A Taxing Environment: Evaluating the Multiple Objectives of Environmental Taxes

MARIE LYNN MIRANDA* AND BRACK W. HALE†

Nicholas School of the Environment and Earth Sciences, Duke University, Box 90328, Durham, North Carolina 27708

Environmental taxes have attracted attention in recent years as a tool to internalize environmental externalities. This paper evaluates Sweden's experience with environmental taxes in the energy sector by examining how environmental taxes compare with estimated environmental externalities associated with the use of oil, coal, natural gas, and forest residue fuels. We also analyze how environmental taxes influence fuel choices in the energy sector by comparing the production, environmental, and tax costs for the same fuels. We find that (i) the Swedish environmental taxes correspond imperfectly with environmental costs; (ii) the Swedish tax and subsidy system introduces changes in fuel choice decisions; (iii) the energy users are responding to the incentives created by the tax and subsidy systems in ways that are consistent with economic theory; and (iv) the Swedish experience with environmental taxes and subsidies bears directly on wider evaluations of energy policy approaches internationally.

Introduction

Scientists and policymakers have long recognized the environmental externalities created by industrial processes. As knowledge of the cost inefficiencies accompanying traditional command and control approaches began to evolve, emphasis shifted to more market-oriented approaches (*1*−*3*), such as environmental taxes. The Kyoto Protocol, a product of the third round of negotiations stemming from the United Nations Framework Convention on Climate Change, encourages the use of "measures, which limit or reduce emissions of greenhouse gases ... (Art. 2.1v.)" (*4*). While the environmental economics literature discusses the relative strengths (and weaknesses) of using environmental taxes (*5*), experience with such taxes is limited. Several countries such as Denmark, The Netherlands, Norway, Sweden, and the United States have introduced environmental taxes on energy, air (particularly carbon) emissions, waste, and/or water. Other countries and the European Union have expressed interest in or have introduced other energy-related taxes (*6*−*8*). Some of the implemented taxes have shown success. Denmark's waste tax reduced waste going to landfills and incinerators by 26% and increased recycling rates (*9*). The 1989 tax on chlorofluorocarbons (CFCs) led to a rapid decrease in ozone-depleting substances in the United States (*1*). In Sweden, a fee on nitrogen oxides resulted in a 35% reduction in the year after it was announced (*2*). Finally, a recent study shows that the Swedish carbon dioxide (CO_2) tax has reduced CO_2 emissions (*10*).

Analyzing the relative effectiveness of environmental taxes is fraught with difficulty because multiple objectives often underlie these measures. With environmental taxes, these objectives may include (i) tax-switching to decrease distortionary effects from traditional revenue sources, (ii) internalization of externalities, and (iii) national self-sufficiency (*2*, *3*, *11*, *12*). Concerns from specific industries over tax impacts on competitiveness have also influenced tax levels and exemptions, despite the lack of empirical evidence to support these concerns (*12*−*14*). This paper examines the Swedish experience with environmental taxes within the energy sector in the late 1990s. We focus on how well these taxes correspond to actual environmental costs and the impact these taxes have on fuel and technology choices (objectives ii and iii from above). We seek to understand how well environmental taxes actually perform and thus what role they might play in achieving energy policy goals and objectives.

The Swedish Setting. We choose the Swedish energy sector for analysis because Sweden has a relatively long history with environmental taxes (*15*); the environmental impacts associated with the energy sector in most countries are a dominant factor in the aggregate; and unlike many countries, Sweden does not heavily subsidize coal and oil, making an analysis of its environmental taxes more straightforward (*13*).

Three goals drive Sweden's energy policy. It seeks to scale back CO_2 emissions to 1990 levels; to phase out nuclear energy; and to retain inexpensive supplies of energy. In seeking to decrease reliance on fossil fuels, Sweden has focused on renewable energy sources, especially forest residue biomass. We compare and contrast three fossil fuel choices—coal, oil, and natural gas—with forest residues. We focus on forest residues because they were embraced by many in Sweden as the mechanism for resolving its three-pronged energy dilemma (*16*).

Taxes and Subsidies. Sweden instituted a CO_2 tax in 1991 with the intent of reducing CO_2 emissions in Sweden. While a relatively large tax, industry receives several breaks: it is not levied on electricity production (*17*) and is levied at a reduced rate for other production processes. Biofuels, such as forest residues, are exempt.

The energy tax serves as a partial replacement for revenue formerly obtained from income taxes; it also allows the government to influence national energy choices. The energy tax is higher on oil than other fuel sources, consistent with Sweden's desire to reduce dependence on foreign oil. In 2001, the tax was not levied on fuels used by industry, on electricity production, or on renewable energy sources (*18*). The energy tax is levied on fossil fuel-fired heat production but not on wood fuel sources. Heat production in any CHP facility receives a 50% rebate on the energy tax (*18*).

To combat acid precipitation, the Swedish government instituted a sulfur tax on peat, coal, and oil (*17*). The negligible sulfur content of wood fuels is not taxed. Similarly, Sweden uses a fee on nitrous oxide emissions. As the revenues from the fee are redistributed directly to plants based on plant NO_x emissions, we do not consider the fee in our analysis.

Forest residues receive a competitive advantage over traditional fossil fuels, in nonindustrial settings particularly,

* Corresponding author phone: (919)613-8023; fax: (919)684-8741; e-mail: mmiranda@duke.edu.

† Present address: Gaylord Nelson Institute for Environmental Studies, University of Wisconsin—Madison, Madison, WI 53706.

10.1021/es025637s CCC: $22.00
Published on Web 11/12/2002

TABLE 1. Base Taxes for Energy Production for Nonindustrial Purposes (SEK/MWh$_{fuel}$)[a]

fuel	CO_2 tax	energy tax	sulfur tax	total
coal (0.5% sulfur)	177	39	20	236
heavy fuel oil (0.4% sulfur)	101	69	10	181
natural gas	106	22		128
wood fuels				0

[a] Sources: refs *17* and *18*.

TABLE 2. Energy Production Stages

production stage	forest residues	fossil fuels
Fuel Extraction	wood residue harvest	coal mining oil or gas extraction
Fuel Processing	chipping refinement	refinement
Fuel Transport	truck (short distance) boat or train (long distance)	truck (short distance) boat or train (long distance) pipeline (natural gas)
Combustion	small heating plants large heating plants condensing plants CHP plants	small heating plants large heating plants condensing plants CHP plants
Ash Disposal	monofill reapplication to forest	monofill

as they are exempt from all three taxes. Table 1 summarizes the applicable taxes for energy production categorized by fuel use and converted to Swedish krona (SEK) per megawatt-hour of fuel input (MWh$_{fuel}$).

The Swedish government has also encouraged the development of renewable energy sources through subsidies. In the 1980s, the government subsidized the construction or retrofitting of plants for solid fuel combustion (*19*). Government support increased in the 1990s and provided funds targeted at the development of alternative fuels (*19*, *20*).

Methods

The methods and data used in this paper are derived from a larger study by the authors (*21*), which analyzes production and environmental costs to explore the relative attractiveness of energy production systems in Sweden. A more detailed summary of the methodology and data used in the larger study is found in the Supporting Information section.

This paper compares production and environmental costs for two forms of forest residues (wood chips and refined residues) and three fossil fuels (coal, oil, and natural gas). We estimate across all stages of the energy production cycle (see Table 2). We categorize energy production into four systems typical of the Swedish energy sector: small heating plants (capacity 1−10 MW); large heating plants (capacity greater than 50 MW); condensing plants, which produce electricity; and CHP plants, which produce both heat (hot water or steam) and electricity. Heating and CHP plants also have the option of employing flue gas condensation (FGC) technologies, which take advantage of the large quantities of steam produced when combusting wood chips. This study uses production costs from the 1990s for each system, which are drawn from the Swedish literature and interviews with representatives from Vattenfall, Graninge, and Sydkraft AB in 1997 (*22*, *23*). Fuel costs for wood chips, refined wood fuels, coal, oil, and natural gas are derived from the literature (*17*, *24*−*26*).

We estimate environmental costs by monetizing environmental impacts for each production stage as quantified in the literature and derived from discussions with Swedish experts. Our environmental cost estimates for forest residue fuels do not include costs incurred during the initial timber harvest, as these result regardless of the ultimate use of forest residues. We assume that plants operate conventional technologies with appropriate emissions control technology. We choose the most current and technologically appropriate emissions data. When these data are not available, we use comparable data from similar plants. We assume that ash from forest residue fuel combustion is reapplied to the forest and that ash from fossil-fuel combustion is monofilled. For air emissions, we use marginal damage cost functions (MDCs) from the literature to convert environmental impacts into a common cost metric by multiplying the MDC for a specific pollutant by the total estimated emissions. The MDCs typically estimate the environmental and human health impacts of one unit of pollutant released into the environment and are derived from a series of previous studies (*27*−*32*). We estimate a range of possible costs rather than a point value because of uncertainty surrounding the actual impacts of environmental emissions and different valuation methods as well as to fluctuating fuel prices. Additionally, as the MDCs are not necessarily Sweden-specific, they may only roughly approximate the actual costs due to emissions, further supporting the use of a cost range.

We aggregate production and environmental costs for each system and fuel type in the form of SEK per MWh$_{fuel}$. This allows for a simple aggregation of the various costs but does not consider the differing energy efficiencies involved in the various systems analyzed. While easier to aggregate, these estimates can only be compared across fuel types. For the final analysis, we convert the estimates into SEK per megawatt-hour of energy output (MWh$_{heat}$ and MWh$_{el}$). These figures may be used to compare costs across both fuel and facility types. The efficiencies used for the conversions can be found in the Supporting Information section.

TABLE 3. Comparison of Environmental Taxes and Estimated Environmental Costs (SEK/MWh$_{fuel}$)

fuel	CO_2 tax	CO_2 cost	sulfur tax	sulfur cost	energy tax	total environ. taxes	total environ. costs
wood		0−4		0−2			(8)−107
coal[a]	0−177	11−32	20	1−41	0−39	20−236	17−203
oil[a]	0−106	8−24	10	8−115	0−69	10−181	17−258
natural gas[a]	0−106	6−19		0−1	0−22	0−128	8−52

[a] The tax ranges span from condensing plants, which are exempt from the CO_2 and energy taxes, to heating plants where all three taxes apply.

Results

Comparing Environmental Costs and Taxes. Table 3 compares the Swedish environmental taxes on CO_2, sulfur, and total environmental taxes with estimated environmental costs. The CO_2 tax represents the lion's share of the total environmental tax imposed on fossil fuels, reflecting Sweden's goal of reducing its CO_2 emissions. One could also argue that, in the absence of taxes on all emitted pollutants, CO_2 is the best known and thus carries the greatest public sentiment. Thus, it may constitute a suitable proxy to cover environmental costs in general. The sulfur tax falls in the middle of the range of estimated costs for coal and at the very low end of the range of the estimated costs for oil.

The absence of taxes on wood fuels either does not reflect the true level of environmental costs imposed by wood fuel usage or assumes that actual environmental costs fall at the bottom of the estimated range, which may apply in certain geographic regions, such as southern Sweden. The taxes on oil correspond with the lower two-thirds of the range of

TABLE 4. Comparison between Production Costs + Environmental Costs and Production Costs + Taxes

plant	MWh$_{fuel}$ production costs	MWh$_{fuel}$ environmental costs	MWh$_{fuel}$ taxes	MWh$_{energy\ output}$ production + environmental	MWh$_{energy\ output}$ production + taxes
small heating				MWh$_{heat}$	
wood chips	202–240	(3)–107		229–399	233–276
wood chips w/FGC	201–239	(5)–96		178–305	183–217
refined wood fuels	268–302	(5)–92		302–453	308–347
coal	170–189	24–208	236	223–451	467–489
oil	82–118	30–261	181	125–417	292–332
natural gas	96–113	8–52	128	113–176	244–262
large heating					
wood chips	154–191	(6)–64		172–297	179–223
wood chips w/FGC	170–220	(8)–62		148–256	155–200
refined wood fuels	220–253	(8)–58		246–361	255–294
coal	110–151	24–208	236	149–411	385–450
oil	75–112	30–261	181	117–421	289–333
natural gas	86–103	8–52	128	105–169	238–257
condensing				MWh$_{electricity}$	
wood chips	193–232	(7)–46		413–660	429–551
refined wood fuels	259–293	(8)–41		558–795	576–697
coal	139–170	17–208	20	363–932	370–474
oil	129–156	17–261	10	339–1008	323–404
natural gas	130–159	8–52		238–416	224–318
CHP					
wood chips	198–240	(8)–51		426–808	352–529
wood chips w/FGC	208–258	(8)–49		376–713	277–433
refined wood fuels	264–302	(8)–45		733–1149	641–842
coal	163–221	22–208	149	407–1226	731–949
oil	142–189	27–261	99	354–1267	495–651
natural gas	151–183	8–52	48	249–420	307–389
converted plant[a]				MWh$_{heat}$	
refined wood fuels	148–180	(8)–92		162–317	172–210
coal	39–48	24–208	236	70–298	306–330
oil	62–76	30–261	181	103–380	270–292

[a] The figures for converted plants are for heating plants only.

environmental costs—indicating that in certain areas the taxes may be set too low. The relatively high energy tax on oil may reflect Sweden's desire to reduce its dependency on foreign oil and demonstrates how the energy tax can be used to direct national energy policy. The taxes on coal and natural gas extend beyond the upper estimates of environmental costs. The taxes on natural gas are 2–3 times higher than the estimated environmental costs and could potentially dissuade the use of a relatively clean fossil fuel. Electricity production is exempt from the CO_2 tax. Since most of Sweden's electricity comes from nuclear and hydropower, there is little concern about the use of fossil fuels in this sector. Should Sweden proceed with the shutdown of its nuclear-generating capacity, it will need to reevaluate the exemption condensing plants receive.

The preceding analysis reveals two important insights about Swedish energy sector taxes on energy. First, the relative ranking of the tax burden on the fuels *is not* generally consistent with the relative environmental costs. While the relative environmental costs and taxes for natural gas are the lowest, the relative costs and taxes are reversed for coal and oil. This appears to result primarily from the high estimates of the carbon costs of coal and an underestimate of the sulfur costs of oil. Second, the taxes *do not* reflect the level of estimated environmental externalities imposed by the respective fuel sources, especially for wood, coal, and natural gas fuel sources. As such, these taxes may introduce distortions into the Swedish energy market and alter fuel choice decisions.

Effect of Taxes on Production Decisions. We now shift our focus to analyze how the environmental taxes alter production decisions. In practice, companies make their decisions by comparing production costs and taxes across different fuel types. Table 4 summarizes the production and environmental costs involved in energy production as well as the taxes imposed on each type of energy production. The costs for forest residue energy production assume ash reapplication.

For ease of aggregation, we have been calculating costs in terms of MWh$_{fuel}$. To allow for broader comparisons, we now convert the estimates into costs per MWh of heat (MWh$_{heat}$) and/or MWh of electricity (MWh$_{el}$) and present them in the last two columns of Table 4. For heating and condensing plants, this involves a simple conversion from MWh$_{fuel}$ to MWh$_{heat}$ and/or MWh$_{el}$ based on plant data used in the initial calculations. Our calculations do not account for part-load operation, underestimating slightly the actual cost of energy output by using peak, rather than average power yield. However, this applies equally to wood, coal, and oil plants. Gas turbines have lower part load power yields, so these figures are relative underestimates.

The calculation of CHP costs is more complicated since they produce both heat and electricity. To disaggregate the two products and convert from SEK per MWh$_{fuel}$, we credit CHP plants for heat produced. We calculate the credit from the least expensive heat production cost, assuming the market would value the heat at this level. However, the lowest price results from natural gas (94 SEK/MWh$_{fuel}$), which is only available in southwest Sweden. Thus, we use the second lowest price, which derives from oil (105 SEK/MWh$_{fuel}$). We convert and subtract this as a credit from the original SEK/MWh$_{fuel}$ calculated for the CHP plant to determine the residual cost of the fuel input going toward electricity output, based on the ratio of heat to electricity production (the α value) for the facility in question. Using the data from the initial calculations, we then convert the residual cost into SEK per MWh$_{el}$.

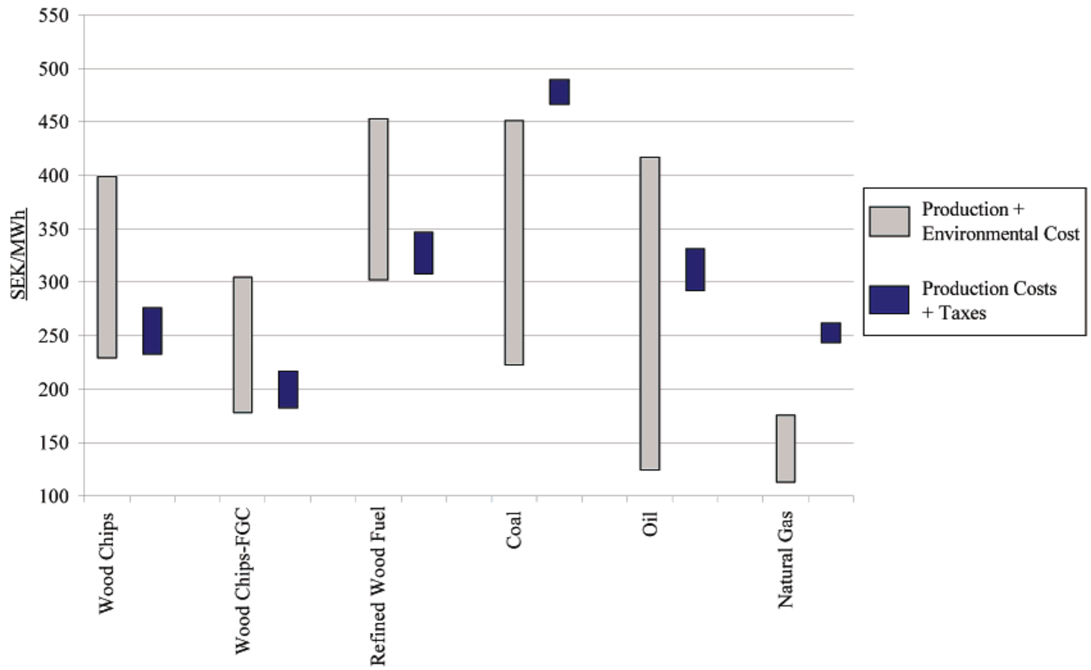

FIGURE 1. Comparing production + environmental costs with production costs + taxes for small heating plants (SEK/MWh$_{heat}$).

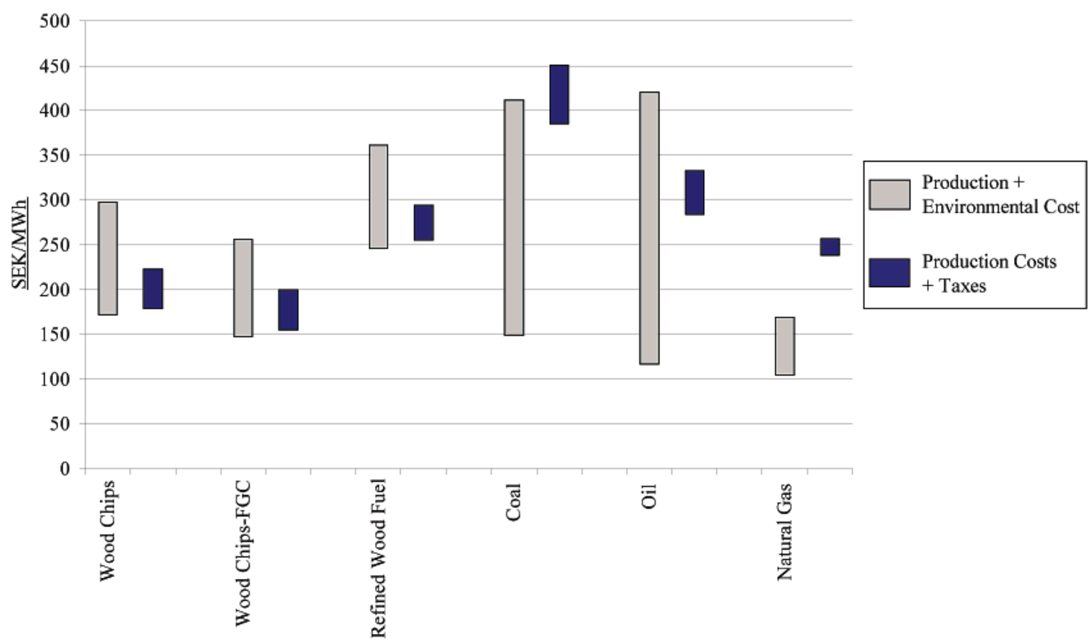

FIGURE 2. Comparing production + environmental costs with production costs + taxes for large heating plants (MWh$_{heat}$).

As is perhaps most clear from Figures 1 and 2, the tax system provides a strong incentive for selecting forest residue fuels over coal, oil, and even natural gas in heating plants. The taxes push the costs faced by companies either beyond or toward the upper total cost value for all fossil fuels, especially so for natural gas. From a company's perspective, wood chips and even very costly refined fuels out-compete coal and oil in heat production facilities. By including taxes, wood chips with FGC out-compete natural gas, and wood chips without FGC are reasonably well-matched against natural gas. Refined fuels, which do not appear as attractive a fuel source based on total cost analysis, become competitive with coal and oil when comparing production costs plus taxes across small and large heating plants. The tax system substantially changes the relative preference held by companies across fuel types. Thus for heat production facilities, the tax system will encourage higher adoption rates of forest residue fuel choices than might otherwise be expected. It is troubling that the taxes make a relatively low cost and clean fuel like natural gas uncompetitive. This effect currently only applies to the areas of southern and western Sweden with access to the natural gas network. However, it may be desirable to extend the natural gas network.

Condensing plants are exempt from the CO_2 and energy taxes despite the significant environmental impacts produced by these facilities. The effect of this policy becomes all the more striking when combined with production costs. Figure 3 demonstrates clearly that the three fossil fuels are much more competitive than forest residue fuels on the basis of production costs plus taxes. This is quite different from the comparative total costs, where natural gas would remain the preferred choice but coal and oil would be comparable with

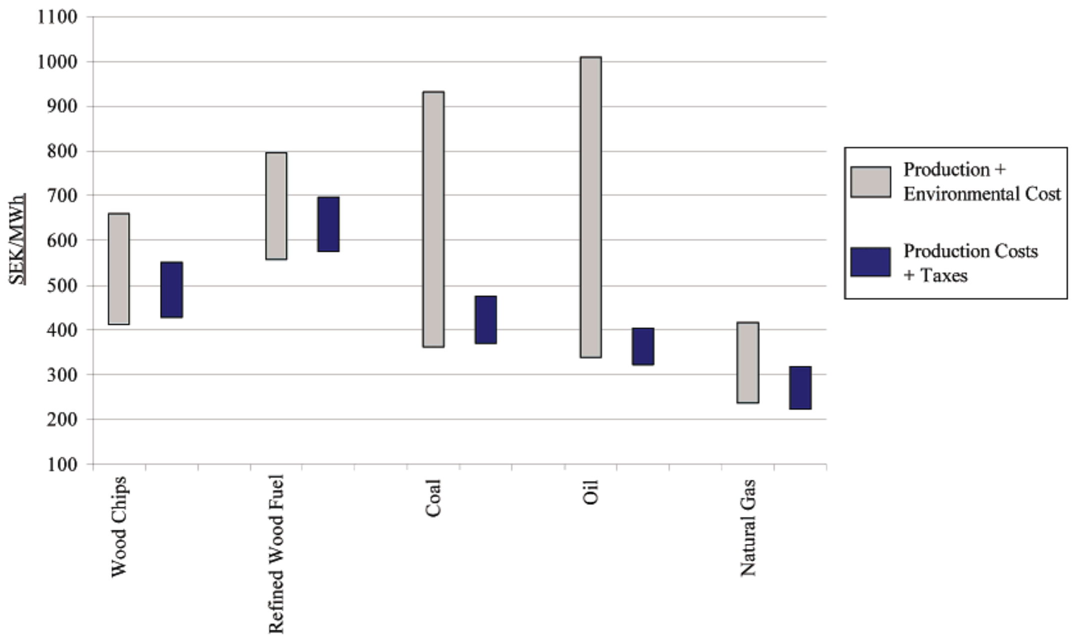

FIGURE 3. Comparing production + environmental costs with production costs + taxes for condensing plants ($MWh_{electricity}$).

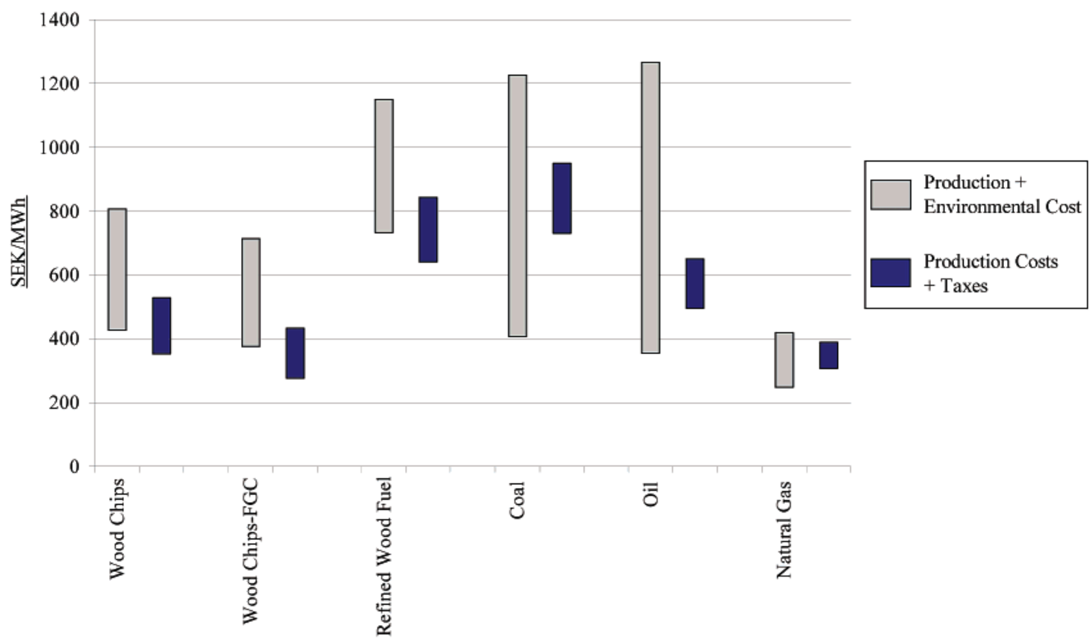

FIGURE 4. Comparing production + environmental costs with production costs + taxes for CHP plants ($MWh_{electricity}$).

wood chips and refined fuels. If and when Sweden replaces the electricity currently supplied by nuclear power, the current tax system (which does not tax electricity production) will support fuels that do not correspond with Sweden's goals to reduce carbon emissions. This is especially clear from our analysis of condensing plants, which only produce electricity.

In CHP facilities, the taxes levied on coal and natural gas put the company cost range in the center of the total cost range (see Figure 4) and toward the lower end of the company cost range for oil. This outcome, which differs from small and large heating plants, results from the energy tax credit these facilities receive. The wood chip and refined fuel taxes are likely too low. Wood chips should out-compete coal and oil on the basis of social cost analysis but should be less competitive than natural gas, which is not currently the case for FGC-equipped combustion facilities. Refined wood fuels should be reasonably competitive with coal, whereas currently companies will likely find the expensive refined fuels a more attractive option than coal.

Refined Fuels. The figures for refined fuels have consistently proven more costly than comparable figures for other fuel sources. Several aspects of these fuels improve their attractiveness, such as suitability for long-distance transport, improved combustion, and better storage potential. Nonetheless, these factors are not sufficient to explain why refined fuels are regularly chosen in Sweden's energy sector. One explanation is the market for converted plants, whose cost structures are different from new plants. The capital costs in a converted plant are sunk. Although some cost may be involved in retrofitting the boilers, a comparison of fuel prices provides a reasonable approximation of the cost differences involved. Converted plants typically cannot burn wood chips for technical reasons.

The decision to use refined fuels is clearly driven by the tax system (see the bottom rows of Table 4 and Figure 5).

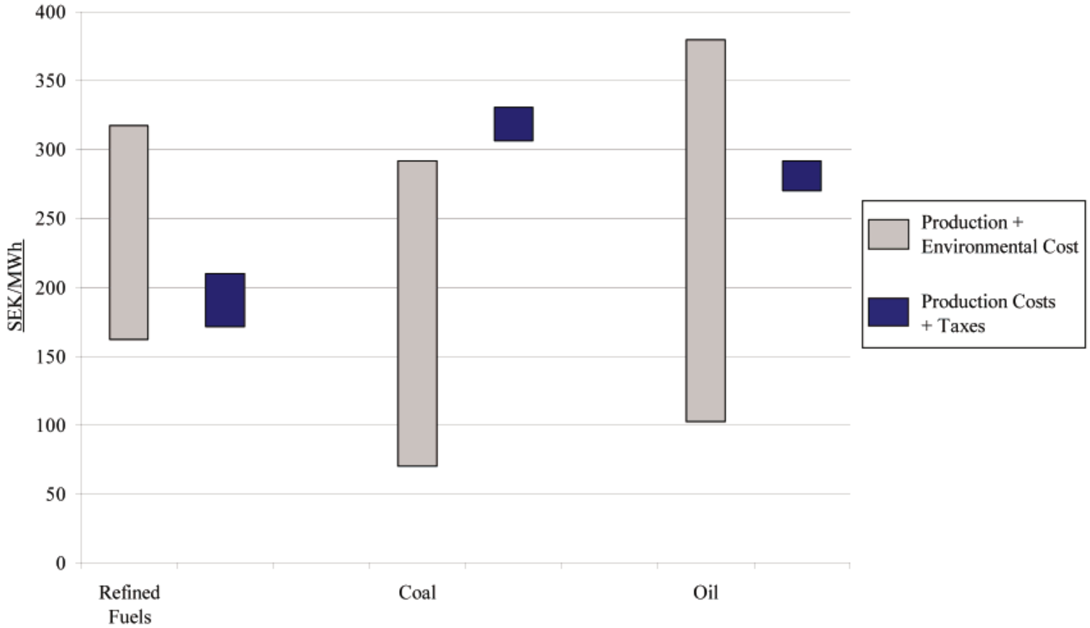

FIGURE 5. Comparing production + environmental costs with production costs + taxes for converted plants (MWh_{heat}).

While total cost analysis indicates that refined fuels should be a generally less attractive option in relation to coal and oil in converted plants, the Swedish tax system creates a powerful incentive to choose refined fuels over the fossil fuel options.

While not incorporated into Table 4, the government subsidies discussed previously will also affect the relative preferences over fuel choices as they encourage companies to choose forest residues more extensively than analysis based on production plus environmental costs suggests they should. This further enhances the attractiveness of wood fuels introduced by the tax system.

Discussion

This paper evaluates Sweden's experience with environmental taxes in the energy sector by (i) examining how environmental taxes compare with estimated environmental externalities associated with the use of oil, coal, natural gas, and forest residue fuels and (ii) analyzing how the environmental taxes influence fuel choices in the energy sector by comparing the production, environmental, and tax costs for the same fuels.

The analysis is complicated by the uncertainty that underlies attempts to monetize costs for all fuel types. As such, caution should be employed in drawing definitive conclusions. Nevertheless, we suggest the following:

(i) Swedish Environmental Taxes Correspond Imperfectly with Environmental Costs. Environmental taxes in Sweden have made renewable fuels, such as forest residues, more attractive and competitive. However, the current tax levels may be encouraging the use of forest residues more ambitiously than our analysis supports. The highest possible level of environmental taxes correspond relatively well to our environmental costs estimates for coal and oil. This means, however, that exemptions received for electricity production and for industrial uses encourage energy production by these fuels at less than socially optimal levels. On the other hand, the taxes on natural gas are about twice the estimated environmental costs. This severely distorts the attractiveness and discourages the use of natural gas, the cleanest of the three fossil fuels. From the perspective of simply internalizing environmental costs, our analysis indicates that forest residue fuels also can carry environmental costs that are not internalized under this system of taxes.

(ii) The Swedish Tax and Subsidy System Introduces Changes in Fuel Choice Decisions. While economic theory advocates making decisions on the basis of total costs, companies generally base their decisions on a combination of production costs and taxes. The tax system for condensing and conventional CHP plants does not dramatically affect the relative ranking of fuel choices. However, the distortions introduced by taxes on converted plants and small and large heating plants dramatically alter fuel choices. This is especially worrisome in that it discourages the use of natural gas. The current tax system will lead to the expansion of forest residue combustion across all production technologies; this tax-induced fuel switching to forest residues will be further encouraged by government subsidies. The current technology for refined wood fuels is characterized by high production costs, which are substantially offset by the tax system.

(iii) Energy Users Are Responding to Incentives Created by the Tax and Subsidy Systems in Ways That Are Consistent with Economic Theory. Since our original study (*21*), trends in the Swedish energy sector have followed our predicted patterns. The district heating sector has seen a large increase in the use of wood fuels, and the use of coal and oil has steeply declined (*19*, *20*, *33*). CHP plants have seen a much less dramatic drop in coal usage, and industrial coal and oil uses have been relatively constant for the past decade (*33*), reflecting the lower levels of taxes on these two sectors. Natural gas use has been relatively stable since 1992 (*33*), probably because of both the limited network and the high tax levels. Given the lower environmental costs associated with natural gas in this study, it may be advantageous for Sweden to improve access to natural gas via an expansion of the natural gas network.

Ekins and Barker (*34*) predict that environmental taxes will result in both improvements in energy use efficiency and development of new technologies. This appears to be the case in Sweden. Shortly after the implementation of this tax system, a report found that FGC is commonplace among new larger scale plants and that many existing plants are retrofitting with FGC (*35*). Bohlin (*19*), Hillring (*20*), and Vehmas et al. (*12*) all surmise that this tax system has increased investment in CHP plants and the district heating system. Further, Bohlin (*19*) attributes the development of refining and extraction technologies to the tax system. The tax system is motivating research and development to improve the attractiveness of refined fuels. In fact, in the mid 1990s, refined fuel prices fell by 25% (*20*), a reflection, at least in part, of improved technology. How energy users are responding to the incentives created by the tax and subsidy system represents a critical area for future research.

(iv) The Swedish Experience with Environmental Taxes and Subsidies Bears Directly on Wider Evaluations of Energy Policy Approaches Internationally. Sweden's experience with environmental taxes demonstrates that it is possible to shape energy choices based on environmental concerns. However, politics also play an important role in determining the level of these taxes and thus the directions of the policy. To the extent that energy users appear to be responding to incentives created by the tax and subsidy systems in predictable ways, policymakers should make sure that taxes and subsidies are evaluated within the larger framework of energy policy goals and objectives. For example, one of the reasons driving Sweden's energy policies has been the desire to decrease reliance on foreign fuel. Although Sweden is rich in forest resources, this industry is open to fuel imports. Ironically, Sweden's import of wood fuels has increased in recent years (*33*). In the district heating sector, imports account for 35−40% of the wood fuel used (*33*). Thus, while the tax system may shift fuel choices, prices ultimately will determine the source of the chosen fuel.

Acknowledgments

We express our gratitude to the following people and organizations for meeting with us during the original study: Ulf Arvidsson and Gunnar Hovsenius of Elforsk; Lars-Erik Axelsson of Skogsindustrierna; Göran Ernstson and Karin Medin of Stockholm Energi; Rolf Edlund of Stora; Erik Larsson of Svenska Fjärrvärme Föreningen; Folke Bohlin and Bo Hektor of Sveriges Lantbruksuniversitet; Thomas Hammar and Christian Lenander of Sydbränsle; Sören Romberg of Södra Skogsenergi; Erik Rensfelt of TPS Termiska Processer; Karin Widegren-Dafgård, Sven-Olov Ericson, Anna Lundborg, and Håkan Lundqvist of Vattenfall; and Jan Johansson and Ulf Johnsson of Växjö Energi. Further, we would like to recognize the contributions of the SNS Energy Reference Group for their valuable insight into this complex issue. Three persons from the Reference Group deserve special attention for their efforts in reviewing the original study: Roland Lövblad of Södra Cell, Marian Radetzki of SNS, and Lars Åstrand. Lars Åstrand also receives our gratitude for his assistance in arranging the field visits in Sweden. We are grateful for financial support from SNS Energy to undertake this study. We also appreciate the helpful comments offered by three anonymous reviewers as well as the editorial staff of this Journal. Finally, we would like to thank Andrew Fritsch, Jacqueline Klug, and Barbara Wyse for able research assistance and Alicia Overstreet for help in manuscript preparation. The views and conclusions presented in this study are those of the authors alone.

Supporting Information Available

Additional data including 8 tables and additional references. This material is available free of charge via the Internet at http://pubs.acs.org.

Literature Cited

(1) Bernow, S.; Costanza, R.; Daly, H.; DeGennaro, R.; Erlandson, D.; Ferris, D.; Hawken, P.; Hoerner, J.; Lancelot, J.; Marx, T.; Norland, D.; Peters, I.; Roodman, D.; Schneider, C.; Shyamsundar, P.; Woodwell, J. *BioScience* **1998**, *48*, 193.
(2) Ekins, P. *Ecol. Econ.* **1999**, *31*, 39.
(3) Svendsen, G. D. C. H. L.; Pedersen, A. *Energy Policy* **2001**, *29*, 489.
(4) United Nations Framework Convention on Climate Change. Kyoto Protocol to the United Nations Framework Convention on Climate Change, 2001.
(5) Baumol, W.; Oates, W. *Swed. J. Econ.* **1971**, 42.
(6) Bund für Natur- und Umweltschutz Deutschland. http://www.oeko-steuer.de (accessed July 2, 2001).
(7) Herber, B.; Raga, J. *Am. J. Econ. Sociol.* **1995**, *54*, 257.
(8) Nakata, T.; Lamont, A. *Energy Policy* **2001**, *29*, 159.
(9) Andersen, M. S. http://www.iisd.ca/linkages/consume/skou-.html (accessed February 24, 2002).
(10) Swedish Energy Agency. *The Climate Report 2001. Executive Summary*; Swedish Energy Agency: Stockholm, 2002.
(11) Althammer, W.; Buchholz, W. *Jahrb. Nationaloekonomie Stat.* **1999**, *219*, 257.
(12) Vehmas, J.; Kaivo-Oja, J.; Luukkanen, J.; Malaska, P. *Energy Policy* **1999**, *27*, 343.
(13) Ekins, P.; Speck, S. *Environ. Resour. Econ.* **1999**, *34*, 369.
(14) Chapman, T. *Chem. Ind.* **1999**, 85.
(15) Bosquet, B. *Ecol. Econ.* **2000**, *34*, 19.
(16) Åberg, C. *Energy Policy* **1997**, *25*, 635.
(17) Swedish Energy Agency. *Energiläget*; Swedish Energy Agency: Stockholm, 2000.
(18) SVEBIO. http://www.svebio.se (accessed January 3, 2001).
(19) Bohlin, F. *Biomass Bioenergy* **1998**, *15*, 283.
(20) Hillring, B. *Biomass Bioenergy* **1999**, *17*, 445.
(21) Miranda, M.; Hale, B. *Using the forests for the trees: production and environmental costs of producing energy from forest residues in Sweden*; Studieförbundet Samhälle och Näringsliv: Stockholm, 1998.
(22) Gustavsson, L.; Börjesson, P.; Johansson, B.; Svenningsson, P. *Energy* **1995**, *20*, 1097.
(23) Aleberg, A.; Litzén, K.; Schwartz, J. *Kostnader för vissa typer av el- och värmeproduktionsanläggningar (costs for certain types of electricity and heat production facilities)*; ALSA Kraft Värme Konsult AB: Bromma, Sweden, 1995.
(24) Energy Information Administration. http://www.eia.doe.gov/emeu/international/ngasprii.htm (accessed January 2001).
(25) Swedish Energy Agency. http://www.stem.se (accessed June 2000).
(26) Swedish Petroleum Institute. http://www.spi.se/olje/arsmedel_uppvarmning.htm (accessed June 2000).
(27) Josselyn, E. Master's Thesis, Colorado School of Mines, 1993.
(28) Fritsche, U. In *External environmental costs of electric power*; Ottinger, R., Ed.; Springer-Verlag: New York, 1991.
(29) Chernick, P.; Caverhill, E. *The valuation of externalities from energy production, delivery, and use*; PLC: Boston, 1989.
(30) Burrington, S. H. In *External environmental costs of electric power*; Ottinger, R., Ed.; Springer-Verlag: New York, 1991.
(31) Bernow, S.; Biewald, B.; Marron, D. *Electr. J.* **1991**, 20.
(32) Pearce, D.; Cline, R.; Pachauri, S.; Fankhauser, S.; Tol, R.; Vellinga, P. In *Climate change 1995: economics and social dimensions of climate change*; Bruce, J. P., Lee, H., Haites, E. F., Eds.; Cambridge University Press: New York, 1996; p 179.
(33) Swedish Energy Agency. *Energiläget*; Swedish Energy Agency: Stockholm, 2001.
(34) Ekins, P.; Barker, T. *J. Econ. Surv.* **2001**, *15*, 325.
(35) SOU. *Biobränslen för framtiden (Biofuels for the future)*; Jordbruksdepartement: Stockholm, 1992.

Received for review March 8, 2002. Revised manuscript received September 16, 2002. Accepted September 26, 2002.

ES025637S