technology generally (but not necessarily) involves lower amounts of environmental pollutants.

Catherine M.H. Keske, Samuel G. Evans and Terrence Iverson

Catherine M.H. Keske *is Associate Professor of Agricultural and Resource Economics in the Department of Soil and Crop Sciences at Colorado State University. She is also an adjunct professor at the Denver University Sturm School of Law. Her M.S. degree from Colorado School of Mines is in Mineral Economics. Dr. Keske's research program focuses on energy, mountain ecosystems, land conservation, and non-market valuation modeling.*

Samuel G. Evans *is a graduate research assistant in the Department of Agriculture and Resource Economics at Colorado State University. He is in the final stages of completing his Ph.D. and has accepted a research associate/post-doctoral position at the University of California-Berkeley.*

Terrence Iverson *is an Assistant Professor in the Department of Economics at Colorado State University. His Ph.D. is from the University of Wisconsin-Madison. Dr. Iverson's research program focuses on climate change and energy economics.*

I. Introduction

Electricity providers across the U.S. are challenged to meet increasingly rigorous environmental targets, while keeping energy prices affordable to customers and delivering expected returns to shareholder investments. The purpose of this article is to present a total-cost energy pricing approach that can be used to address these challenges, and encourage technological innovation in electricity generation. This is an example of a market-based solution that can offer load-serving entities a flexible bridge to cost avoidance as they address increasingly rigorous environmental targets. The Excel-based, total-cost pricing tool is publicly available,[1] and the data reflect previously published work on the marginal damage costs of electricity generation in the U.S.[2]

1040-6190 doi:/10.1016/j.tej.2012.02.004

II. Study Background

U.S. power plants are facing increasingly rigorous environmental quality standards. For example, the U.S. Environmental Protection Agency (EPA) Mercury and Air Toxics Standards released in December 2011 now mandate reductions in power plant mercury emissions.[3] The EPA estimates that approximately 1,400 units at 600 power plants will be affected by these standards, including approximately 1,100 existing coal-fired units and 300 oil-fired units. The EPA also recently released an on-line, searchable map and database of the nation's greenhouse gas emitters. This is expected to increase societal pressure for power plants to reduce air emissions.[4] EPA regulations for greenhouse gas emissions, which are anticipated to also affect power plant functionality and costs, are slated for spring 2012.

Substantial capital upgrades to U.S. energy infrastructure are expected during the next decade. New plants are being built to replace outdated technology, achieve renewable energy integration, and meet increasingly stringent environmental performance targets. As a result, electricity costs are projected to rise substantially while the total retail sale projections are flat.[5] There is clearly a need for an energy pricing policy that rewards innovation, but provides incentive to keep costs low, while meeting energy targets.

This article presents a total-cost electricity pricing model that more closely reflects the full social costs of electricity generation that could be used either as an alternative to, or in conjunction with, other legislative policies in a regulated electricity market. When total social costs are calculated, the lowest-cost technology frequently (but not necessarily) involves lower amounts of environmental pollutants. One objective of this article is to provide a practical illustration of how the private costs, which are reflected in the levelized cost of energy (LCOE), and external costs from environmental and performance attributes of electricity generation, can be combined so that policymakers can make informed decisions about the lowest-cost technologies. The article uses the state of Colorado as an example, although the specific details could be adapted to include other states. For example, the proposed total-cost electricity pricing model could also be used as part of a lowest-cost resource plan, which is a common approach for public utilities creating electric resource plans.[6]

By the mid-1990s, over half of all states had either implemented an adders policy or were considering doing so.

III. Methodology: Overview of Adders and Value-Based Feed-in-Tariff Literature

The proposed total cost pricing methodology is a hybrid externality-pricing approach that borrows from the adders and the value-based feed-in-tariff (FIT) literature. Environmental adders incorporate 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,[7] though a respectable minority of policy-oriented economists saw a constructive role for adders' policies.[8] 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.

The methodology in this article utilizes secondary data to

1040-6190/$–see front matter, doi:/10.1016/j.tej.2012.02.004

determine shadow prices for the external costs of electricity generation in a marginal damage function that is applicable to Colorado. These are mercury, carbon dioxide, nitrogen oxide, sulfur dioxide, and fine particulate matter $PM_{2.5}$ levels, as well as water consumption and quality. These were selected because federal and/or state regulation has either recently been implemented or is pending for five of the six. While not a pollutant, water is a scare resource in Colorado that can be consumptively used, disruptively diverted, thermally loaded, or otherwise impaired during electricity generation. Its external costs are difficult to measure comprehensively, yet the value of water is considered much higher than what has been reflected in water market prices. To estimate marginal damage functions, this report uses published studies incorporating a range of different valuation methodologies. Whenever possible, data are cited or interpolated to be relevant to Colorado and conservative assumptions are chosen in incorporating them into the model.[9]

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. A major appeal of an adders policy is that it applies to all technologies neutrally. Utilities are required to rank decision options on the basis of total social cost, but they are free to choose the best technology to accomplish this. Since utilities are not actually charged the adders, the baseline level is flexible and can be set according to policy targets. For example, the adder could be a sum of the marginal damages plus the private costs (i.e., the bid price) for each energy source. Alternatively, the adder could be set to zero for the cleanest energy source, and adders could reflect differences in marginal damages between the cleanest source and the respective alternatives. Generators with low operating costs are still financially rewarded. However, financial incentives are also provided for generators to achieve environmental (e.g., mercury emissions) and performance (e.g., consistently available power) targets. Elements from adders policies may be effectively integrated into a hybrid model that considers the value-based FIT literature.

A major appeal of an adders policy is that it applies to all technologies neutrally.

FITs are a policy mechanism for rapidly deploying renewable energy technologies. Already popular in Europe, FITs are gaining attention of U.S. policymakers and regulators as a potential alternative or complement to renewable portfolio standards and tradable renewable credit programs. FIT design varies considerably across regions; however, the policies have common features. First, FITs mandate that utilities purchase the renewable energy from eligible sources. Second, FITs establish a pricing mechanism that applies to all generators developing a given technology.[10]

Two FIT design options have been explored in detail and implemented in various global jurisdictions. The most widely implemented is the *project-cost* approach. In this approach, the governing institution (usually a national government) agrees to pay a set price for a given technology based on the project's costs plus a reasonable rate of return. This attracts investors by minimizing price uncertainty over multi-year contracts. The project-cost approach has proven successful in a number of European countries in developing renewable capacity. However, the

1040-6190/$–see front matter, doi:/10.1016/j.tej.2012.02.004

project-cost approach is not technology neutral, thus violating a key objective of the policy design mechanism proposed in this article. In light of this, it is more helpful to focus on an alternative FIT pricing mechanism known as the *value-based* approach.

Under the value-based FIT methodology, prices are set to reflect the value to society provided by electricity generation. This approach has not been adopted as extensively as the project-cost approach, but it has the potential to achieve technological neutrality. Value-based FITs are set according to a selected baseline technology and the avoided costs of generation from a traditional energy source by working with that selected technology. Avoided costs can include (but are not required or limited to) direct project costs, environmental damages, and undesirable performance attributes like intermittency.

IV. Total Cost Pricing

This section outlines how optimal electricity prices can be calculated by using a total cost pricing model. The premise is based upon lessons learned from the environmental adders and the value-based FIT literature. A more detailed mathematical representation of the algorithm is available in the original on-line published report, and is beyond the scope of this article.[11] Like the value-based FIT, this algorithm positively rewards social cost savings from reductions in private costs, environmental damages, and distributional performance measures. The pricing formula could be incorporated into a FIT policy with an explicit purchase obligation, or it could simply be used as a pricing rule to guide public utility oversight of new source generation contracts. In summary, this algorithm combines elements of prior adders policies with underlying principles of the value-based FIT in order to reward power plant providers for selecting technologies that comply with increasingly rigorous environmental standards.

Avoided costs can include direct project costs, environmental damages, and undesirable performance attributes like intermittency.

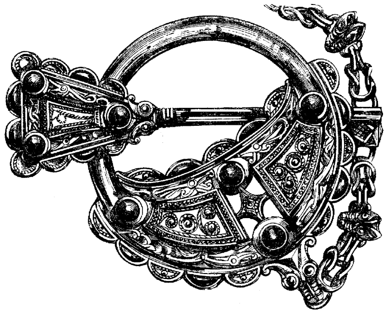
The algorithm combines private generation costs incurred by firms, damages from environmental externalities, and utility performance costs to create a comprehensive cost algorithm to minimize total social costs. The hybrid adders/value-based FIT algorithm minimizes total costs and rank orders the technology by the lowest total costs. Total costs reflect a sum of the private costs (the LCOE for new builds), plus the product of the estimated emissions associated with the respective technologies times the calculated marginal damages.[12] The marginal damage from water use is also multiplied by the quantity of water used and added to the sum of total costs. The estimated engineering emissions values and marginal damage values associated with each technology are available in the on-line spreadsheet and can be customized to adjust to technological innovation that reduces total emissions.[13]

To provide a bit more elaboration, the private generation costs are the most straightforward. In a purely regulated environment, private costs would be comprised of the investment and operating costs to build, run, and maintain a given facility, along with an appropriate rate of return for investors. In a competitive situation, private costs could simply reflect the winning price from a competitive bid process. The pricing algorithm uses KEMA[14] values as the default private costs. It is important to note that the Excel-based pricing tool[15] also allows users to ignore the default values and impute customized private costs in accordance to their own source or proprietary data set.

For the purposes of this blueprint, the environmental damages are estimated as the marginal damage for environmental attributes in the state of Colorado.[16] Utility performance costs (or integration costs) capture the increment in bulk power system operating costs that would result from adding a particular generation technology—typically an intermittent source or ''variable power source''—to the existing portfolio.[17] Integration costs could also include transmission and distribution losses that result from locating a facility in a particular location. Integration costs fall on the utility and thus on customers, so, while they constitute private costs, they indeed contribute to social costs. Due to the complexity of the existing bulk power system, integration costs are also difficult to estimate. Precise calculations require detailed system modeling that is beyond the scope of this article.

In so far as pricing rule implementation, once the regulator determines the total social cost per kWh of electricity for every possible source, the optimal electricity source can be determined. Since one does not want to pay more for a source then its private cost (and because it is socially optimal to provide an adequate price to encourage generation from the socially optimal source) the contract price for the socially optimal source is its private cost. The private cost for the social-cost-minimizing source provides the baseline against which other technologies are gauged.

This could be implemented using a couple of different approaches. One approach is that the contract price for another source is equal to the baseline, plus or minus the social value that would result from generating electricity from a non-optimal source. In other words, the contract price for another technology would be equal to the baseline, plus the marginal damage cost times the difference in emissions. A generation source outside of the optimum should be paid a higher price to the extent that the alternative source reduces environmental damages from emissions. The reverse approach could also be taken, in which the baseline technology could be set as the technology with the lowest total social costs, and adders could be added to adjust for the subsequent contract prices.



The algorithm is technology neutral because it prices the attributes of electricity without distinguishing the technology directly—though the result of the algorithm will favor some technologies indirectly, but only to the extent that they generate low social costs. In some instances, the results can be surprising: the pricing algorithm may not ''choose'' the generation technology that one might be predisposed to think of as the optimal alternative. This unbiased assessment creates incentive to develop new technologies in line with stated public interests. In contrast, renewable energy standard polices or project-cost FITs are one-dimensional and reward a single identified technology.

An important implication of the pricing rule is that it only rewards social-cost-minimizing power sources. Multiple externalities and/or integration costs would subsequently add to the contract price. In other words, the higher the total costs, the less competitive the generation source.

V. Simulation Results

The Excel-based total benefit pricing tool is available online, with five-step instructions for operation. To demonstrate the benefit-pricing tool, seven technologies have been chosen for comparison. While care has been taken to choose values that appropriately reflect the current state of technology, users should note that there is a lot of variation in these estimates based on factors such as plant size and technological design.

The pricing tool parameterizes the benefit-pricing algorithm as described in the previous section. As previously outlined, total social costs are comprised of private generation costs, environmental costs, and variable power costs.[18] The algorithm rank orders the lowest social cost technology, based upon the parameters and energy technologies selected for comparison. Although default cost estimates are provided for all three cost categories, based upon the most currently available scientific literature, the pricing tool enables users to impute customized cost data, to reflect information and cost updates. In other words, the pricing tool is both customizable, as well as technology neutral.

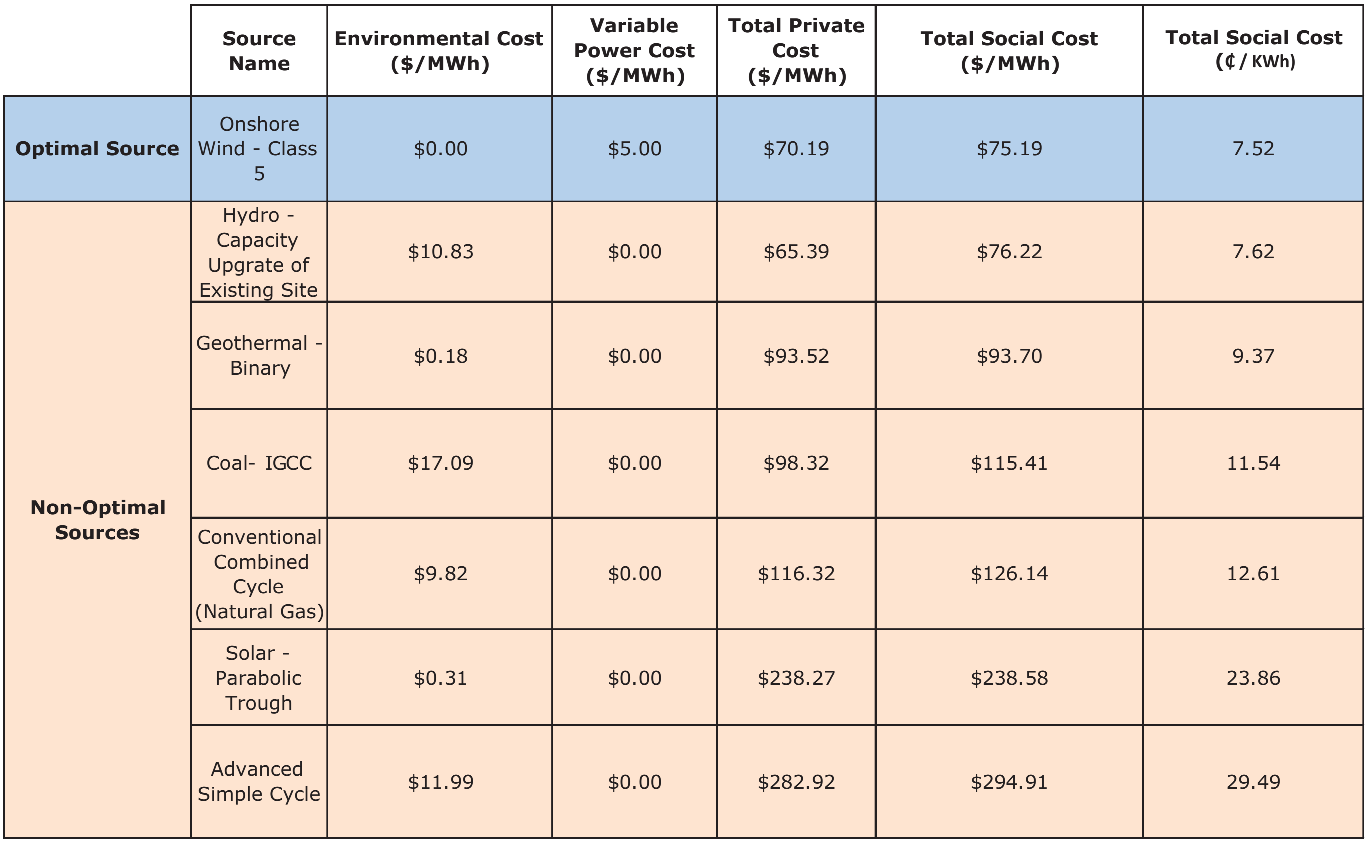
Two features of the environmental cost component can be customized. The user can determine which environmental costs are considered in the model, as well as the marginal damage levels. For an included pollutant, the user must choose either the lower, middle, or upper marginal damage estimates, (or none) which reflect secondary data applied to Colorado. By default, marginal damage estimates are set to mid-range values. Second, for each technology the user must input the relevant emissions factor for each pollutant. This is a measure of effluent per unit of electricity produced. For SO_2, NO_x, CO_2, PM, and MeHg, the units must be provided in tons per megawatt hour of electricity produced. For water the unit is acre-feet consumed per megawatt hour of electricity produced. The emissions factors for the seven default technologies have been calculated based on various sources.[19]

In summary, the model calculates total social cost, a ranked list of technologies according to total social cost, and the social price of each technology. The Optimal Source matrix displays social costs for up to seven energy sources in $/MWh and cents/kWh. **Table 1** shows an applied, simplified illustration and simulation of the pricing model using seven common technologies and default values. In the Excel workbook, this scenario can be run by clicking the ''default scenario'' button in the pricing algorithm worksheet.

Figure 1 displays the rank order of total social costs decomposed into private cost, environmental costs, and variable power costs. Environmental damage values have been set to reflect median

Table 1: Default Technology Values

			Environmental Costs (Emissions Factors)						Variable Power Costs **($/MWh)**
Source	Capacity (MW)	Private Costs (LCOE) ($/MWh)	SO_2 (tons/ MWh)	NO_x (tons/ MWh)	CO_2 (tons/ MWh)	HeMg (tons/ MWh)	PM (tons/ MWh)	Water (acre ft/ MWh)	
Conventional combined cycle	500	116.32	.000002	.00003	.4195	0	.00001	.000675	0
Advance simple cycle	200	282.92	.000004	.00004	.507	0	.00003	.000675	0
IGCC (coal)	300	98.32	.000047	.00020	.7295	2.1E−9	.00002	.001196	0
Wind	100	70.19	0	0	0	0	0	0	5
Hydro- capacity upgrade	80	65.39	0	0	0	0	0	.038054	0
Solar- parabolic trough	250	238.27	0	0	0	0	0	.001074	0
Geothermal- binary	15	93.52	0	0	0	0	0	.000644	0



	Source Name	Environmental Cost ($/MWh)	Variable Power Cost ($/MWh)	Total Private Cost ($/MWh)	Total Social Cost ($/MWh)	Total Social Cost (¢/KWh)
Optimal Source	Onshore Wind - Class 5	$0.00	$5.00	$70.19	$75.19	7.52
Non-Optimal Sources	Hydro - Capacity Upgrate of Existing Site	$10.83	$0.00	$65.39	$76.22	7.62
	Geothermal - Binary	$0.18	$0.00	$93.52	$93.70	9.37
	Coal- IGCC	$17.09	$0.00	$98.32	$115.41	11.54
	Conventional Combined Cycle (Natural Gas)	$9.82	$0.00	$116.32	$126.14	12.61
	Solar - Parabolic Trough	$0.31	$0.00	$238.27	$238.58	23.86
	Advanced Simple Cycle	$11.99	$0.00	$282.92	$294.91	29.49

Figure 1: Diagram of Total Social Costs

estimates. For the simplified context shown here, onshore wind turns out to be the socially optimal technology. Environmental costs represent only a small fraction of total social costs, and they do not substantially influence the ranking of sources; a notable exception is the ranking between wind and hydro when consumptive water use is considered.

VI. Summary and Discussion

This energy pricing blueprint demonstrates how social cost pricing might work in the regulated utility framework. The preparation of this algorithm has required an evaluation of the experiences from other states and countries, and comes with the acknowledgement that there is an extraordinary amount of complexity with currently existing policies. Thus, the implementation of this pricing rule would require frequent updating of this data, and more in-depth modeling. The pricing rule described is a novel one that has never been fully implemented at the state regulatory level. It is susceptible to many of the same criticisms that have been leveled against past policies. Nonetheless, much of the purpose of this blueprint is to show how a total-cost, value-based model might work and to have the regulator and other stakeholders consider how it might be used to inform future rate making and resource planning in a regulated market with increasingly rigorous environmental standards.

One example of how the model could be implemented might be to attract funding to generation projects from suboptimal sources identified by policymakers as warranting early-stage subsidies. As previously discussed, the algorithm would not provide an adequate price to attract capital investments to suboptimal sources. Instead, it would typically only support the source identified as minimizing social costs. Implementation of the pricing tool could be necessary to

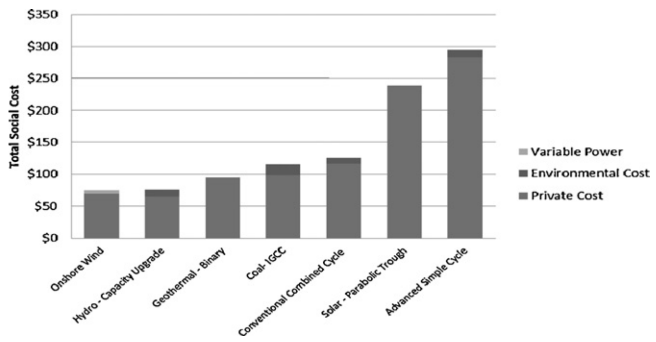


Figure 2: Illustration of Staged Pricing Schedule (a staged pricing schedule with a temporary subsidy at PC^j can support generation from technologies with identified long term potential p^j)

include some flexibility to allow regulators to modify the algorithm price.

The simplest approach would be a staged pricing schedule. This is illustrated in **Figure 2**. Under this pricing schedule, the price would first start at the source-specific private cost, PC^j, and then fall over time, eventually dropping to the social-cost-minimizing algorithm price. Such a contract would ensure generator profitability for some initial phase, but also send a clear signal that the subsidy is only temporary and that the source must eventually be able to compete on social cost grounds. The length of the subsidy would have to be determined by policymakers and it would naturally depend on the expected rate of technological development for the subsidized source, along with its perceived future value.

A total-cost pricing approach is technology neutral—it would link sourcing decisions to true social costs without favoring one technology platform over another. Under the total-cost pricing mechanism, generators would be financially rewarded for lowering the environmental costs that they pass on to society or for lowering the integration costs that they pass on to the bulk power provider—this would be on top of existing incentives to lower their own private generation costs. The mechanism would provide incentives for electricity generators to modify existing operations and to innovate.

These environmental and performance adders could be used either as an alternative to, or in conjunction with, renewable performance standards or newly passed power plant regulations. 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. In summary, this value-based blueprint demonstrates a methodology for social cost pricing and how it is possible to keep both environmental and economic goals in mind when creating energy policy.■

Endnotes:

1. The Excel-based pricing tool is available at the Web site of one of this article's authors: http://soilcrop.colostate.edu/keske/index.html.

2. Catherine M.H. Keske, *Costs of Environmental and Performance Attributes of the Colorado Electricity Sector*, Elec. J., Nov. 2011, at 75–83.

3. The U.S. EPA also amended new source performance standards (NSPS) to revise the standards that new coal- and oil-fired power plants must meet for particulate matter (PM), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). More information can be found at http://www.epa.gov/mats/actions.html.

4. John M. Broeder, *Online Map Shows Biggest Greenhouse Gas Emitters*, N.Y. Times, Jan. 11, 2012, at A-16, at http://www.nytimes.com/2012/01/12/science/earth/epa-unveils-map-of-major-greenhouse-gas-producers.html. The online map and database are available at the EPA Website: http://ghgdata.epa.gov/ghgp/main.do.

5. See generally, Peter Fox-Penner, Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities (Island Press, 2010).

6. Public Service Company of Colorado 2011 Electric Resource Plan, Oct. 31, 2011, at http://www.xcelenergy.com/staticfiles/xe/Regulatory/Regulatory%20PDFs/PSCo-ERP-2011/Exhibit-No-KJH-1-Volume-1.pdf.

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

1040-6190/$–see front matter © 2012 Elsevier Inc. All rights reserved., doi:/10.1016/j.tej.2012.02.004

8. See Dallas Burtraw and W. Harrington, *et al.* (1995) *Optimal 'Adders' for Environmental Damage by Public Utilities*, 29(3) J. ENVTL. ECON. & MGMT. S1–S19 (1995) and M.A. Freeman, Dallas Burtraw, W. Harringon and A. Krupnick, *Weighing Environmental Externalities: How to Do It Right*, ELEC. J., Aug./Sept. 1992, at 18–25.

9. Keske, *supra* note 2.

10. For a comprehensive review of the FIT literature see A. Klein, B. Pfluger, *et al.*, *Evaluation of Different Feed-in Tariff Design Options: Best Practice Paper for the International Feed-in Tariff Cooperation*, German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2008; B. Burgie and K. Crandall, *The Application of Feed-in Tariffs and Other Incentives to Promote Renewable Energy in Colorado*, C.P.U. Commission, Denver, 2009; and, T. Couture and Y. Gagnon, *An Analysis of Feed-in Tariff Remuneration Models: Implications for Renewable Energy Investment*, 38(2) ENERGY POLICY, 2010, at 955–965.

11. For a more detailed mathematical representation of the algorithm, consult 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 16–19, at http://soilcrop.colostate.edu/keske/index.html.

12. Keske, *supra* note 2.

13. Keske *et al.*, *supra* note 11.

14. J. Klein, I. Rhyne, *et al.*, *Comparative Costs of California Central Station Electricity Generation*, California Energy Commission, CEC-200-2009-017-SD, 2009, at http://www.energy.ca.gov/2009publications/CEC-200-2009-017/CEC-200-2009-017-SD.PDF. Also see Charles O'Donnell, Pet Baumstark, Valerie Nibler, Karin Corfee, Kevin Sullivan, KEMA Inc. report, *Public Interest Energy Research Program Update* prepared for California Energy Commission. CEC-500-2009-084.

15. Keske *et al.*, *supra* note 11.

16. Keske, *supra* note 2.

17. Michael Milligan and Brendan Kirby, *Calculating Wind Integration Costs: Separating Wind Energy Value from Integration Cost Impacts*, National Renewable Energy Laboratory Technical Report 550-46275, Golden, CO, 2009.

18. All monetary values are normalized to 2010 dollars using the U.S. Bureau of Labor Statistics' inflation calculator, at http://data.bls.gov/cgi-bin/cpicalc.pl.

19. See the following: J. Klein, I. Rhyne, *et al.*, *Comparative Costs of California Central Station Electricity Generation*, California Energy Commission, CEC-200-2009-017-SD, 2009, at http://www.energy.ca.gov/2009publications/CEC-200-2009-017/CEC-200-2009-017-SD.PDF; Jordan Macknick, *Concentrated Solar Power (CSP): Water Challenges and Opportunities*, National Renewable Energy Laboratory, Golden, CO, Aug. 26, 2010; P. Torcellini, N. Long, *et al.*, *Consumptive Water Use for U.S. Power Production*, ASHRAE Winter Meeting. Anaheim, CA, 2004; *Cost and Performance Baseline for Fossil Energy Plants: Vol. 1 Bituminous Coal and Natural Gas to Electricity Final Report*, National Energy Technology Laboratory, DOE-NETL Report No. 2007/1281, 2007, Retrieved from NETL Website: http://www.netl.doe.gov/energy-analyses/baseline_studies.html.

The length of the subsidy would have to be determined by policymakers.