Environmental Tax Reform: Principles from Theory and Practice to Date

Ian W.H. Parry*, John Norregaard, and Dirk Heine

Fiscal Affairs Department, International Monetary Fund

*Corresponding author. Email: iparry@imf.org.

1. Introduction

For most environmental problems well-designed fiscal policies are the most natural instruments for reflecting environmental damages into the price of products and non-market activities (like driving).

Taxes that are, at least in part, justified on environmental grounds have long been a significant source of government revenue—environmental tax revenues (primarily taxes on motor fuels and vehicles) constitute around 3 to 10 percent of total tax revenues in typical OECD countries (Figure 1). The Nordic countries were the first to adopt the concept of environmental tax reform—broadly speaking, the re-structuring of the tax system to more effectively promote environmental objectives—during the early 1990s. The reform movement spread fairly quickly to other countries like the Netherlands, United Kingdom, and Germany and is now under serious consideration in emerging and developing countries, such as China, Vietnam, Cambodia, South Africa, Thailand, and Tunisia.

Moreover, several factors point to continued momentum for environmental tax reform. One is pressure for new revenues for fiscal consolidation. Another is growing acceptance among some policymakers that emissions pricing instruments are far more effective at exploiting the entire range of emissions reduction opportunities than regulatory approaches (e.g., EC 2007, TemaNord 2011a). And environmental problems are of growing concern, from rising greenhouse gas concentrations to deteriorating urban air quality in industrializing nations, and increasing congestion (a related externality) of transportation systems.

The analytical and empirical literature provides insights on the design of environmental taxes with regard to the efficient tax level (and adjustment over time), tax base, and revenue use, accounting for potential complications like multiple externalities, pre-existing policies and other 'distortions', and linkages with the broader fiscal system. In practice, gauging efficient tax levels is challenging, given limited local evidence on environmental damages. Moreover, distributional, competitiveness, and revenue considerations may complicate policy design.

This paper has two objectives. First is to review core principles from the literature on environmental tax design.[1] Second (which is less common in the literature) is to take a look—

[1] For other discussions that cover some of the same issues see, for example, Bovenberg and Goulder (2002), Fullerton et al. (2008), and Metcalf (2009).

albeit a very quick one—at how these principles might be applied in practice.[2] We consider (briefly) a diverse mix of countries, including Sweden (a pioneer of environmental taxes), Germany (where earlier environmental tax reforms have lost momentum), Turkey (where environmental tax revenues are atypically high—see Figure 1) and Vietnam (where environmental taxes are introduced into a heavily distorted, low-income economy). For each country, appropriate taxes to internalize CO_2, local air pollution (SO_2 and NO_x), and broader externalities in transportation, are considered.[3]

While, to varying degrees, improvements have been made in these countries, and revenues from environmental taxes appear to have been used productively, there is plenty of scope for further tax reform. Although common in practice, taxes on vehicle ownership and electricity consumption are redundant from an environmental perspective if more finely-tuned instruments are employed (though they could have some rationale on fiscal grounds in countries where broader taxes are easier to evade). Moreover, effective tax rates sometimes vary substantially across different emissions sources, and rates can be out of line with our, admittedly, 'back-of-the-envelope' calculations for externalities. To simplify and better target externalities for all four countries, we would recommend defining separate charges for each pollutant, and levying these charges upstream on fossil fuels, according to their emissions content (with refunds for downstream emissions capture at industrial and generation plants). And transportation taxes should be progressively re-structured as capability is developed for charging by the mile (to better target congestion). Refining these recommendations in the future will require a lot more work on the quantification of local externalities, however.

The next section reviews general principles for environmental tax design. Section 3 provides our country assessment. Section 4 offers concluding remarks.

2. Principles of Environmental Tax Design

Here we start with the Pigouvian framework and then consider a wide range of potentially complicating factors. We do not linger on the case for environmental taxes over other policy instruments as the issues have been reviewed extensively elsewhere.[4]

---

[2] For other assessments of environmental tax reforms see, for example, Sterner (2002) and Schlegelmilch (1999).

[3] For some discussion of environmental taxes in other contexts see, for example, Fullerton (2005) on household waste, Boyd (2003) on water pollution taxes, and Sigman (2003) on hazardous waste charges. More generally of course, there is a huge literature on natural resource taxation for externality and revenue purposes (e.g., Fisher 1981 and Daniel et al. 2010).

[4] See for example, Goulder and Parry (2008), Hepburn (2006), Krupnick et al. (2010), and Nordhaus (2007). Basically, market-based instruments (emissions taxes and emissions trading systems) exploit all emissions reduction opportunities as the emissions price is reflected in the price of intermediate and final goods across the economy. In contrast, regulatory approaches (e.g., energy efficiency standards, renewable fuel mandates) focus on a much narrower range of reduction opportunities. Combining (complementary) regulations can be more effective though some behavioral responses (e.g., inducing people to use their cars or air conditioners less) are always difficult to regulate. Market-based instruments are also cost effective in the sense that a uniform emissions price equates incremental abatement costs across firms, households, and sectors (e.g., Dales 1968, Kneese and Bower 1968, Montgomery 1972). In the absence of fluid credit trading markets, regulatory policies imposing uniform standards

A. Tax Design in a (Hypothetical) Economy with a Single Externality Distortion

According to the traditional Pigouvian framework (Pigou 1920), environmental taxes should equal marginal damages and be levied directly on the source of emissions. The framework has little to say about appropriate revenue use, as it leaves aside other sources of distortion in the economy so there is no scope for efficiency-enhancing revenue recycling.

Corrective tax. A tax equal to marginal damages induces the efficient level of emissions reduction, indicated by E^* in Figure 2, where the marginal benefit (or avoided incremental environmental damage) equals marginal abatement costs (ignore the steeper curve for now). This framework applies to both flow pollutants and stock pollutants: in the case of CO_2, for example, the marginal damage is the present value of future (worldwide) damages (broadly defined) from an extra ton of emissions, accounting for the gradual uptake of CO_2 from the oceans and gradual adjustment of temperatures to higher concentrations (e.g., Nordhaus 1994).

With a flat marginal benefit curve, the Pigouvian tax is independent of the emission reduction. This seems a reasonable first-pass approximation for major air pollutants, where the predominant damage is mortality risk to vulnerable populations, and the incidence of fatalities seems to increase roughly in proportion with ambient pollution concentrations.[5] As for CO_2, the marginal benefit curve for one country in one year is essentially flat, given that future climate sensitivity depends on global emissions since the industrial era (and taking the probability of tipping points as continuous in atmospheric accumulations).

The welfare gains from the corrective tax are shown by the shaded triangle in Figure 2. Note that, even if the tax is set at, say, 50 percent above or 50 percent below marginal damages, a large portion (roughly three quarters) of the welfare gains from the true corrective tax are still achieved. Or put another way, given inherent imprecision in externality measurement (see below) an observed tax that is 50 percent above or 50 percent below estimated marginal damages may still perform fairly reasonably in terms of expected welfare gains, hence we should not be overly concerned about fine tuning taxes to estimated marginal damages.

Externality measurement. Even for the United States, where there has been a large body of multi-disciplinary modeling, considerable uncertainty remains over the exact quantification of local pollution damages (see Box 1). In part, this reflects controversy over the value of a statistical life (VSL) to monetize pollution-fatality effects.

---

across firms can cause a considerable loss of cost effectiveness when there is substantial heterogeneity in firm abatement costs (e.g., Newell and Stavins 2003, Tietenberg 2006). Current thinking on the choice between emissions taxes and emissions trading systems is that this is less important than implementing one of them, and getting the design details right—that is, covering all emissions sources, raising revenue and using it efficiently and, for emissions trading systems, including provisions to limit price volatility.

[5] According to some recent modeling, mortality risk might actually be concave, rather than linear, in pollution concentrations, implying some modest upward slope to the marginal benefit curve (e.g., Pope et al. 2004, 2006).

In addition however, damages vary across space with local population exposure and natural factors affecting pollution dispersion. In principle firms could be charged different taxes according to their location, or where their emissions are transported to (e.g., Baumol and Oates 1988, Montgomery 1972). However, this could be administratively complex, and in any case welfare gains from imposing a (second-best) uniform price on emissions appear to be far greater than the additional welfare gains from optimally differentiating emissions prices by region (Muller and Mendelsohn 2009). Hence our discussion focuses on uniform taxes.

For the countries we study, local evidence on pollution damages is limited, if available at all. 'Placeholder' environmental damages for these countries might be crudely extrapolated from US (or other country) studies, though it may still be possible to draw qualitative policy insights.

Tax adjustment. Corrective taxes should be adjusted over time in line with growth in marginal environmental damages. For example, the value of pollution-health effects should be adjusted for the VSL, which rises with growth in income (depending on the income elasticity of the VSL). For climate change, marginal damages from CO_2 emissions rise over time, approximately with growth in the size of (world) GDP potentially at risk (e.g., US IAWG 2010).

Tax Base. The (flatter) marginal cost curve in Figure 2 arises through the horizontal summation of a set of (steeper) marginal cost schedules reflecting the costs of individual behavioral responses to reduce emissions. A tax levied on a proxy for emissions will exploit a narrower range of these reduction opportunities than would be achieved under the direct targeting of externalities (e.g., Sandmo 1976). The corresponding marginal cost schedule under a 'proxy' tax would therefore be steeper (see Figure 2). Under constant marginal benefits, the optimal (implicit) tax would be unaffected. But the emissions reduction, and welfare gain from the proxy tax, is smaller than under the emissions tax, perhaps dramatically so. With linear marginal costs, if the proxy tax induces a fraction z of the emissions reductions that would be forthcoming under the emissions tax (in either case with taxes set to internalize environmental damages), welfare gains would also be that fraction z of those under the emissions tax.

For example, suppose (based on Krupnick et al. 2010, Figure 6.2a) that under a comprehensive carbon tax, 25 percent of the energy-related CO_2 reductions would come from reduced electricity demand and 75 percent from other sources (switching towards cleaner generation fuels, reducing demand for transportation fuels, etc.). Excise taxes on electricity consumption—which have become quite prevalent in developed countries[6]—might then sacrifice around three quarters of the welfare gains from carbon taxes.

Another important example of efficiency losses due to proxies is vehicle ownership taxes (e.g., excise taxes, registration fees, annual road taxes). These taxes are a weak proxy for taxing CO_2 emissions from motor fuels (leave aside, for a moment, the possibility that they vary with engine size or CO_2 per mile). Suppose (based on Fischer et al. 2007) that 15 percent of the CO_2 emissions reduction from a fuel tax came from a reduction in the demand for vehicles and the other 85 percent from reductions in miles driven per vehicle and longer-run, fuel-economy

[6] For example, the European Union Energy Directive 2003/96/EC imposes minimum excise tax rates on electricity.

improvements. Then vehicle ownership taxes would reduce emissions by only 15 percent of the reductions induced by (equivalently-scaled) fuel taxes.

In the ideal Pigouvian framework, all emissions would be directly priced at marginal damages and there would be no proxy taxes (on electricity, vehicle ownership, etc.).[7]

A related issue: pricing covered emissions at the same rate. Not only should all emissions sources be priced, but they should also be priced at the same rate.

In this regard, using multiple pricing instruments, for example an emissions trading system for some sources and a tax for others, is inefficient, unless policies are harmonized. And taxes should vary in proportion to emissions, avoiding 'notches', like those for vehicles related to CO_2 per km (see Box 2).

Administrative complications. Administrative costs raise important policy design issues.

First, if marginal administration costs are rising as more diffuse emissions sources are brought under the tax, there is a trade-off between emissions coverage and administrative feasibility (Metcalf and Weisbach 2009). Take the example of taxing non-CO_2 greenhouse gases (GHGs) and CO_2 emissions beyond the energy sector (fossil fuel emissions are relatively straightforward to administer through taxes on the carbon content of fuels). Some sources of non-CO_2 GHGs can be monitored and taxed (e.g., vented methane from underground coalmines, fluorinated gases in air conditioners/refrigerants). But other sources might be better incorporated through offsets where the onus is on the individual entity to demonstrate valid reductions (e.g., capture of methane from livestock waste in airtight tanks or covered lagoons). In principle, forest carbon sequestration projects can be integrated into domestic tax regimes, through emissions offset provisions, but only in cases where carbon benefits can be reasonably measured (e.g., Macauley and Sedjo 2011).

A second (and less appreciated) point is that minimizing administration costs implies environmental taxes should be levied upstream to limit the number of collection points. For instance, in the EU Emissions Trading System (ETS), pricing the carbon content of fuels further upstream in the energy supply chain—rather than pricing emissions from the smokestack—would increase emissions coverage and lower administrative costs. Such schemes can be complemented with downstream crediting as viable technologies for disposing of emissions during fuel combustion emerge, or if embodied carbon in final products is never released (e.g., oil lubricants, tarmac). Similarly, a tax on the SO_2 and NO_x content of fuels could be imposed upstream with downstream crediting for emissions 'scrubbed' by flue gas filter technologies.[8] Alternatively such downstream technologies could be mandated, though at the possible risk of imposing excessive costs if this is uneconomic for some firms.

---

[7] In this setting proxy taxes are welfare reducing. Although they would further reduce emissions, this would not produce an efficiency gain with the externality already fully internalized.

[8] That is, a power plant or manufacturing firm that demonstrated (through continuous emissions monitoring technologies) that their emissions out of the smokestack are less than the embodied emissions in their fuel inputs could claim a credit equal to the difference in emissions times the (upstream) emissions price.

Another example is vehicle tailpipe emissions where individual sources of local pollution are far too numerous to be taxed directly. In this case, an upstream fuel tax (to encourage better fuel economy and reduce vehicle miles traveled) coupled with emissions regulations on vehicles (to encourage installation of abatement technologies) may approximately mimic the effects of a direct tax on emissions (e.g., Eskeland 1994).

B. Multiple Externality Situations

Multiple externality problems—most notably in transportation—have implications for environmental tax design. Here we first discuss the appropriate level of fuel taxes, assuming they are the only available fiscal instrument, and then briefly note more precisely-targeted taxes.

Motor fuel taxes (for passenger vehicles). We focus on fuel taxes for passenger vehicles.[9] There are four main externalities associated with the use of passenger vehicles and their fuels.[10]

First is CO_2 emissions, which are proportional to fuel combustion (leaving aside blending from biofuels). Here the appropriate fuel tax would equal the CO_2 produced per unit of fuel combustion times the marginal damage from CO_2 emissions.

Second, fuel taxes reduce local pollution emissions, but by less than in proportion to the fuel reduction. Emissions fall as people drive less in response to higher fuel prices. However, at least in countries imposing the same binding emissions per mile standards on all vehicles (irrespective of their fuel economy), to an approximation emissions are not affected by long run, fuel economy improvements. In assessing corrective fuel taxes, pollution damage estimates therefore need to be scaled by the fraction of the fuel reduction that comes from reduced driving (as opposed to better fuel economy).

Furthermore, tax-induced reductions in vehicle miles driven will also reduce traffic congestion and accidents. In computing corrective taxes, congestion and accident externalities obtained on a per km basis need to be expressed per unit of fuel (i.e., multiplied by fuel economy), and then (as for local pollution) scaled back by the fraction of the incremental, tax-induced fuel reduction that comes from reduced driving.

Better Instruments for Vehicle Externalities. But there are much better fiscal instruments for addressing motor vehicle externalities than fuel taxes (e.g., TRB 2006, Parry et al. 2007).

[9] At least for the United States, corrective fuel tax estimates for fuels powering both passenger vehicles and heavy trucks seem to be in the same ballpark, even though the nature and size of individual externalities varies across these vehicles (e.g., Parry 2011).

[10] The discussion here draws on the corrective fuel tax formula derived in Parry and Small (2005). There are a range of other possible externalities that are ignored here either because they are difficult to define (e.g., energy security implications of oil dependence) or appear to be relatively small for passenger vehicles (e.g., noise, road wear and tear). For more discussion of motor vehicle externalities see, for example, de Borger and Proost (2001), Delucchi (2000), FHWA (1997), Quinet (2004), Maibach et al. (2007).

Besides complementary policies (like road upgrades to improve traffic flow and to reduce collision risk) traffic congestion should be reduced through (electronically-collected) per mile tolls on congested roads that rise and fall during the course of the rush hour, while accident externalities are best addressed through mileage tolls, ideally adjusted for driver and vehicle crash risk. These broader instruments are beyond our scope, but note that the corrective fuel tax would be reduced considerably with their introduction.

C. Other Pre-Existing Distortions

This subsection discusses implications of market power, energy subsidies, pre-existing regulations, and broader fiscal distortions. Distortions in technology markets and appropriate treatment of energy under the VAT are discussed in Boxes 3 and 4 respectively, but are not considered in our country evaluation (the former calls for supplementary instruments while there are no glaring problems with VAT systems in regard to energy).

Institutional distortions. In principle, the optimal tax on emissions differs from marginal environmental damages when the tax leads to a reduction in the output of a product that differs from its efficient level for non-environmental reasons.

One possibility is that output is already sub-optimal because of market power. The implied downward adjustment in the optimal environmental tax may often be of little practical relevance, however (Oates and Strassmann 1984). One reason is that, at least for some countries studied below, energy markets exhibit a fair, or growing, degree of competition. Another is that the distortions created by market power (expressed relative to marginal supply costs) are not always large. Furthermore, if most of the behavioral response from emissions pricing comes from reducing emissions intensity through substituting cleaner inputs or adoption of end-of-pipe abatement technologies rather than reducing the overall level of output (which tends to be true of the power sector), then the compounding of market power distortions will again be limited.

Another distortion is pre-existing price controls, or other subsidies, that may exacerbate excessive production in polluting industries.[11] While removing the subsidy and then internalizing environmental externalities through tax instruments is usually the most efficient response, if the subsidy is likely to be durable, then setting a higher environmental tax to partly offset it might be warranted on second-best grounds.

Pre-existing regulations. Unlike vehicle emissions standards, pre-existing regulations do not always affect tax design. For example, if regulations on emissions per kWh, or automobile fuel economy, remain binding, this eliminates some of the potential behavioral responses from emissions or fuel taxes, but it does not affect the optimal level of these taxes (e.g. Parry et al. 2010).[12]

[11] Even in developed countries, energy subsidies are still substantial, amounting to approximately $50 billion a year (e.g., Coady et al. 2010, OECD 2011).

[12] In terms of Figure 1, these regulations steepen the marginal abatement cost curve, but do not affect the marginal benefit curve and hence the corrective tax.

Broader Tax Distortions. The broader fiscal system causes important sources of distortion elsewhere in the economy which can have implications for environmental tax design.

Taxes on labor income (e.g., personal income and payroll taxes) reduce work effort below levels that would maximize economic efficiency (e.g., by reducing participation rates among secondary workers, or effort on the job). General consumption taxes like the VAT have the same effect as they also lower the real returns to work effort. And taxes on savings and investment similarly reduce capital accumulation below economically efficient levels. Environmental taxes interact with these sources of distortion in two opposing ways (e.g., Goulder et al. 1999).

First, using environmental tax revenues to reduce broader tax distortions (either directly or indirectly through deficit reduction if this obviates the need to raise income taxes) produces gains in economic efficiency, which can be large, relative to those from reducing the externality itself. Second, however, as environmental taxes are passed forward into the prices of fuels, electricity, and so on, this increases the general price level. In turn, this reduces real household wages and the real return on capital, which lowers labor supply and capital accumulation over the longer term in the same way that a direct tax on wages and savings/investment income does.

The general finding in the theoretical literature is that (with some qualifications) the net impact from shifting taxes off income and onto emissions is to increase the costs of pre-existing taxes, that is, the gains from recycling revenues are more than offset by efficiency losses in factor markets from higher energy prices. Consequently, the optimal tax is below the marginal external damage, but only moderately so, implying that the Pigouvian tax is still a reasonable, rough approximation.[13] There are some exceptions to this finding—for example, net employment effects can be positive if taxes are shifted onto a product that is a relatively weak substitute for leisure, or if externality mitigation raises the marginal value of work time relative to leisure time, though these special exceptions do not seem applicable for the cases studied below.[14] In general therefore, taxes on fuels and energy products need to be justified on environmental grounds.

The most important point here, however, is the importance of revenue recycling. If emissions tax revenues are not used to increase economic efficiency through cutting distortionary taxes (or funding socially desirable spending), the net benefits from emissions taxes is greatly reduced (e.g., Fullerton and Metcalf 2001, Goulder et al. 1999, Crampton and Kerr 2002, Hepburn et al. 2006). In fact, the case for using environmental taxes on cost effectiveness grounds over regulatory approaches (e.g., emissions standards) can then be substantially undermined (e.g., Goulder et al 1999). Environmental taxes tend to have a bigger impact on energy prices than regulatory policies (because the former involve the pass through of tax

[13] In fact, Jacobs and de Mooij (2011) find that (under certain circumstances) the Pigouvian tax is the optimal tax even in a distorted tax system if the government optimally trades off its efficiency and distributional effects.

[14] For further discussion of these issues see, for example, Bovenberg and de Mooij (1994), Bovenberg and Goulder (1996, 2002), Parry (1998). The above discussion assumes long-run, competitive equilibrium in the labor market. In the shorter term, employment effects may be more opaque with temporary disequilibria (e.g., Bosquest 2000).

revenue into prices) and the revenue-recycling benefit is needed to offset the effect of these greater energy price increases on exacerbating factor tax distortions.

Earmarking. One important implication from this is a potential red flag for schemes to earmark environmental tax revenues, for example, on environmentally-related public projects. Ideally, earmarking would be limited to cases where spending generates comparable efficiency gains to those from using the revenues for cutting distortionary taxes (e.g., Bird and Jun 2005). Furthermore, with earmarked revenues, there has been an observed tendency to set tax levels to meet revenue needs, which may imply tax rates well below levels needed to correct for externalities (e.g., Opschoor and Vos 1989).[15]

One possible exception is when revenues are 'earmarked' in the form of production subsidies for firms affected by the environmental tax. The usual idea here is to improve acceptability by limiting the overall impacts on product prices. This approach need not sacrifice too much in the way of effectiveness and cost effectiveness, at least if the bulk of low-cost emissions reductions are from reducing emissions intensity rather than reducing the scale of output (e.g., Bernard et al. 2007).

Revisiting the case for vehicle and electricity taxes. Finally, although we have critiqued the use of taxes on electricity consumption and vehicle ownership on environmental grounds, these taxes can make sense on fiscal grounds in countries where revenues from the broader tax system are limited by exemptions, lack of coverage, and easy evasion. In this case, some taxation of widely consumed goods can be efficient as part of the overall tax system, though ideally these taxes target bases that are inelastic, which is usually at odds with targeting taxes on emissions to maximize environmental impacts (e.g., IMF 2011a).

D. Some Practical Concerns: Distribution and Competitiveness

Environmental taxes are sometimes at odds with distributional objectives, at least in developed countries where lower income households tend to have disproportionately large budget shares for energy goods (e.g., Metcalf 2009).

Distributional effects might be taken into account by estimating environmental taxes from models distinguishing different income groups, with social welfare weights applied to those groups (e.g., Cremer et al. 1998, 2003, Mayeres and Proost 2001). However the choice of weights is disputed.[16]

[15] A practical caveat here however, is that earmarking may create political pressure for sustaining the environmental tax and improving its initial credibility (Brett and Keen 2000).

[16] They might be inferred from observed distributional/efficiency trade-offs in other government decisions (e.g., Gruber and Saez 2002, UK Treasury 2011). However, these estimates may be an unreliable indicator of society's true preferences to the extent that tax rates are driven by interest group competition and political ideology rather than benevolent government optimization.

Another possibility is to scale back other energy taxes at the time new environmental taxes are introduced, to limit the overall impacts on energy prices. As already noted, with adequate taxation of fuels and emissions, excise taxes on electricity use and vehicle ownership become redundant and can be reduced to limit overall burdens on consumers and motorists. Another possibility is to make off-setting (progressive) adjustments to the broader fiscal system—for example in Australia's prospective carbon pricing system revenues obtained from allowance auctions will be used to finance a reduction in the personal income tax threshold to ameliorate effects on low-income households.

Environmental taxes also raise concerns about competitiveness, through the impacts of higher energy prices on energy-intensive firms competing in global markets for, say, aluminum, cement and steel. These issues are less of a concern if environmental taxes are harmonized across countries, which makes sense for a global pollutant like CO_2 but not when pollution is localized and marginal damages vary by country (e.g., Oates 2002). Competitiveness concerns might be addressed through temporary tax reliefs to affected industries, though this introduces distortions, and there is a danger of such reliefs becoming permanent. Another possibility is border tax adjustments, though these are complex to design.[17] Again, the first step should be to remove any redundant taxes (e.g., on electricity) to neutralize effects on energy prices.

3. Environmental Tax Systems and Reforms: the Case of Germany, Sweden, Turkey, and Vietnam

This section begins with some very brief background on the energy systems in the countries we study. We then provide some, admittedly very crude, sense of the appropriate structure of taxes based on illustrative values for externalities. Next we discuss the evolution of environmental/energy tax systems and to what extent current practice conforms to our basic design principles. We provide only a partial documentation of data sources—see Heine et al. (2011) for the complete documentation.

A. Comparison of Energy Systems

The diversity with regard to the structures of present energy systems is apparent from Figures 3 and 4 which show, respectively, the current mix of fuels in power generation and final energy consumption.

As regards power generation, Sweden stands out as it does not rely on fossil fuels—almost half of electricity is now produced by hydro, almost 40 percent by nuclear, and 9 percent from biofuel boilers.[18]

[17] In principle a tax needs to be applied to all goods from all countries that sell products to the domestic economy. Moreover, the marginal fuel source for electricity generation used in making products is sometimes opaque and border adjustments may also run afoul of international trade obligations. For some discussion of how these challenges might be overcome see, for example, Hilbert and Berg (2009).

[18] Oil-fired generation was phased out following the 1973/4 oil price shock. In 1980 construction of new nuclear plants was banned, though this ban was lifted in 2011. At any rate, existing plants could be operational for several decades.

Germany currently relies on coal for about 45 percent of its electricity generation, with the remainder mostly split between natural gas (14 percent), nuclear (23 percent), and renewables (18 percent). About half of the coal is lignite, produced domestically, and the remainder is hard coal, two-thirds of which is currently imported (Eurostat 2011).[19] With plans to phase out nuclear by 2022 (AtG 2011), the fuel mix in Germany is set to change significantly, with much of the generation gap made up by further expansion of renewables, both from domestic and imported sources.[20]

Given their large upfront costs, nuclear plants have not been constructed in Turkey and Vietnam, hence their reliance on fossil fuels—primarily natural gas, but also coal and small amounts of oil (Figure 3). Hydro power is also important however, accounting for 36 percent of generation in Vietnam and 19 percent in Turkey.

About 35-45 percent of overall energy consumption comes from oil in Germany, Sweden, and Turkey, though somewhat less (28 percent) in Vietnam (Figure 4), where car ownership rates are low. In Vietnam, there are 13 passenger vehicles per 1000 people in 2010, compared with 131 in Turkey, 523 in Sweden, and 623 in Germany (World Bank 2011a). Road transport accounts for around 45-65 percent of oil use in each country, the remainder is used to varying degrees for other transportation modes, industrial purposes, and home heating (IEA 2010).

Coal accounts for 13-23 percent of final energy consumption in Germany, Turkey and Vietnam (Figure 4), reflecting usage in power generation and steel production. Natural gas accounts for a large share of final energy consumption in Germany and Turkey (31 and 26 percent, respectively) given its widespread use both in power generation and home heating. In Sweden, heating is mainly from electricity and biomass (mostly wood fibre which caters for long-distance, district heating). Despite widespread use of natural gas in power generation, the share of natural gas in final energy consumption in Vietnam is 'only' 6 percent, given that electricity is just 12 percent of energy consumption and there is little useage of natural gas in other sectors.

Renewables account for 45 percent of final energy consumption in Sweden, given the intensive use of hydro in power generation and biomass in heating. In Vietnam, the renewable share is even higher (47 percent) with a large contribution from biomass—mostly direct (rather than processed) fuel wood and agricultural residue—used for heating and cooking.

---

[19] Domestic hard coal production has long been subsidized though subsidies are set to phase out by 2018 (BFM 2011). It is not clear however, whether these subsidies have much impact on lowering coal prices and increasing coal use and emissions, given that Germany is approximately a price taker in the world market for hard coal. As global lignite markets are fragmented due to the fuel's low energy-to-weight ratio (Euracoal 2011), foreign competition is much less than for hardcoal and which might explain why lignite has not been subsidized (Lechtenböhmer et al 2004).

[20] Current expansion of the central European grid, and particularly closures of bottlenecks between the German and Nordic grids, for example, will enable Germany to import hydro power from pumped-storage facilities in Sweden for grid load balancing. This will in turn allow increased reliance on power supply from intermittent sources, such as domestic on-shore wind.

B. Illustrative Values for Pigouvian Taxes

The rightmost box for each country in Figure 5 summarizes, for coal, natural gas, and light fuel oil, external costs for CO_2, SO_2, NO_x, and Figure 6 does the same for transportation externalities (for two countries), expressed per unit of fuel use and also in gigajoules to facilitate 'apples-to-apples' comparison.[21] For SO_2, damages are prior to scrubbing (which removes around 90 percent of emissions). All figures are expressed in year 2010 US $.

These values are 'illustrative', given data limitations and methodological controversies (e.g., over climate discounting) and are only meant to provide a broad-brush sense of efficient taxes without getting into detailed parameter assessments. We do not value externalities from nuclear power.[22] Nor do we differentiate taxes within our four fuel groups—this would be potentially important in cases with significant heterogeneity in embodied pollution content (most notably differences in sulfur content between hard coal and lignite).[23]

CO_2. For the sake of argument, given the well known controversy, we use 'lower' and 'higher' damage values: the former is taken from the central case estimate of $23 per ton for CO_2 damages from US IAWG (2010), page 1 (updated to 2010 $), which is approximating the prevailing price in the EU ETS, and the latter, $82 per tonne, corresponds to a shadow price for rapid stabilization of atmospheric concentrations from UK DECC (2010). Given that (global) damages are uniform, regardless of where emissions are released, the same values are applied to different countries. Coal is approximately 77 percent more carbon intensive per tera-joule than natural gas, and 27 percent more intensive than oil.

SO_2 and NO_x (for stationary sources). NRC (2009) provides a state-of-the-art assessment of local pollution damages for the United States. Averaged across the country, their central case damage estimates are $9,887 per ton for SO_2 and $1,998 per ton for NO_x (in year 2010$). Damages per ton for SO_2 are greater, given the greater potential for chemical reactions with SO_2 to form fine particulates (which permeate the lungs). Again, coal is the most emissions intensive fuel and natural gas the least intensive (natural gas does not produce SO_2, and its NO_x intensity is one-fifth of that for coal).

To adjust for the VSL, we multiply by a country's real per capita income (in Purchasing Power Parity equivalent to account for the real spending power of local income) relative to that

[21] *Note to reviewers*: The next version of the paper will include a discussion of direct particulate emissions, which will moderately increase damage estimates for coal.

[22] In principle, corrective taxes are warranted to address risks from nuclear accidents (so long as liability is limited by legislation), nuclear proliferation, and long-term storage, but these risks are extremely difficult to quantify. And externalities from routine releases would generally justify only minimal taxes. See, for example, NRC (2009) and Rothwell (2010).

[23] We used local data on fuel emissions factors (see Heine et al. 2011), given that these factors differ somewhat across countries due, for example, to upstream regulations on the pollution content of fuels.

in the United States, raised to the income/VSL elasticity (Cifuentes et al. 2005). Real income in Sweden is 82 percent of that for the United States, 77 percent for Germany, 29 percent for Turkey, and 7 percent for Vietnam. For the VSL/income elasticity we use a value of 0.75.[24] These adjustments lead to damage values per ton that are just under half as large in Turkey relative to Germany and Sweden and about one-sixth as large in Vietnam.[25]

Making further adjustments for local population exposure, climate and geographical factors, green preferences, etc. is beyond our scope. We simply note that damages for Vietnam and Turkey may be understated to the extent their populations are less healthy (and therefore more vulnerable to pollution-related illness) than in rich countries, while on the other hand damages for Sweden and Vietnam may be overstated, given the relatively close coastal location of many emissions sources, which favors pollution dispersion.

Motor fuel taxes. Here we infer external costs for local pollution, congestion, and accidents for *gasoline*-powered vehicles in Sweden and Germany, based loosely on Mailbach et al. (2007), tables 7, 10, and 15.[26] In each case, externalities are scaled back by 50 percent on the assumption that reduced driving accounts for half of any tax-induced reduction in fuel use (Parry 2011). External costs per km are expressed per liter of fuel, assuming on-road fuel economy of 13 km per liter. Combined with our lower carbon value (the high carbon value makes only a modest difference in relative terms) yields our corrective fuel tax assumptions: $1.00 per liter for Germany and $0.90 per liter for Sweden, with congestion easily the most dominant component, accounting for about $0.70 per liter in each case. Again, we caution against taking these figures too literally as they are sensitive to different assumptions. And we do not even attempt guesstimates for optimal fuel taxes in Turkey and Vietnam, given the lack of evidence on local external costs (though we make some qualitative judgments below).

C. Evaluating Environmental Tax Systems

Based on the above discussion, our tentative policy recommendations would include:

---

[24] Income data is from World Bank (2011b). Our elasticity assumption is based on a personal communication with Alan Krupnick, who has worked on stated preference VSL studies for emerging and low-income countries. Others however, argue for using an elasticity of unity or higher (e.g., Hammitt and Robinson 2011). These higher values would substantially reduce extrapolated pollution damage estimates for Vietnam and Turkey, but would make little difference for Germany and Sweden.

[25] Our damage estimates for SO_2 are nearly double those (after updating to 2010) in another study by Extern E (2005). The most important reason for the difference appears to be their use of disability adjusted life years, which leads to a significantly smaller value for mortality than use of VSLs.

[26] We assume that marginal congestion costs for small and medium urban areas, about 11 US cents per km, are representative of those on average across the entire country; local pollution costs are taken to be 0.8 cents per km; and external accident costs are taken to be 3 cents per km in Germany and 1.5 cents in Sweden. See Heine et al. (2011) for details.

- Taxes on fossil fuels for stationary sources to charge for CO_2, SO_2 and NO_x, with tax refunds for downstream emissions capture. To avoid double pricing, a tax refund should also be granted for allowance purchases by entities covered by the EU ETS.

- Taxes on motor fuels to account for a broader range of externalities (though with a planned transition to per mile charges as the capability for their implementation is developed).

- Given the above, no taxes/subsidies for hydro and other renewables, electricity, and vehicle ownership on environmental grounds. Some taxation of nuclear may be appropriate, but the efficient level seems beyond quantification.

To compare existing practice against these recommendations, various panels in Figure 5 summarize average taxes paid on fuels—average taxes may be less than statutory rates because of exemptions—and differentiated by the fuel user (see Heine et al. 2011 for estimation details). Note that CO_2 taxes include the charge from sources covered by the EU ETS.

Sweden. Together with the other Nordic countries, Sweden took the lead in environmental tax reform during the early 1990s followed by further reforms in the early 2000s. These reforms represented a key component in a broader tax-shifting operation that strengthened indirect taxes, particularly the VAT, and environmental taxes, and reduced taxes on labor. The aim here was to stimulate employment though, as noted above, the literature casts doubt on this possibility.[27]

The Swedish reform added three new taxes between 1991 and 1992: two upstream on oil and natural gas to charge for CO_2 and (for oil) SO_2 and one downstream on industrial sources of NO_x. These increases were partly compensated by a reduction in 'traditional' energy excises—mainly on motor fuels and other oil products. Due to worries about reduced competitiveness, a tax change in 1993 made manufacturing completely exempt from traditional energy taxes and made it pay only 21 percent of CO_2 tax rates from 2004 onwards (Johansson 2006, p.1). Meanwhile, the CO_2 tax on fuels used in manufacturing plants covered by the EU ETS was gradually reduced to 15 percent of the statutory rate (TemaNord 2009, p.81). Electricity generators have been fully exempt from all corrective taxes but the one on SO_2 (Speck and Jilkova 2009, p.45).

As regards SO_2 (which is mostly a coal problem) the tax level ($4,165 per tonne) is about half our illustrative value for environmental damages, and on average (due to exemptions) industry pays less than households and generators (Figure 5). The NO_x tax ($5,553 per tonne), in contrast, is more strikingly out of line with our externality value (it is three times this value), but it is not paid by households, industry, and even some generators. Similarly, the formal CO_2 tax ($146 per tonne) is almost 80 percent larger than even our higher CO_2 value, though the full rate is essentially reflected only in motor fuels. Figuring in traditional energy excises and the ETS, the overall picture is one of high taxation of fuels for households, and taxes for industry and generators that are either about right, or too low. Welfare gains from policy reforms will be limited however, given the small share of coal and natural gas in total energy consumption

[27] For more background on the Swedish tax reforms see, for example, Millock and Sterner (2004), TemaNord (2011), Agell et al. (1999), Johansson (2006), and Swedish Agencies for Environment and Energy (2007) .

(Figure 4). Gasoline taxes ($ 0.67 per liter) appear to be in the right ballpark—they are 70 percent of our externality value (Figure 6).

Adjustment of emissions tax rates over time is problematic. The SO_2 and NO_x taxes have been fixed in nominal terms since 1991, reducing their real values by about 35 percent (Heine et al. 2010), and while the CO_2 tax has been updated for inflation this has occurred sporadically, rather than annually.

Revenue use has been efficient in most cases, in the sense of scaling back energy taxes made redundant by the new environmental taxes and reducing distortionary income taxes. A slight caveat is that NO_x tax revenues have funded a production-enhancing subsidy in affected industries resulting in some (though probably modest—see above) loss of efficiency.

Some broader remaining taxes in the energy system are essentially redundant (at least from an externality perspective). These include a 3.7 cents tax per kWh tax on household electricity consumption (which is now almost pollution free) and vehicle ownership taxes that impose a burden on motorists equivalent to about 10 percent of that from motor fuel taxes (Heine et al. 2011).

In sum, recommended reforms (if only for the sake of transparency in some cases) at least for the would include levying the NO_x charge upstream on fuels, while perhaps lowering its rate; levelizing the price on all CO_2 emissions (i.e., removing all exemptions from carbon charges, phasing out energy taxes, providing tax credits for ETS allowance purchases, and setting the uniform emissions price equal to $23 per ton or higher); levying all emissions taxes in proportion to the pollution content of fuels; and replacing traditional excises on electricity and vehicles with broader fiscal instruments.

Germany. A comprehensive environmental tax reform was introduced in Germany in 1999, involving a gradual increase in taxes on transport fuels, and new taxes on natural gas, heating fuels, heavy fuel oil, and (primarily) residential electricity consumption. The reform was intended to be broadly revenue neutral, with about 85 percent of revenue recycled via equal reductions in employers' and employees' payroll taxes (about 13 percent was used for budget consolidation and 1 percent was earmarked for renewable energy deployment). However, the reform was subject to considerable public dissatisfaction, which presumably helps to explain why, subsequently, tax rates were allowed to fall in real terms (BMU 2004). The reform was viewed as regressive despite evidence to the contrary (e.g., Knigge and Görlach 2005, Koolhaas 2005, Salmons and Miltner 2009, p.98) and not helping with employment or competitiveness (and public surveys suggest the recycling of revenues was poorly understood—see BMU 2004, Ludewig et al 2010).

As part of the tax changes, a comprehensive set of tax reliefs on energy products (other than transportation fuels) was also granted to manufacturing and power generation, with the justification of protecting their international competitiveness: reliefs were initially 80 percent, but later reduced to 40 percent (Speck and Jilkova 2009).[28] There are no downstream rebates for scrubbing technologies: instead, these technologies are mandated.

According to Figure 5, fossil fuels for stationary sources appear to be under-taxed for nearly all end users (the exception being residential natural gas consumers who pay a tax in line with illustrated environmental damages). And, as for Sweden, taxation of the same emissions sources across different end users is highly uneven, with households paying the most for natural gas and generators the most for coal. The shortfalls of taxes relative to externalities in Figure 5 is especially pronounced in the case of light fuel oil and coal (though note that SO_2 damages for coal would be a lot lower net of scrubbing). Again, there are redundant taxes on electricity use (2.7 cents per kWh at the household level) and vehicles, though motor fuel taxes ($0.86 per liter) appear to be somewhere in the right ballpark (Figure 6).

Our recommendations for reform would be largely the same as those for Sweden.

Turkey. Turkey is an 'outlier' in environmental tax terms in that, while its per capita GDP is only a fraction of that of OECD/EU country averages, it has the highest gasoline tax in the OECD ($0.98 per liter)—a rate that, furthermore, has been steadily increased in recent years. This high tax rate goes a long way in explaining why Turkey is at the very top of OECD counties in terms of revenue raising from environmentally-related taxes (Figure 1).

It is difficult to judge whether this high fuel tax rate is warranted on economic grounds. The rate seems high from an externality perspective—optimal fuel tax rates tend to be smaller for lower income countries, due to lower wages, and therefore lower values of congestion.[29] However, the main reason for the fuel tax increases has been fiscal (rather than environmental): revenues were needed for fiscal consolidation in the early 2000s, and fuel taxes are relatively difficult to evade compared with Turkey's personal income tax system.[30] Nonetheless, better still from a fiscal perspective would be to tax vehicle ownership (which is more inelastic) than fuel.

As for other fuels, there is over-taxation in some cases (fuel oil and natural gas for industry) and no taxation at all in others (other users of these fuels and all users of coal). From an environmental perspective, our estimates suggest that in Turkey all coal use should be taxed at well over $155 per tonne (with refunds for scrubbers), natural gas at least $0.06 per m^3, and light fuel oil at $0.40 per gallon or more.

Vietnam. The government of Vietnam decided in 2004 that a comprehensive environmental tax reform was required, in part prompted by increasing public awareness of pollution levels. While

---

[28] Manufacturing firms were also eligible (with restrictions) for direct refunds if the extra tax burden was larger than the tax relief from reduced payroll taxes, in some cases reducing the effective tax rate to close to nil.

[29] There are factors going in the opposite direction however, for example, there tends to be a higher incidence of pedestrian fatalities in lower income countries, which magnifies the accident externality. For comparison, Parry and Strand (2011) put the corrective gasoline tax in Chile (which is similar to Turkey in terms of per capita income and a large portion of its population residing in large cities) at $0.61 per liter (in 2006$).

[30] Moreover, Turkey has a much lower dependency on personal vehicles than Germany and Sweden (see above), which may render fuel taxes a form of progressive taxation.

the 2008-2010 financial crisis may have delayed the initiative somewhat, the Government is now committed to environmental tax reform.

Currently, coal and gasoline are taxed in Vietnam, but at low levels relative to those in other countries ($0.52 per tonne and 20 cents per gallon, respectively), while natural gas is not taxed at all. How might our recommendations for reform differ for Vietnam compared with those for other countries?

One difference is that the value of local pollution damages are likely much smaller, due to a much lower willingness to pay for reduced mortality risk. Our illustrative externalities imply, for example, that the total corrective tax on coal for Vietnam is $50 per tonne or more, compared with about 310 per tonne or more in Sweden and Germany (Figure 5).

Another potential difference is that optimal taxes may be affected if, for fuels supplied by state-run enterprises, prices differ from marginal costs.[31]

As in the case of Turkey, raising revenues from vehicle ownership, which are currently zero for both cars and scooters, would make sense, given the difficulty of raising revenues from broader fiscal instruments (though the development of administrative capability for registering all these vehicles needs to be completed).

4. Conclusion

Substantial progress has been made in developing key principles for the design of environmental/energy tax systems. We have a reasonable sense of where, ideally, taxes should be levied, and where they should not, how revenues should best be used, and pitfalls to avoid in tax design (like notches and differentiated treatment of the same emissions from different sources). We have attempted, albeit in a highly cursory way, to illustrate how these principles might be applied to different countries.

Perhaps the most useful reform would be to define a set of pollution charges—for CO_2, SO_2 and NO_x—roughly grounded to respective damage estimates, and applied upstream to fuels in proportion to fuel content (with credits for downstream emissions capture, but no other exemptions). Other taxes in energy and transport systems would then become redundant, at least on environmental grounds. For motor vehicles, the problem is that some important externalities are related to vehicle use, which calls for a longer term shift away from heavy taxation of fuels and vehicles towards more innovative charges varying with km driven on busy roads.

Probably the most policy-useful area for future research is measurement of local externalities (especially pollution and congestion) for different countries, to help pin down reasonable tax levels with more confidence. Research on creative ways (other than inefficient, uncreative tax exemptions) is also needed to enhance the acceptability of environmental taxes

[31] *Note to reviewers*: for the next revision we hope to have obtained estimates of the direction and size of these pre-existing price distortions and what they imply for optimal taxes.

(e.g., by alleviating competitiveness concerns). Still, for most of the pressing environmental problems, well-designed fiscal instruments should be the environmental movement's best friend.

References

Agell, J., Englund, P. & Södersten, J., 1999. "Tax Reform of the Century—the Swedish Experiment." *National Tax Journal* 49: 643-64.

AtG, 2011. Dreizehntes Gesetz zur Änderung des Atomgesetzes, Bonn, Bundesgesetzblatt.

Baumol, William J., and Wallace E. Oates, 1988. *The Theory of Environmental Policy*. 2nd edition. Cambridge: Cambridge University Press.

Bernard, A.L., Carolyn Fischer, and A.K. Fox, 2007. "Is There a Rationale for Output-Based Rebating of Environmental Levies?" *Resource & Energy Economics* 29: 83-101.

BFM, Dreiundzwanzigster Subventionsbericht (Berlin: German Federal Ministry of Finance, 2011).

Bird, Richard M. and Joosung Jun, 2005. "Earmarking in Theory and Korean Practice". Discussion paper, Institute for International Business, University of Toronto, Toronto, Ontario.

BMU, 2004. Umweltbewusstsein in Deutschland 2004. Berlin: Federal Ministry for Environment, Nature Protection and Reactor Safety.

BMU, 2008. *Umweltschädliche Subventionen in Deutschland*, Dessau: German Federal Ministry for Environment, Nature Protection and Reactor Safety.

Bovenberg, A. Lans and Ruud A. de Mooij, 1994. "Environmental Levies and Distortionary Taxation." *American Economic Review* 84: 1085-1089.

Bovenberg, Lans and Lawrence H. Goulder, 1996. "Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analyses." *American Economic Review* 86.

Bovenberg, Lans and Lawrence H. Goulder, 2002. "Environmental Taxation and Regulation" In A. Auerbach and M.Feldstein, eds., *Handbook of Public Economics*, volume 3. Elsevier.

Bosquet, B., 2000. Environmental tax reform: does it work? A survey of the empirical evidence. *Ecological Economics*, 34(1), pp.19–32.

Boyd, Jim, 2003. "Water Pollution Taxes: A Good Idea Doomed to Failure?" *Public Finance and Management* 3.

Brett, Craig and Michael Keen, 200. "Political Uncertainty and the Earmarking of Environmental Taxes." *Journal of Public Economics* 75: 315-340.

Cifuentes, Luis A., Alan J. Krupnick, Raúl O'Ryan and Michael Toman, 2005. "Urban Air Quality and Human Health in Latin America and the Caribbean." Working paper, Inter-American Development Bank, Washington, DC.

Coady, David, Robert Gillingham, Rolando Ossowski, John M. Piotrowski, Shamsuddin Tareq, and Justin Tyson, 2010. "Petroleum Product Subsidies: Costly, Inequitable, and On the Rise." Staff Position Note No. 2010/05, International Monetary Fund, Washington, DC.

Cramton, P. and S. Kerr, 2002. "Tradable carbon permit auctions: how and why to auction not grandfather." *Energy Policy* 30: 333–45.

Cremer, Helmuth, Firouz Gahvari, and Norbert Ladoux, 1998. "Externalities and Optimal Taxation." *Journal of Public Economics* 70: 343-364.

Cremer, Helmuth, Firouz Gahvari, and Norbert Ladoux, 2003. "Environmental Taxes with Heterogeneous Consumers: An Application to Energy Consumption in France." *Journal of Public Economics* 87: 2791-2815.

Dales, J.H., 1968. *Pollution, Property, and Prices*. University of Toronto Press.

Daniel, Philip, Michael Keen and Charles McPherson, 2010. *The Taxation of Petroleum and Minerals: Principles, Problems, and Practice*. Routledge, New York, NY.

De Borger, Bruon and Stef Proost. 2001. *Reforming Transport Pricing in the European Union*. Edward Elgar, Northampton, MA.

Delucchi, Mark A. 2000. "Environmental Externalities of Motor Vehicle Use." *Journal of Transport Economics and Policy* 34: 135-168.

EC, 2007. *Green Paper on Market-Based Instruments for Environment and related Policy Purposes*. European Commission, COM (2007) 140 Final.

Eskeland, Gunnar S., 1994. "A Presumptive Pigovian Tax: Complementing Regulation to Mimic an Emissions Fee." *World Bank Economic Review* 8: 373-94.

Euracoal, "Why is there no Lignite Market" (European Association for Coal and Lignite, 2011), http://www.euracoal.org/pages/layout1sp.php?idpage=910, Accessed September 09, 2011.

Eurostat, 2011. *Eurostat Energy Database*, series nrg_101a, Luxembourg.

ExternE, 2005. *Final Technical Report*, Brussels: ExternE-Pol.

FHWA. 1997. *1997 Federal Highway Cost Allocation Study: Final Report.* US Federal Highway Administration, Department of Transportation, Washington, D.C.

Fisher, Anthony, 1981.*Resource and Environmental Economics*. Cambridge University Press, Cambridge, UK.

Fischer, Carolyn and Richard G. Newell, 2008. "Environmental and Technology Policies for Climate Mitigation." *Journal of Environmental Economics and Management* 55: 142-162.

Fischer, Carolyn, Ian W.H. Parry and Winston Harrington, 2007. "Should Corporate Average Fuel Economy (CAFE) Standards be Tightened?" *Energy Journal* 28: 1-29, 2007.

Fullerton, Don, 2005. "An Excise tax on Municipal Solid Waste." In S. Cnossen)ed.), *Theory and Practice of Excise Taxation: Smoking, Drinking, Gambling, Polluting, and Driving*, Oxford, Oxford University Press, 155-188.

Fullerton, D. and G. E. Metcalf, 2001. "Environmental Controls, Scarcity Rents, and Pre-existing Distortions." *Journal of Public Economics* 80: 249–67.

Fullerton, Don, Andrew Leicester and Stephen Smith, 2008. "Environmental Taxes." In the *Mirrlees Review: Reforming the Tax System for the 21st Century*. Institute for Fiscal Studies, London.

Goulder, Lawrence H. and Koshy Mathai, 2000. "Optimal CO_2 Abatement in the Presence of Induced Technological Change." *Journal of Environmental Economics and Management* 39:1-38.

Goulder, Lawrence H. and Ian W.H. Parry, 2008. "Instrument Choice in Environmental Policy." *Review of Environmental Economics and Policy* 2: 152-174.

Goulder, Lawrence H. and Stephen H. Schneider, 1999. "Induced Technological Change and the Attractiveness of CO_2 Emissions Abatement Policies." *Resource and Energy Economics* 21:211-53.

Gruber, Jon and Emmanuel Saez, 2002. "The Elasticity of Taxable Income: Evidence and Implications." *Journal of Public Economics* 84: 1-32.

Hammitt, James K. and Robinson, Lisa A., 2011. "The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations." *Journal of Benefit-Cost Analysis*: 2 (1), Article 1.

Heine, Dirk, John Norregaard and Ian W.H. Parry, 2011. "Environmental Tax Reform: Principles from Theory and Practice to Date." Working Paper, International Monetary Fund, Washington, DC (forthcoming).

Hepburn, Cameron, 2006. "Regulating by Prices, Quantities or Both: an Update and an Overview." *Oxford Review of Economic Policy* 22: 226-247.

Hepburn, C., M. Grubb, K. Neuhoff, F. Matthes and M. Tse, 2006. "Auctioning of EU ETS phase II allowances: how and why?" *Climate Policy* 6: 137–60.

Hilbert, J. and H. Berg, 2009. "Border Tax Adjustments for Additional Costs Engendered by Internal and EU Environmental Protection Measures: Implementation Options and WTO Admissibility." Dessau: German Federal Ministry for Environment, Nature Protection and Reactor Safety.

IEA, 2010. "World Energy Balances." World Energy Statistics and Balances (database), International Enegry Agency, doi: 10.1787/data-00512-en (Accessed on 10 November 2011).

IMF, 2011a. *Revenue Mobilization in Developing Countries*. International Monetary Fund, Washington, DC.

Jacobs, Bas and Ruud de Mooij, 2011. "Pigou Meets Mirrlees: On the Irrelevance of Tax Distortions for the Second-Best Pigouvian Tax." CESifo Working Paper No. 3342.

Johansson, B., 2006. "Economic Instruments in Practice 1: Carbon Tax in Sweden." Working paper, Swedish Environmental Protection Agency.

Kneese, Allen V. and Blair T. Bower, 1968. *Managing Water Quality: Economics, Technology, Institutions*. Johns Hopkins Press.

Knigge, M. & Görlach, B., 2005. Auswirkungen der ökologischen Steuerreform auf Unternehmen, Berlin: Ecologic Institut für Internationale und Europäische Umweltpolitik.

Kohlhaas, M., 2005. Gesamtwirtschaftliche Effekte der ökologischen Steuerreform, Berlin: Deutsches Institut fuer Wirtschaftsforschung.

Krupnick, Alan J., Ian W.H. Parry, Margaret Walls, Tony Knowles and Kristin Hayes, 2010. *Toward a New National Energy Policy: Assessing the Options.* Resources for the Future and National Energy Policy Institute, Washington, DC.

Ludewig, D., Meyer, B. & Schlegelmilch, K., 2010. Greening the Budget: Pricing carbon and cutting energy subsidies to reduce the financial deficit in Germany, Washington D.C.: Heinrich Boell Foundation.

Lechtenböhmer, Stefan, Kora Kristof, and Wolfgang Irrek, Braunkohle, 2004. *Ein subventionsfreiher Energieträger?* BMU Report FKZ 3630180. Wuppertal: Wuppertal Institute for Climate, Environment and Energy.

Macauley, Molly and Roger A. Sedjo, 2011. "Forests in Climate Policy: Technical, Institutional and Economic Issues in Measurement and Monitoring." In *Mitigation and Adaptation Strategies for Global Change*.

Maibach, M., et al., 2007. *Handbook on Estimation of External Cost in the Transport Sector*. CE Delft Solutions for Environment, Economy, and Technology.

Mauzerall, Denise, Babar Sultan, Namsoug Kim, and David F. Bradford, 2005. "NO_x Emissions from Large Point Sources: Variability in Ozone Production, Resulting Health Damages and Economic Costs." *Atmospheric Environment* 39: 2851–66.

Mayeres, Inge and Stef Proost, 2001. "Marginal Tax Reform, Externalities, and Income Distribution." *Journal of Public Economics* 79:343-363.

Metcalf, Gilbert, E., 2009. "Designing a Carbon Tax to Reduce U.S. Greenhouse Gas Emissions." *Review of Environmental Economics and Policy* 3: 63-83.

Metcalf, Gilbert E. and David Weisbach, 2009. "The Design of a Carbon Tax." *Harvard Environmental Law Review* 33: 499-506.

Millock. K. and T. Sterner, 2004. "NO_x Emissions in France and Sweden: Advanced Fee Schemes versus Regulation." In *Choosing Environmental Policy – Comparing Instruments and Outcomes in the United States and Europe*, Washington, D.C., Resources for the Future.

Montgomery, W. David. 1972. "Markets in Licenses and Efficient Pollution Control Programs." *Journal of Economic Theory* 5: 395–418.

Muller, Nicholas Z., and Robert Mendelsohn, 2009. "Efficient Pollution Regulation: Getting the Prices Right." *American Economic Review* 99: 1714–39.

Newell, Richard G. and Robert N. Stavins, 2003. "Cost Heterogeneity and the Potential Savings from Market-Based Policies." *Journal of Regulatory Economics* 23: 43-59.

Nordhaus, William D., 1994. *Managing the Commons: The Economics of Climate Change*. MIT Press, Cambridge, MA.

Nordhaus, William D., 2002. "Modeling Induced Innovation in Climate-Change Policy." In A. Grubler, N. Nakicenovic and W. D. Nordhaus, *Technological Change and the Environment*, Resources for the Future, Washington, DC, 182-2009.

Nordhaus, William D., 2007. "To Tax or not to Tax: Alternative Approaches to Slowing Global Warming." *Review of Economics and Policy* 1: 26–44.

NRC, 2009. *The Hidden Costs of Energy: Unpriced Costs of Energy Production and Use*. National Research Council, Washington, DC, National Academy Press.

Oates, Wallace E., 2002. "A Reconsideration of Environmental Federalism". In J. List and A. De Zeeuw (eds.), *Recent Advances in Environmental Economics*, Edward Elgar, Cheltenham, UK, 1-32.

Oates, Wallace E. and Diana L. Strassmann, 1984. "Effluent Fees and Market Structure." *Journal of Public Economics* 24: 29-46.

OECD, 2010. Taxation, Innovation and the Environment, Paris: Organisation for Economic Co-operation and Development

OECD, 2011. *Fossil-fuel Support*. Secretariat, Organization for Economic Cooperation and Development, Paris, France.

Opschoor, J. B. and H. B. Vos, 1989. *Economic Instruments for Environmental Protection*. Paris, OECD.

Parry, Ian W.H., 2011. "How Much Should Highway Fuels Be Taxed?" In Gilbert E. Metcalf (ed.), *U.S. Energy Tax Policy*, Cambridge University Press, 269-297.

Parry, Ian W.H., 1998. "The Double Dividend: When You Get It and When You Don't." *National Tax Association Proceedings* 46-51.

Parry, Ian W.H. and Kenneth A. Small, 2005. "Does Britain or The United States Have the Right Gasoline Tax?" *American Economic Review* 95: 1,276-1,289.

Parry, Ian W.H. and Jon Strand, 2011. "International Fuel Tax Assessment: An Application to Chile." *Environment and Development Economics*, forthcoming.

Parry, Ian W.H., Margaret Walls and Winston Harrington, 2007. "Automobile Externalities and Policies." *Journal of Economic Literature* XLV: 374-400.

Parry, Ian W.H., William A. Pizer and Carolyn Fischer, 2003. "How Large are the Welfare Gains from Technological Innovation Induced by Environmental Policies?" *Journal of Regulatory Economics* 23: 237-255.

Parry, Ian W.H., David Evans and Wallace E. Oates, 2010. "Are Energy Efficiency Standards Justified?" Discussion paper, Resources for the Future, Washington, DC.

Pigou, Arthur C. 1920. *The Economics of Welfare*. London, Macmillan.

Pope, C.A., 3rd, R.T. Burnett, et al., 2004. "Cardiovascular Mortality and Long-Term Exposure to Particulate Air Pollution: Epidemiological Evidence of General Pathophysiological Pathways of Disease". *Circulation* 109: 71-77.

Pope, C.A., 3rd and D.W. Dockery, 2006. "Health Effects of Fine Particulate Air Pollution: Lines that Connect." *Journal of the Air & Waste Management Association* 56: 709-42.

Popp, David, 2004. “ENTICE: Endogenous Technological Change in the DICE Model of Global Warming.” *Journal of Environmental Economics and Management* 48: 742-768.

Quinet, Emile, 2004. “A Meta-Analysis of Western European External Costs Estimates.” *Transportation Research Part D 9*: 465-476.

Rothwell, Geoffrey, 2010. “New U.S. Nuclear Generation: 2010–2030.” Resources for the Future, Washington, DC.

Sallee, James M. and Joel Slemrod, 2010. “Car Notches: Strategic Automaker Responses to Fuel Economy Policy.” Working Paper No. 16604, National Bureau of Economic Research, Cambridge, MA.

Salmons, R. & Miltner, A., 2009. Trends in the competitiveness of selected industrial sectors in ETR countries. In Carbon-energy taxation: lessons from Europe. Oxford: Oxford University Press.

Sandmo, Agnar, 1976. “Direct versus Indirect Pigovian Taxation.” *European Economic Review* 7: 337–49.

Sigman, Hilary, 2003. “Taxes on Hazardous Waste: The U.S. Experience.” *Public Finance and Management* 3: 12–33.

Schlegelmilch, K. ed., 1999. *Green budget reform in Europe: countries at the forefront*, Berlin: Springer.

Small, Kenneth A., 2010. “Energy Policies for Passenger Transportation: A Comparison of Costs and Effectiveness.” Discussion paper, University of California, Irvine.

Speck, S. & Jilkova, J., 2009. Design of environmental tax reforms in Europe. In M. Andersen & P. Ekins, eds. *Carbon-energy taxation: lessons from Europe*. Oxford: Oxford University Press, p. 24.

Sterner, T., 2002. *Policy Instruments for Environmental and Natural Resource Management*, Washington D.C.: RFF Press.

Swedish Environmental Agency and Swedish Energy Agency, 2007. Economic Instruments in Environmental Policy, Report No. 5678, Stockholm: Naturvårdsverket.

TemaNord, 2011a. *Greening the Economy: Nordic experiences*, Copenhagen: Nordic Council of Ministers.

TemaNord, 2011b. *Reforming environmentally harmful subsidies*, Copenhagen: Nordic Council of Ministers.

TemaNord, 2009. *The Use of Economic Instruments in Nordic Environmental Policy*, Copenhagen: Council of Nordic Ministers.

Tietenberg, Tom, 2006. *Emissions Trading: Principles and Practice*, 2nd ed. Resources for the Future, Washington, DC.

TRB, 2006. *The Fuel Tax and Alternatives for Transportation Funding*. Transportation Research Board of the national Academies, Washington, DC.

UK DECC, 2010. *Valuation of Energy Use and greenhouse Gas Emissions for Appraisal and Evaluation*. Department of Energy and Climate Change, London, UK.

UK Treasury, 2011. *The Green Book: Appraisal and Evaluation in Central Government*. HM Treasury, London, UK.

US IAWG, 2010. *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government, Washington, DC.

World Bank, 2011a. *Global Development Indicators*. Available at: http://data.worldbank.org/data-catalog/world-development-indicators.

World Bank, 2011b. *GDP per Capita, Purchasing Power Parity*. http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD.

Wynter, C. I. et al. 2004. “Correlation of Coal Calorific Value and Sulphur Content with 57Fe Mössbauer Spectral Absorption.” *Hyperfine Interactions* 153: 147-152.

Box 1. Uncertainties in Measuring Local Pollution Damages

Assessing the local pollution damages from fuel combustion requires three steps (e.g., Mauzerall et al. 2005, Muller and Mendelsohn 2009, NRC 2009). First is use of an air quality model that links emissions into atmospheric concentrations—not only of primary pollutants but also secondary pollutants (e.g., fine particulates, ozone) that might be formed through subsequent chemical reactions—taking into account wind speeds, geographical factors that influence pollution dispersion, height of the smokestack, etc. Second, the human health effects of these pollution concentrations need to be modeled, accounting for local population exposure (or more precisely the number of seniors, people with pre-existing conditions, and others that are most vulnerable to health effects) and 'dose-response' relationships based on epidemiological evidence. Ideally, other physical effects (e.g., morbidity, building corrosion, crop damage, impaired visibility) would also be assessed though, for the pollutants discussed here, they tend to be small in magnitude relative to health effects. Finally, physical effects need to be monetized using evidence, for example, about people's willingness to pay for mortality risk reductions.

All three steps involve considerable uncertainties. For example, modeling secondary pollution formation through atmospheric chemistry is especially difficult (NRC 2009). The last step is perhaps the most disputed, as there remains disagreement among an appropriate number of the value of a statistical life (VSL). For example, the US Department of Transportation used a VSL of $3.5 million to value road deaths in 2004, but has since increased this value to $6 million; Mendelsohn and Muller (2009) used a VSL of $4 million; NRC (2009) used $6 million (in year 2000 dollars), while the US Environmental Protection Agency used a VSL of $9.1 million for new clean air rules in 2010 (Viscusi 2010).

Box 2. The Problems with Tax 'Notches'

A prominent example of tax notches is the recent trend to assign new vehicles to different brackets according to their engine size or, even more recently, CO_2 per km, and levy different taxes according to the bracket.[32] These tax systems are not cost effective because they do not provide the same reward for reducing CO_2 across different behavioral responses—therefore they do not strike the right balance between, for example, reducing CO_2 per km in small vehicles, reducing CO_2 per km in large vehicles, and shifting demand from large to small vehicles. Instead they place too much of the burden on shifting people into small vehicles, and on reducing CO_2 for vehicles that are currently slightly above lower tax brackets (Sallee and Slemrod 2010). The notches in the tax system also distort vehicle choice by causing a bunching of demand for vehicles with CO_2 per km just sufficient to be in a lower tax bracket. Moreover, there is a tension between revenue needs (often a concern to policymakers) and reducing emissions—as sales shares for low tax, low CO_2 per km vehicles rise, revenues fall.

If new vehicle taxes are to be retained (in a second-best world), a better approach is to combine a simple, proportional tax on new vehicle prices with a revenue-neutral 'feebate'. The former is easily set to meet a revenue objective without distorting vehicle choice. The latter involves fees on fuel-inefficient vehicles in proportion the difference between their CO_2 per km and a pivot point CO_2 per km, while corresponding rebates are paid for relatively fuel-efficient vehicles. The feebate provides a cost-effective way to reduce emissions per km, as the same reward per ton is provided, regardless of how the emissions reduction comes about (e.g., Small 2010). And the feebate component can be kept (approximately) revenue-neutral by setting the pivot point equal to average CO_2 per km of the previous year's vehicle fleet.

Another example of tax notches is simply where firms only pay tax if their emissions exceed a threshold level—besides limiting emissions coverage, these exemptions can create other distortions like discouraging mergers or firm growth.

And a third example is fuel taxes that vary discretely with embodied pollution per unit. These tax systems provide no incentives for refiners to further remove impurities once they have achieved a lower tax notch.

[32] Basing the tax on CO_2 per km promotes a broader range of responses for reducing emissions beyond smaller engine size, such as use of lighter materials or reduced cabin size.

Box 3. Distortions in Technology Markets

The processes of (clean) technology *development* and *deployment* are potentially characterized by additional market failures, though of the countries studied here the former are perhaps only relevant to Germany given the concentration of R&D in large, high-income countries. At the development stage, the problem is that innovators may not be able to capture the spillover benefits of new technologies to other firms who (legally) imitate them or use them in their own research programs. At the deployment level, possibilities include, for example, lack of consumer awareness about the future saving from more energy-efficient technologies.

To the extent that R&D market failures have been quantified, in general they appear to be significantly smaller in magnitude over a long time horizon than environmentally-related market failures (e.g., Goulder and Matthai 2000, Nordhaus 2002, Parry et al. 2003, Popp 2004). In turn, this means that any adjustment to account for them in setting the environmental tax is relatively modest, though the general recommendation is that these market failures should be addressed through separate technology instruments (e.g., Goulder and Schneider 1999, Fischer and Newell 2008).

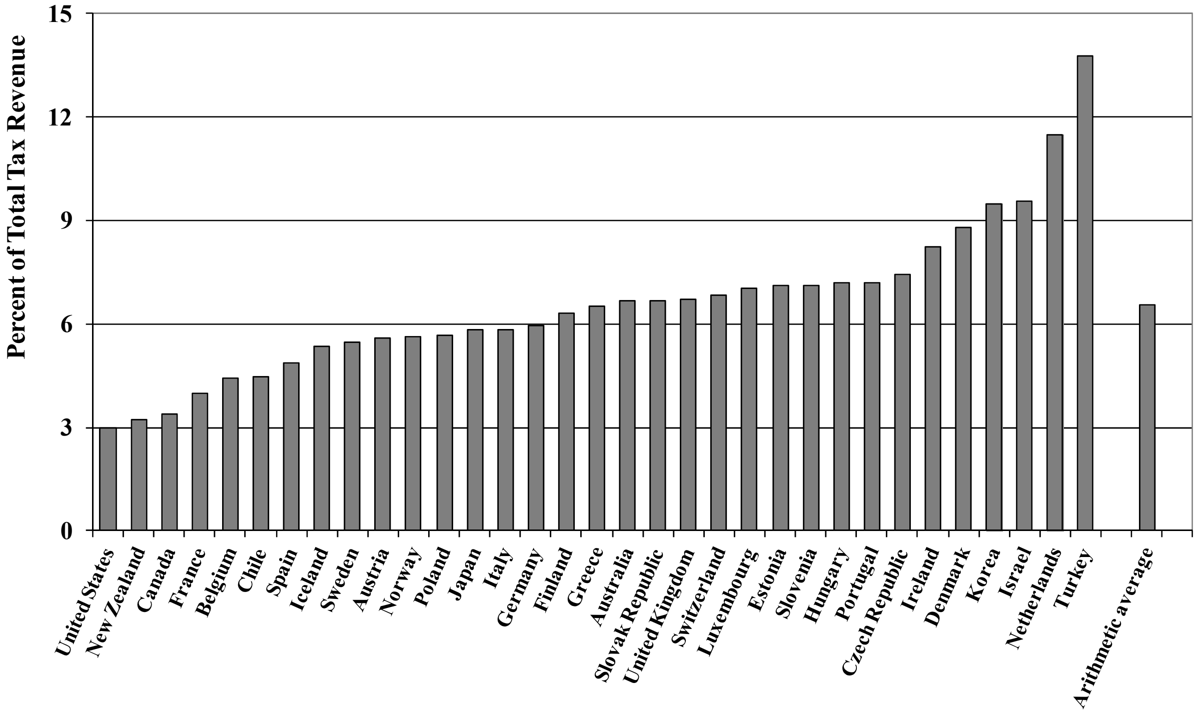
Market failures at the deployment level could be relatively large, given the large value of savings from energy efficiency improvements (e.g., Krupnick et al. 2010). But these market failures are more contentious (e.g., Gillingham and Sweeney 2011)—there has been a decades-long dispute over whether the savings from improvements in energy efficiency are undervalued by the private sector. But again, any additional market failures call for incentives targeted at specific technologies, rather than environmental taxes set above marginal environmental damages.[33]

Box 4. Coverage of Energy under the VAT

Leaving environmental considerations aside, all consumption goods should ideally be included under the coverage of a broader value added (or other consumption) tax system, to raise revenues in a way that avoids distorting consumer choices. Inputs into the production of goods should be exempt from such taxes to avoid distorting production efficiency, though this is automatic under VAT systems so long as these intermediate goods are sold to entities that pay VAT. This means that all power generation fuels, and electricity used by industry, should be tax exempt, or equivalently, any taxes paid under the VAT should be reimbursed. In contrast, household consumption of electricity should be taxed at the same rate as other goods, as should household purchase of vehicles and associated fuels. Ideally, the VAT should be applied to fuel prices *after* inclusion of corrective taxes to avoid distorting the choice amongst consumption goods, taking into account their full social costs.

[33] At present however, the literature provides only limited guidance on the appropriate choice among technology development instruments (e.g., R&D subsidies, patents, technology prizes) and among deployment instruments (e.g., minimum sales shares for new technologies, adoption subsidies).

Figure 1. Revenues from Environmentally Related Taxation, 2008



Source. OECD (2010), Figure 2.2.

Figure 2. Welfare Effects of Environmental Taxes in the Pigouvian Framework

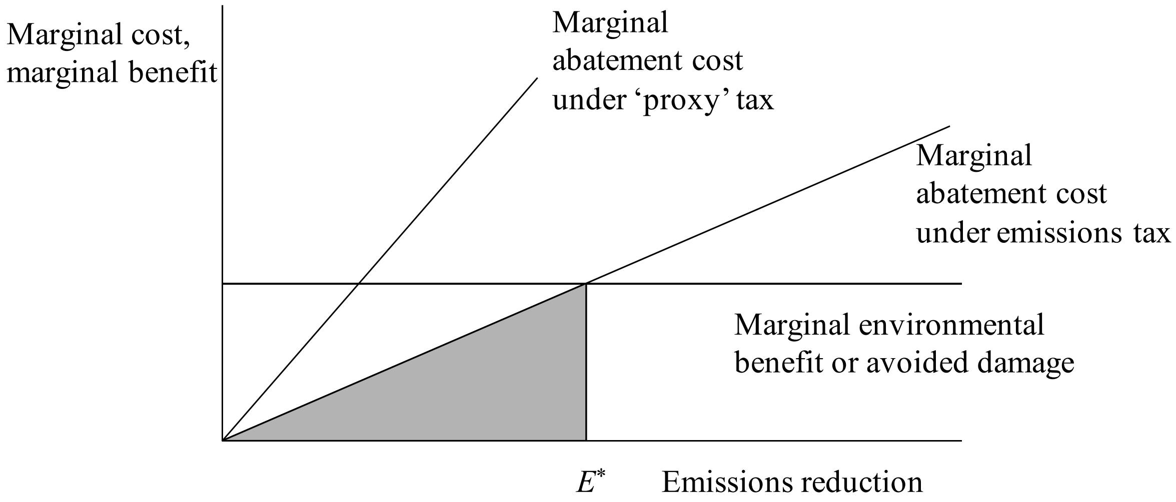
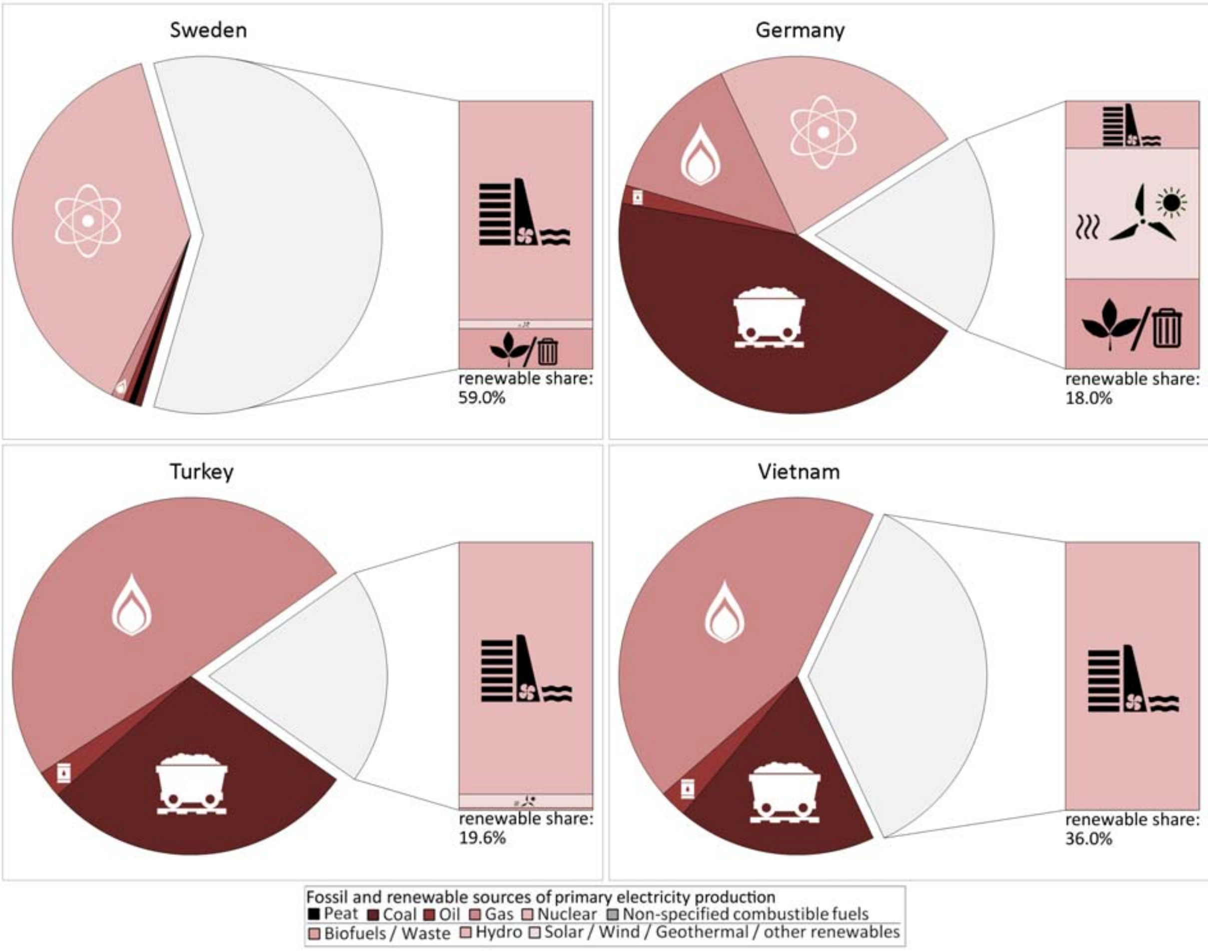


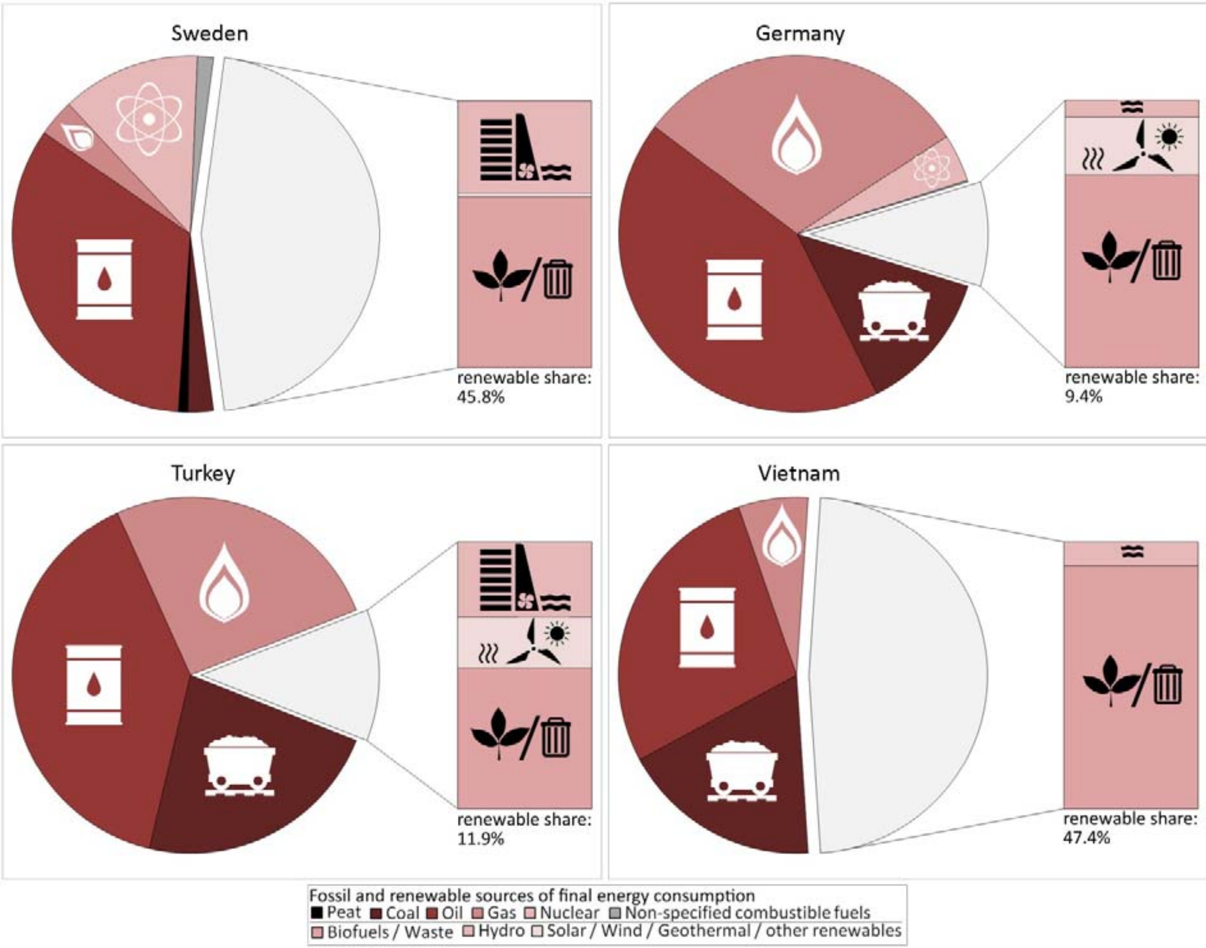
Figure 3. Power Generation by Fuel Type, 2010



Source. Heine et al. (2011).

Notes. Color coding indicates the carbon intensity of the different fuels in terms of tonnes of CO_2 per unit of energy produced, where a darker color represents higher emissions intensity. Emissions are expressed on a lifetime basis.

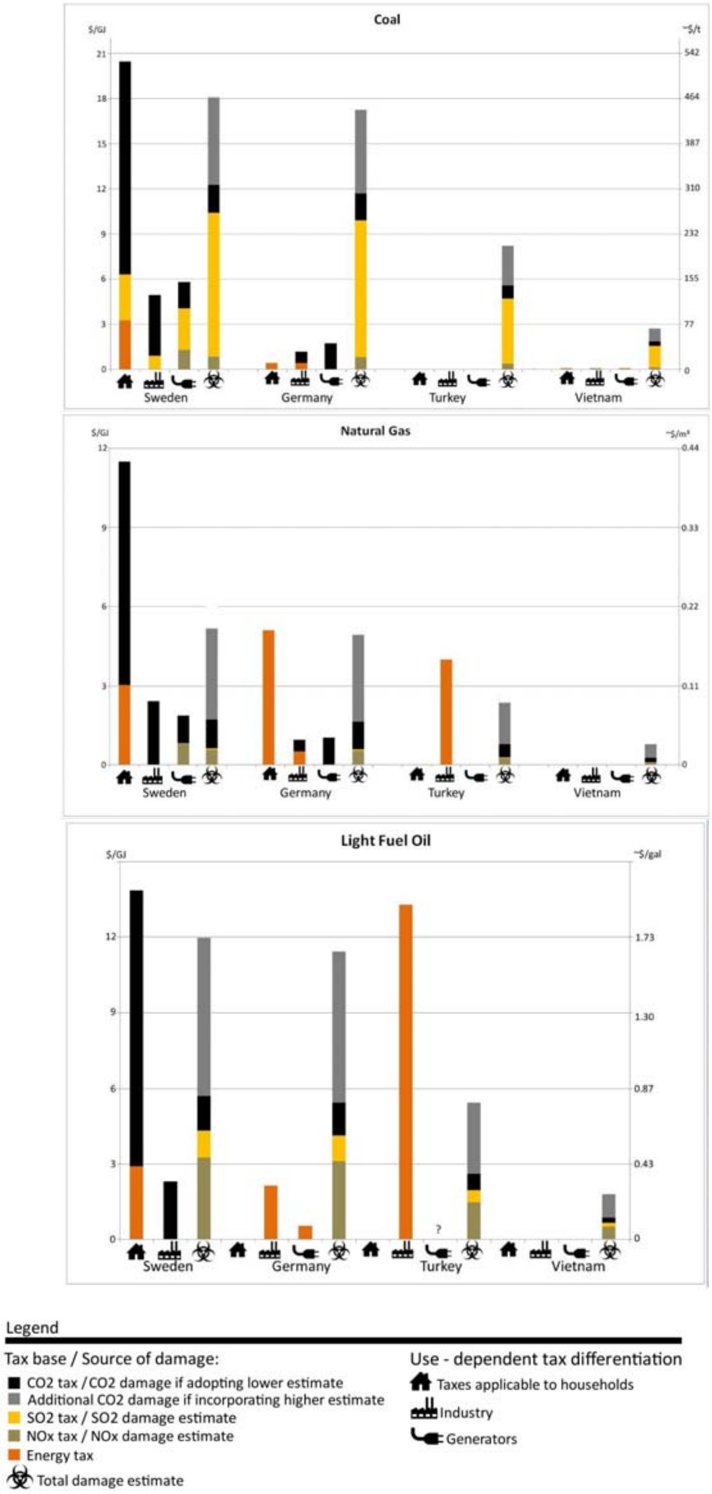
Figure 4. Final Energy Consumption by Fuel Type, 2010



Source. Heine et al. (2011).

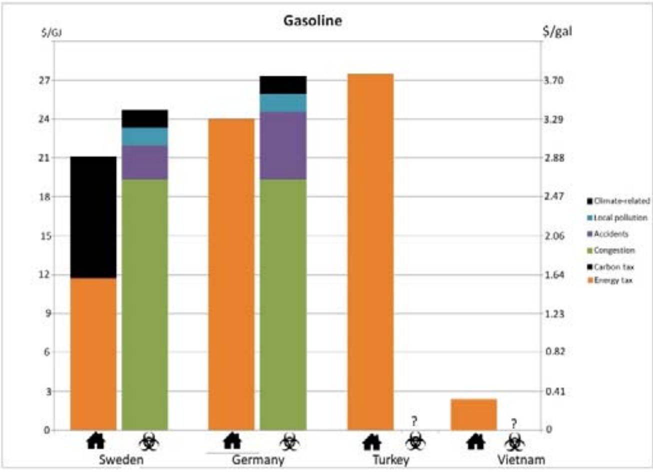
Notes. Color coding reflects emissions intensity, as in Figure 3.

Figure 5. Externalities and Fuel Taxes for Stationary Sources



Source. Heine et al. (2011).
Notes. Tax rates are less than statutory levels to the extent some sources pay lower, or zero taxes.

Figure 6. Externalities and Fuel Taxes for Mobile Sources



Source. Heine et al. (2011).