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## Working Party on Integrating Environmental and Economic Policies

### Lessons in Environmental Policy Reform: The Swedish tax on NOx emissions

*This is a first in a planned series of case studies entitled "Lessons in Environmental Policy Reform", targeting non-expert policy makers. The paper discusses the tax on NOx emissions that is employed in Sweden.*

*An earlier version of the paper was discussed at the WPIEEP meeting 16-17 November 2011, and the present version takes into account comments made then.*

*This paper has been prepared under PWB item: 2.3.4.4.1 "Managing the Transition in Environmental Policy Reform"*

*Action required: For declassification*

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**NOTE FROM THE SECRETARIAT**

In the document ENV/EPOC/WPIEEP(2011)10 discussed at the first WPIEEP meeting on 16-17 March 2011, it was proposed to establish a series of case studies titled "*Lessons in Environmental Policy Reform*". These case studies would be developed around a common structure with the aim of informing policy makers of how environmental policy reforms have taken place in practice.

As a first case study in this regard, the paper ENV/EPOC/WPIEEP(2011)20 was presented to the WPIEEP meeting held 16-17 November 2011, where it received a very positive welcome.

Among the several helpful suggestions made at the meeting was a wish for more comparisons with policy instruments addressing similar emissions in other countries. The available resources and data, and the scope of the paper, does not allow a comprehensive international comparison to be made, but some attempts in this regard are included in Section 6.

Thanks to kind help from Swedish authorities, the discussion of the "political economy" surrounding introduction of the tax, some 20 years ago, has been extended.

**ACTION REQUIRED**: For declassification.

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*Lessons in Environmental Policy Reform:*

# THE SWEDISH TAX ON $NO_X$ EMISSIONS

## 1. Environmental policy problem

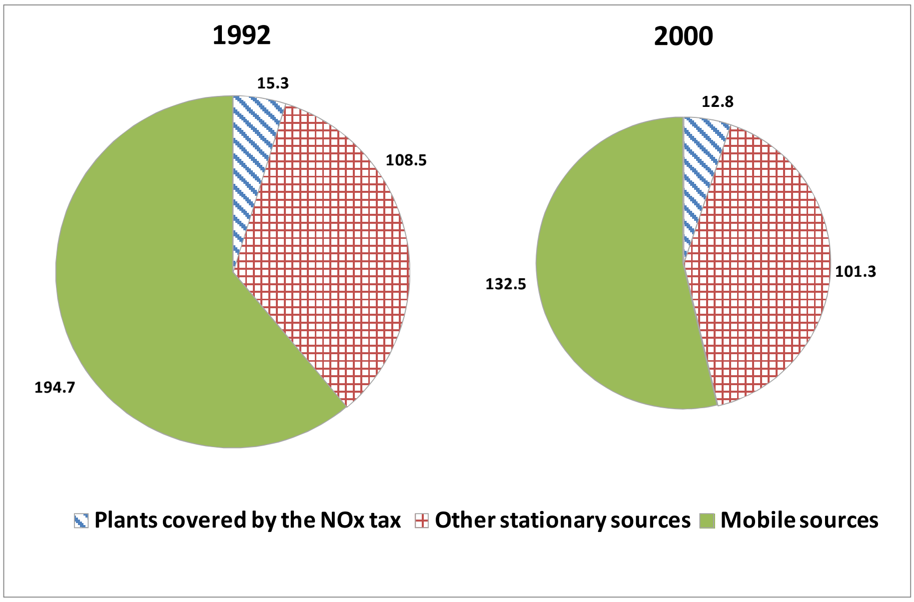
1. $NO_x$ is a term used to cover nitric oxide, NO, and nitrogen dioxide, $NO_2$. They are produced from the reaction of nitrogen and oxygen in the air during combustion, especially at high temperatures. $NO_x$ emissions eventually form nitric acid when dissolved in atmospheric moisture, and this is a component of acid rain.[1]

2. Soil acidification has been a major political issue in Sweden since the 1980s. Sweden is more sensitive to acid deposition than most other countries. While in many parts of Europe, acid deposition is partially neutralised on reaching the ground through the process of weathering (chemical decomposition), even moderate acid depositions are sufficient to acidify the soil in Sweden. Most of Scandinavia has geological structures with little calcium and thus little buffering capacity. Sweden is therefore one of the countries that has been most affected by acid rain, causing negative effects on lake and forest ecosystems. Only in the interior of Northern Sweden it seems that the acid depositions have had practically no effect on the soil.

3. According to SEPA (2003), only about 20% on average of nitrogen deposition occurring in Sweden stems from pollution sources within the country itself. The greatest part derives from emissions coming from Central Europe and in the United Kingdom. However, it was nevertheless felt necessary to limit domestic emissions – in addition to working for international co-operation to control emissions.

4. In 1992, more than 60% of the Swedish $NO_x$ emissions stemmed from the transport sector, but by 2000, the sector's share had decreased to 54%, see Figure 1, while *total* emissions had decreased by 23%.

**Figure 1. Emissions of nitrogen oxides in Sweden by sector, 1992 and 2001**




Source: SEPA (2003).

1 See http://en.wikipedia.org/wiki/NOx.

5. Given the strong political attention given to environmental problems related to $NO_x$ emissions, a strategy to bring down overall domestic $NO_x$ emissions by 30% between 1980 and 1995 was adopted in 1985. In 1988, stationary combustion plants were subjected to *individual*, non-tradable, quantitative emission limits through a permitting system according to the law on environmental protection, but it soon became clear that these emission limits would not be effective enough to attain the desired reductions at the desired speed. The Parliament had set guidelines on how the permits ought to be formulated, but these guidelines were not legally binding. The Swedish Parliament therefore decided in 1990 complement the individual limits with a tax[2] of 40 SEK per kg of $NO_x$ emitted from all stationary combustion plants producing at least 50 MWh of useful energy per year.

## 2. Environmental and fiscal constraints

6. Because the costs of reducing $NO_x$ emissions were believed to (and in fact did) vary much across polluters, it was thought useful to use an economic instrument to address the problem. But while *e.g.* $CO_2$ and $SO_2$ emissions depend to a large extent on the carbon and sulphur content of the fuels combusted, most $NO_x$ emissions are produced by reactions with nitrogen present in the air during the combustion process. The emissions will in practice vary significantly depending on the combustion technology employed and the maintenance of the combustion equipment, cf. Box 1.

7. This means that while it is possible to tax the carbon and sulphur content of fuels to limit $CO_2$ and $SO_2$ emissions, other means are needed to tackle $NO_x$ emissions. In principle, a tax levied on measured $NO_x$ emissions would be the best, but this can be administratively complicated and costly. When the tax was proposed, it was estimated that continuous measuring of $NO_x$ emissions would cost about SEK 350 000 (about EUR 37 000) per plant per year.[3] The magnitude of these costs made it necessary to limit the tax to relatively large plants. The very largest energy producers were, however, already obliged to have equipment for continuous emission measurements installed, so for them, the $NO_x$ tax did not cause any additional measurement costs.[4]

8. While the system of individual emission permits for firms according to the law on environmental protection mentioned above covers firms larger than 50 MW, the tax covers all firms with a capacity larger than 10 MW. Initially, about 200 plants producing more than 50 GWh of usable energy per year were regulated. In the following three years, average emissions per unit of useful energy produced fell by 40% among regulated plants. Its effectiveness, coupled with falling monitoring costs, led to extensions of the system, first in 1996 to about 270 plants producing at least 40 MWh of useful energy per year, and then from 1997 onwards, to about 400 plants producing at least 25 MWh of useful energy per year.[5] Currently,

2 This levy is often referred to as a 'charge', but it seems clear that according to OECD's definitions, it is rather a 'tax'; *i.e.* an "*unrequited* payment to general government".

3 SEPA (2003) indicates that the costs of operating a continuous measuring system at that time had decreased to about SEK 100 000 per year – with significant variations from plant to plant. The investment costs were estimated to between SEK 250 000 and SEK 300 000, excluding costs related to any changes in the building structure that might be required.

4 If the measuring equipment should be temporarily out of order (up to 60 days per year), the firms are obliged to report emissions equal to 150% of what was measured in a period with similar production conditions in the same year. If emissions are not measured, or an uncertified measuring approach is used, conservative default values are applied, according to the amount of fuel combusted.

5 The EU *Directive on Large Combustion Plants* specifies emission limits for several air pollutants and a requirement to continuously monitor concentrations of $SO_2$, dust and $NO_x$ in flue gases. All combustion plants with a thermal input of more than 100 MW have been subject to continuous emission monitoring since November 2002. For Sweden, the Directive has no real implications on $NO_x$ emissions since most plants affected are already regulated by the $NO_x$ tax.

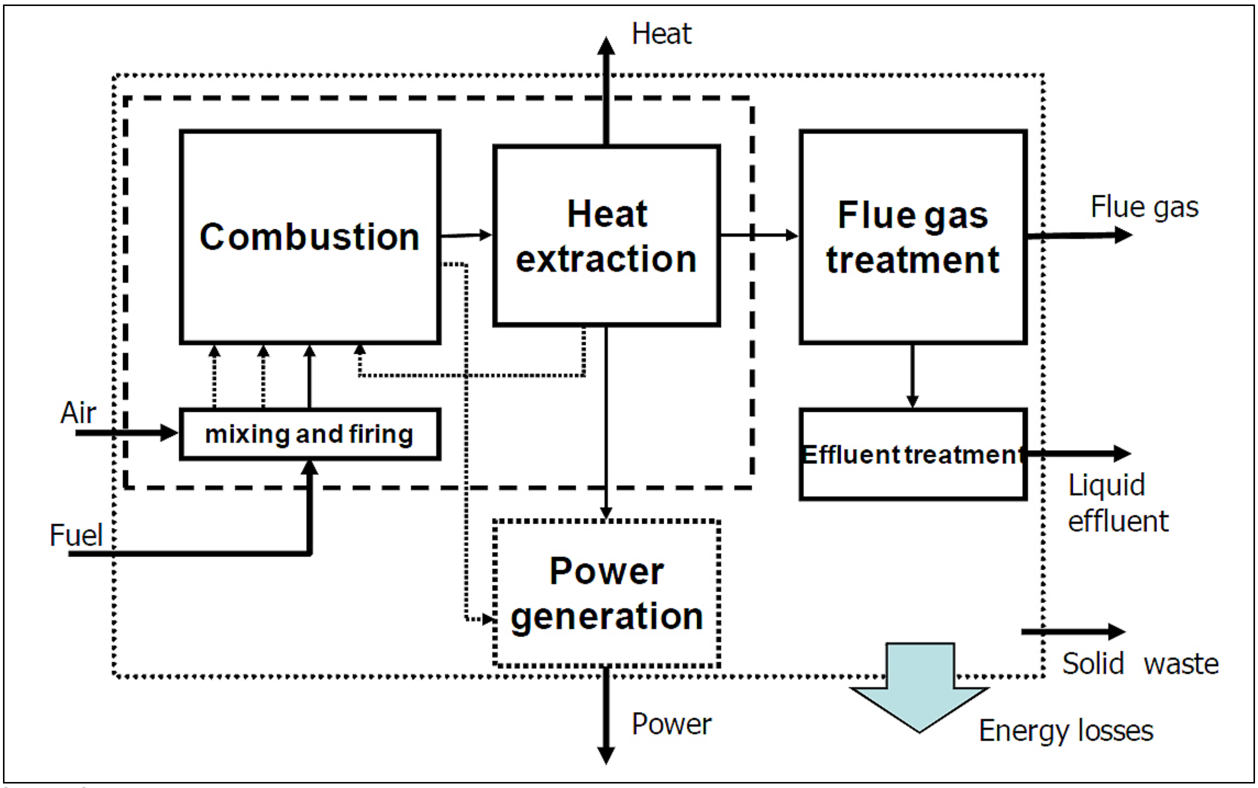
all stationary combustion plants producing above the energy output limit and belonging to any of the sectors power and heat production, chemical industry, waste incineration, metal manufacturing, pulp and paper, food and wood industry, are subject to the $NO_x$ tax.

9. The cement and lime industry, coke production, and much of the mining industry, refineries, blast-furnaces, glass and isolation material industry, wood board production and processing of biofuels are exempt from the tax, due to concerns about unfeasibly high costs. In the proposition to the Parliament, it was stated that the tax was meant to address combustion systems that *produce a medium for energy transmission* – steam – to be used for heating of buildings, electricity generation or in industrial processes. Soda boilers used in the pulp and paper industry form an integrated part of the pulp production, with the main task of regenerating chemicals, and were exempted from the tax.

**Box 1. What causes $NO_x$ emissions?**

Combustion uses fuel to produce heat. Heat extraction and conversion are the primary functions of combustion units. It is during these steps that the energy is converted into a useful form: piped steam, hot water, hot oil, and/or electricity. Heat requires fuel and an oxidising agent, generally air. Fuel and air are fed, mixed and fired to create a flame, which is propagated throughout the combustion chamber, whose shape, size and materials all can affect $NO_x$ formation and overall efficiency. A conflict may appear between energy-efficiency and $NO_x$ formation, as one way of increasing combustion-efficiency is to raise temperature and pressure, which considerably increases the formation of $NO_x$. Fluidised bed combustors partly overcome this limitation and allow simultaneous efficiency gains and cleaner flue gases. The relationship between combustion parameters and $NO_x$ formation is highly non-linear and complex. The exhaust gases leave the combustion chamber and may go to post combustion processes intended to reduce air pollutants (*e.g.*, $NO_x$, $SO_2$, CO and PM). These pollutants can be transformed, precipitated and washed in liquids or deposited as sludge, depending on their nature and concentrations. Given the complexities of $NO_x$ formation, it is crucial with direct, continuous monitoring at the plant.

**Scheme of the main steps in a combustion process**




*Source*: Sterner and Turnheim (2008).

## 3. Political context and the reform process

10. There was much focus in most political parties in Sweden on the environmental problems caused by $NO_x$ emissions at the time when the tax was being prepared. People had *e.g.* seen dying forests with their own eyes, and there was a broad understanding that this was linked to $NO_x$ (and sulphur dioxide, $SO_2$) emissions.

11. The country had a Social Democrat minority government, which in general relied on parliamentary support from a Left-wing Communist Party and/or a "Green Party", which had been elected to the Parliament for the first time in 1988 – obtaining 20 out of the in total 349 seats.[6]

12. The tax on $NO_x$ emissions was proposed by a public commission, with *i.a.* all parliamentary parties, the most relevant ministries,[7] and stakeholder representatives from civil society represented. This commission investigated economic instruments that could be applied for environmental policy in a report issued in 1989.[8] This proposal was presented for broad public consultation, and a large number of public and private stakeholders expressed their views. Most of the stakeholders supported the main lines of the proposal – but one can note that the institution responsible for issuing the individual environmental operational permits expressed some scepticism. It stated that emission reductions could be achieved simpler via stricter use of these permits – but while a $NO_x$ tax would provide equal incentives 'at the margin' to all polluters covered to reduce emissions, and thus minimise total abatement costs, it would be very difficult to achieve this via individual environmental permits.

13. On 5 April 1990, the Government proposed to the Parliament that a tax as suggested by the commission be introduced as from 1 January 1992, as part of a major deal with one of the *opposition* parties, the liberal "Peoples Party" regarding a "tax reform of the century"; a "tax switch", which also included the introduction of $CO_2$ and $SO_2$ taxes and reductions in marginal income tax rates.

14. The lead-in time chosen for the $NO_x$ tax, which was in line with the proposal from the public commission, was meant *i.a.* to allow the affected firms install the compulsory, certified measurement equipment.

15. All parties in the Parliament supported the proposal when it was debated in June 1990, but some parties wanted to apply *additional* policy instruments to address $NO_x$ emissions stemming from other sectors, including the transport sector.

16. At this time, the election period in Sweden was only three years, and in the general election that was held in September 1991, the "Green Party" dropped out of the Parliament,[9] while a new, right-wing "populist" party, focusing on tax reductions and a smaller public sector, obtained 25 seats. After the 1991 election, this latter party provided parliamentary support for a new centre-right minority coalition government – but the $NO_x$ tax was nevertheless implemented after the foreseen lead-in time.

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6 The Social Democrats had 156 members of the Parliament and the Left-wing Communist Party had 21 members. These two parties could thus achieve a majority, without the support of the Green Party.

7 One can notice that it was the Ministry of Environment and Energy that was responsible for the energy sector at that time, not *e.g.* the Ministry of Industry. However, in any case, there was generally broad agreement across the relevant ministries about the approach chosen.

8 SOU 1989:83, *Ekonomiska styrmedel i miljöpolitiken. Energi och trafikk.* (Economic instruments in environmental policy. Energy and traffic.) The commission also proposed several other economic instruments in several reports, including the Swedish $CO_2$ and $SO_2$ taxes.

9 In the 1991 election, the Social Democrats got 138 seats and the Left-wing Communist Party 16 seats.

17. The tax rate was originally set to SEK 40 per kg $NO_x$ – based on an estimate of the marginal costs of abatement measures that were expected to trigger an emission reduction of some 5-7 000 tonnes $NO_x$ per year – the amount necessary to fulfil the mentioned objective of reducing $NO_x$ emissions by 30% between 1980 and 1995. None of the stakeholders taking part in the public hearing made any comments regarding the tax rate.[10] From 1 January 2008, the tax rate was increased to SEK 50 (EUR 5.5) per kg $NO_x$, among other things, in order to re-establish the original *real* value of the tax rate, to maintain a strong abatement incentive.

18. The issue of a broadening of the tax to additional sectors has been mentioned in several documents presented to the Parliament, but no in-depth public investigation of the issue have been made, and no proposal to this end has been presented.[11]

## 4. Dealing with distributional and competitiveness concerns

19. The main mechanism for dealing with distributional and competitiveness concerns in this case is the refund mechanism that is included in the design of the tax. Except for a minor amount retained to cover administrative costs,[12] all the revenues (amounting to SEK 817 million – about EUR 85 million – in 2010)[13] are returned to the firms covered by the tax, *in proportion to the amount of useable energy they produce*. In practice, this means that firms with low $NO_x$ emissions per unit of energy produced are *net beneficiaries* of the scheme – only firms with large $NO_x$ emissions per energy unit are net tax payers.

20. The net winners and losers among the firms in the different industrial sectors covered by the tax in 2010 are illustrated in Figure 2. Each vertical bar in the graph represents a separate firm. The bars showing positive values represent firms that receive more in refund than what they paid in taxes – the "winners" in the system. While there are "winners" and "losers" in all sectors, the "losers" dominate in the pulp-and paper industry[14] and the wood industry – but the net tax payments per firm are relatively modest. One can also notice a few large "winners" in the sector of combined heat and power generation – with one plant receiving more than EUR 3 million in net refund.

21. One potential competitiveness issue nevertheless remained: competition between the energy-producing firms that are covered by the scheme and firms with an energy-production below the threshold could be an issue. As mentioned above, the significant costs involved in continuous monitoring of $NO_x$ emissions meant that authorities had to set a threshold, below which level of energy production a firm was exempted from the tax. This was deemed to be of importance for the competitiveness of district heating,

10 One can notice that the tax rate was *not* based on estimates of the damage caused by a kg $NO_x$ emitted.

11 It can be mentioned that in 2007 and 2010, Norway and Denmark introduced taxes on $NO_x$ emissions with tax rates EUR 2.1 and EUR 0.7 respectively, with – at the outset – broader sectoral coverage than what is applied in Sweden, and *without* a refund system as applied in Sweden. The Danish tax rate is scheduled to increase to EUR 3.4 per kg NOx from 01.07.12. The tax rate applied in Norway is based on an estimate of the value of the damage caused by a kg $NO_x$ emitted. However, due to strong opposition from industry, in Norway, emission sources covered by environmental agreements with the State concerning the implementation of measures to reduce $NO_x$ in accordance with a predetermined environmental target have been exempted from the tax. Taxes on $NO_x$ emissions have also been introduced in several other countries, but in most cases, the tax rates are quite modest.

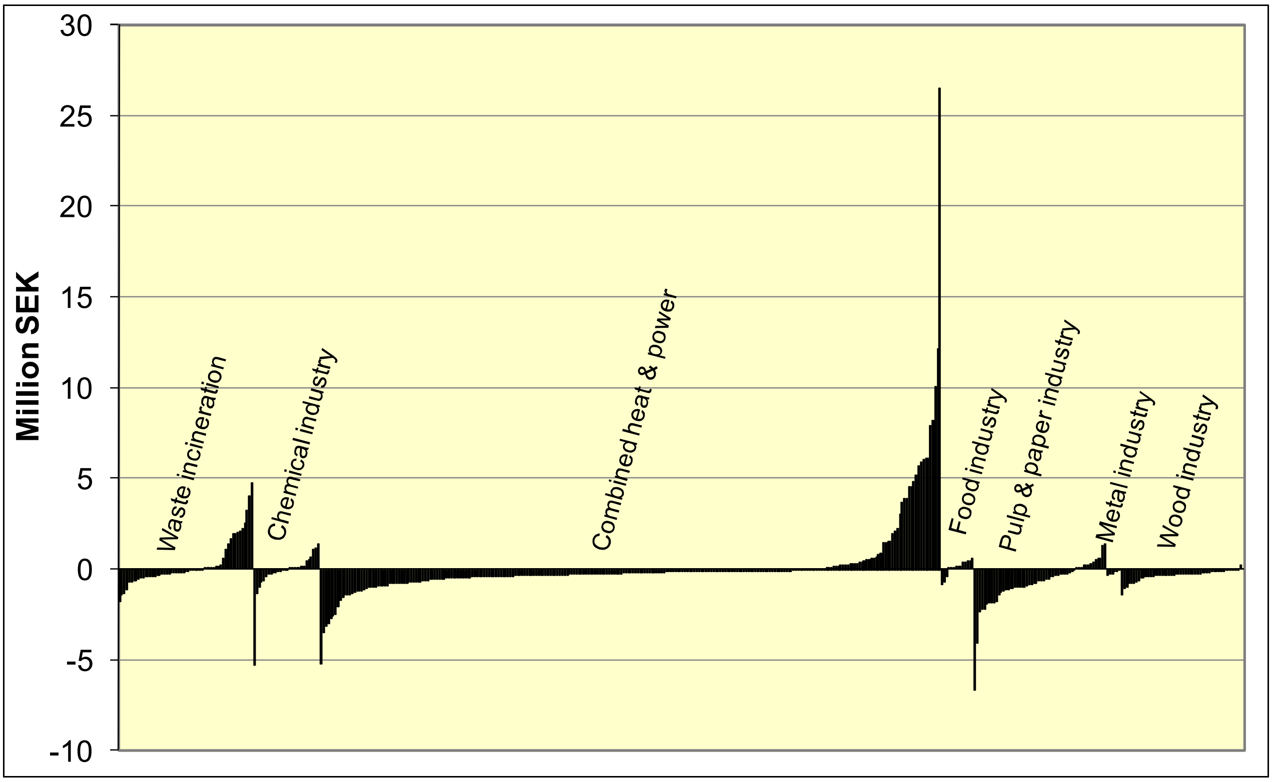
12 SEPA (2003) stipulates that the administrative costs represented about 0.7% of the total tax revenue.

13 In 1992, the first year the tax applied, the revenues were SEK 612 million, according to SEPA (2003).

14 Possibly for this reason, the pulp and paper sector at one stage suggested that the refund system should be changed, in such a way that each sector received a refund equal to the total tax payments from that sector (with a deduction for administrative costs). This proposal was, however, not adopted.

compared to individual heating in homes and offices. This has been addressed by the refund system already described, but also by twice reducing the threshold value, from originally 50 MWh of useful energy per year to 25 MWh of useful energy per year – partly in response to the development of cheaper measurements technologies. The lower is the threshold, the broader is the coverage of the tax – and the smaller are the competitiveness problems vis-à-vis firms that are not covered.

**Figure 2. Net tax payers and net refund receivers in different sectors**
2010




Source: Swedish Environment Protection Agency.

22. Due to the refund mechanism, there was hardly any *net* cost increase for industry, and hence virtually no impacts on product prices. This in turn meant that there is no negative income distribution impact related to the scheme.

23. On the other side, this is also one of the disadvantages of a refunded tax: It will provide a smaller incentive for users that buy products causing large $NO_x$ emissions in their production to substitute away from such products than what a tax that is not refunded would do, as it would cause less of a price increase for these products. In other words, there would only be a modest demand impact of the tax.[15] Turning for a moment the attention to climate change policies, it would be very difficult to achieve a fundamental decarbonisation of the economy if one only were to rely on taxes where *e.g.* electricity generators and other industries had their tax payments refunded, in one way or another.

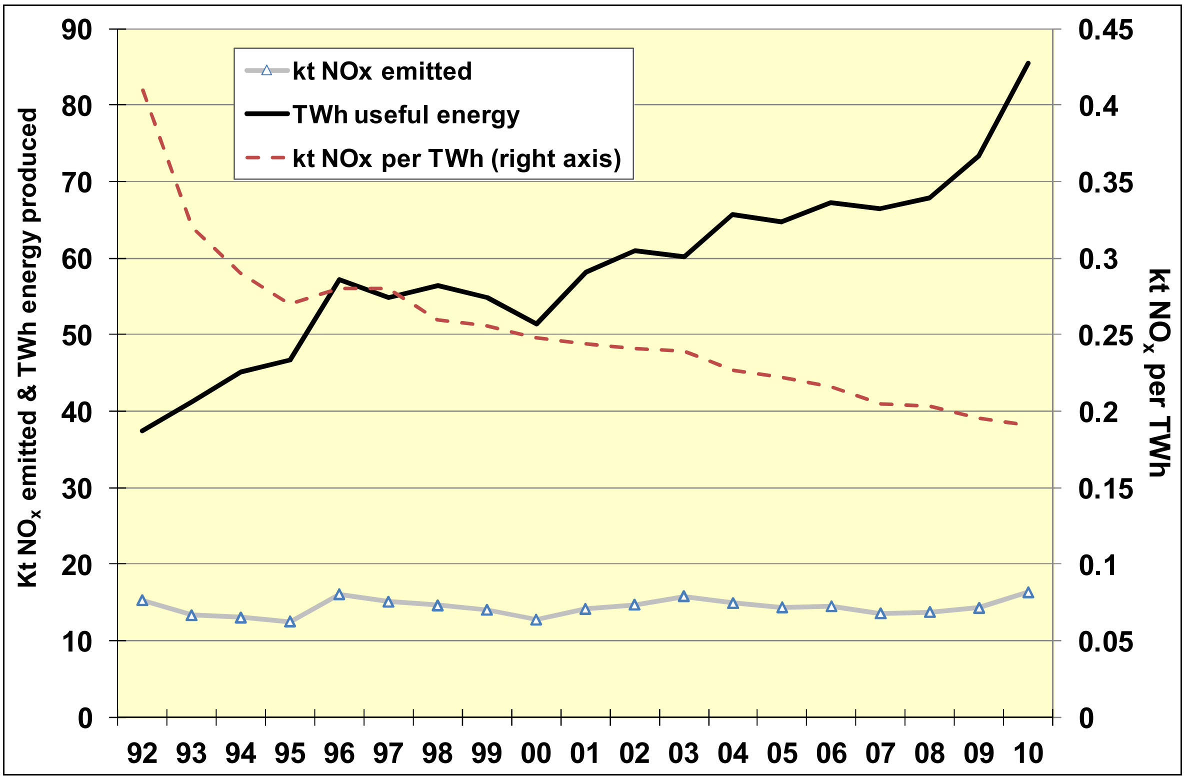
15 The tax and refund system applied in Sweden is very close in its impacts to an emission trading system with free allocation of permits, *based on current output levels*. For further discussion, see OECD (2008) and Sterner & Höglund Isaksson (2006).

## 5. Outcomes

### *5.1 Environmental impacts*

24. Figure 3 illustrates the environmental outcome of the tax. From 1992 to 2010, *total* $NO_x$ emissions from the plants covered by the tax were relatively stable. However, over the same period, the amount of energy produced by these plants more than doubled – partly because of the lowering of the threshold for tax inclusion mentioned above, meaning that more firms became covered by the tax. Hence, over the period, $NO_x$ emissions *per unit of energy produced* has been reduced by more than 50%.

**Figure 3. Total $NO_x$ emissions, total energy production and $NO_x$ emissions per energy unit**



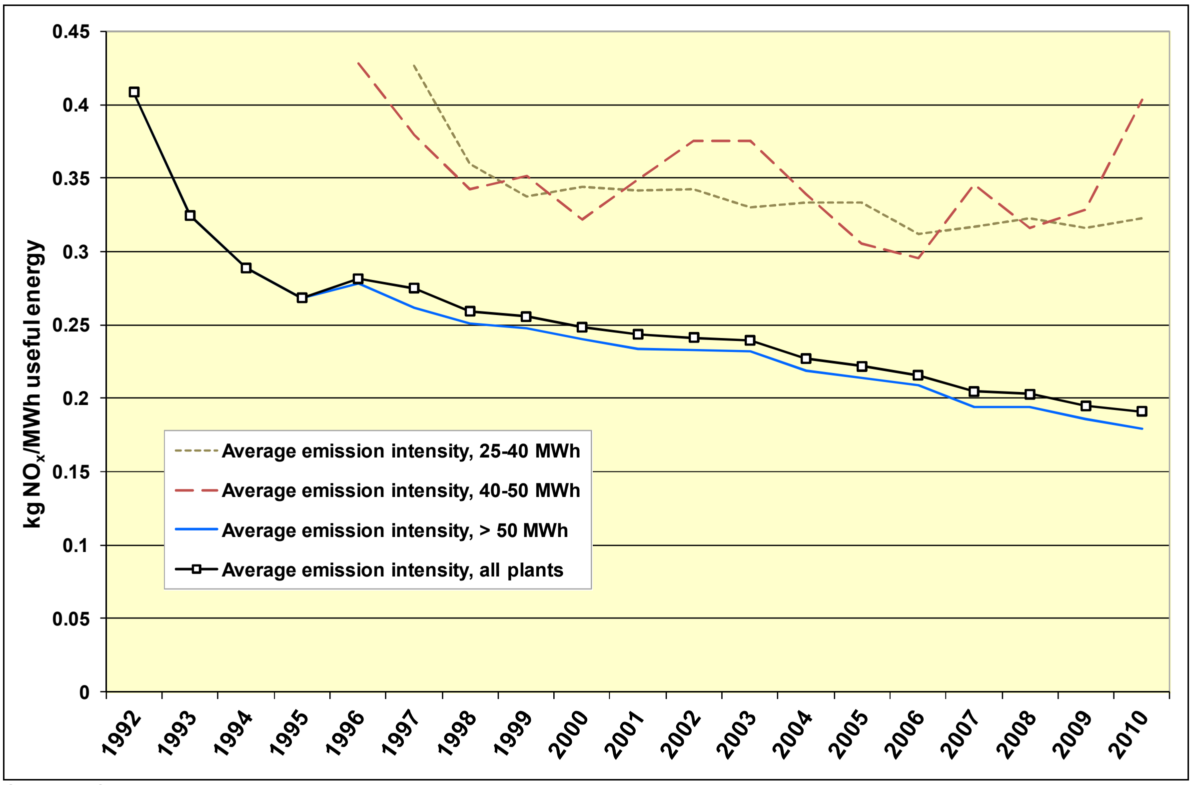

Source: Swedish Environment Protection Agency.

25. Figure 4 indicates that it is in the firms with an energy production larger than 50 GWh per year that the improvements in $NO_x$ emissions per unit have been most important. For the firms with an energy production less than 50 GWh a year, the emission intensity did decrease significantly the first year after taxation was introduced, but emissions since then have been more varied.

26. The tax on $NO_x$ emissions has had a strong impact on innovations related to abatement of $NO_x$ emissions.[16] Based on a survey of 114 plants regulated by the $NO_x$ tax from 1992 to 1996, Höglund (2000) estimated the total costs per unit $NO_x$ reduced. During these first five years of the tax and refund system, the average total cost was estimated at 25 to 40 SEK per kg $NO_x$ reduced.

16 See OECD (2010a and 2010b).

**Figure 4. $NO_x$ emissions per energy unit for firms in different size categories**




Source: Swedish Environment Protection Agency.

27. Splitting the total costs of the $NO_x$ tax into detailed cost components, Höglund (2000) found that abatement costs make up about 50% of total costs, or 12 to 25 SEK per kg of reduced $NO_x$ emissions, depending on the assumed lifetime of fixed investments. Monitoring costs, including annual calibration of monitoring equipment, were estimated at 140 000 to 193 000 SEK per plant per year, or about 20% of total costs. Administration costs were found to be low. About 2% of total costs were spent on additional administration within plants and 1% on administration by Swedish Environmental Protection Agency (SEPA), according to this study.

28. $NO_x$ abatement often gives rise to increased emissions in other pollutants, like carbon oxide (CO), nitrous oxide ($N_2O$) and ammonia ($NH_3$). Although the damage values of these pollutants to society are difficult to estimate, Höglund (2000) made an attempt, using estimates by SEPA (1997). The cost for emission increases in these pollutants was found to represent about 23% of total costs. Finally, the refund mechanism gives rise to a welfare loss due to distortions in resource allocation, which was estimated at about one SEK per kg $NO_x$ reduced, or 3% of total average costs. The cost components are summarised in Table 1.

**Table 1. Relative contribution of different components to the total cost of the Swedish $NO_x$ tax**

| Cost component | |
|---|---|
| $NO_x$ abatement | 50% |
| Monitoring and compulsory calibration of monitoring equipment | 20% |
| Plant administration | 2% |
| Regulator administration | 1% |
| Increased emissions of CO, VOC, $N_2O$ and $NH_3$ | 23% |
| Distorted resource allocation due to refunding | 3% |
| Total (25 to 40 SEK per kg $NO_x$ reduced) | 100% |

*Source*: Höglund (2000).

29. In 1996, plants belonging to the energy sector had reduced emission intensities by more than their cost-minimising level, while pulp- and paper, as well as chemical- and food sector plants, fell short of reaching their cost-optimal level of abatement. The over-compliance of the energy sector plants may be explained by the public ownership of these plants, which adds compliance with environmental objectives to the profit-maximising objective, and by the fact that energy is the final product of the sector. In the pulp- and paper and chemical- and food industry sectors, the attention to the cost-effectiveness of their energy production may be subordinate to more pressing needs in other parts of the production.

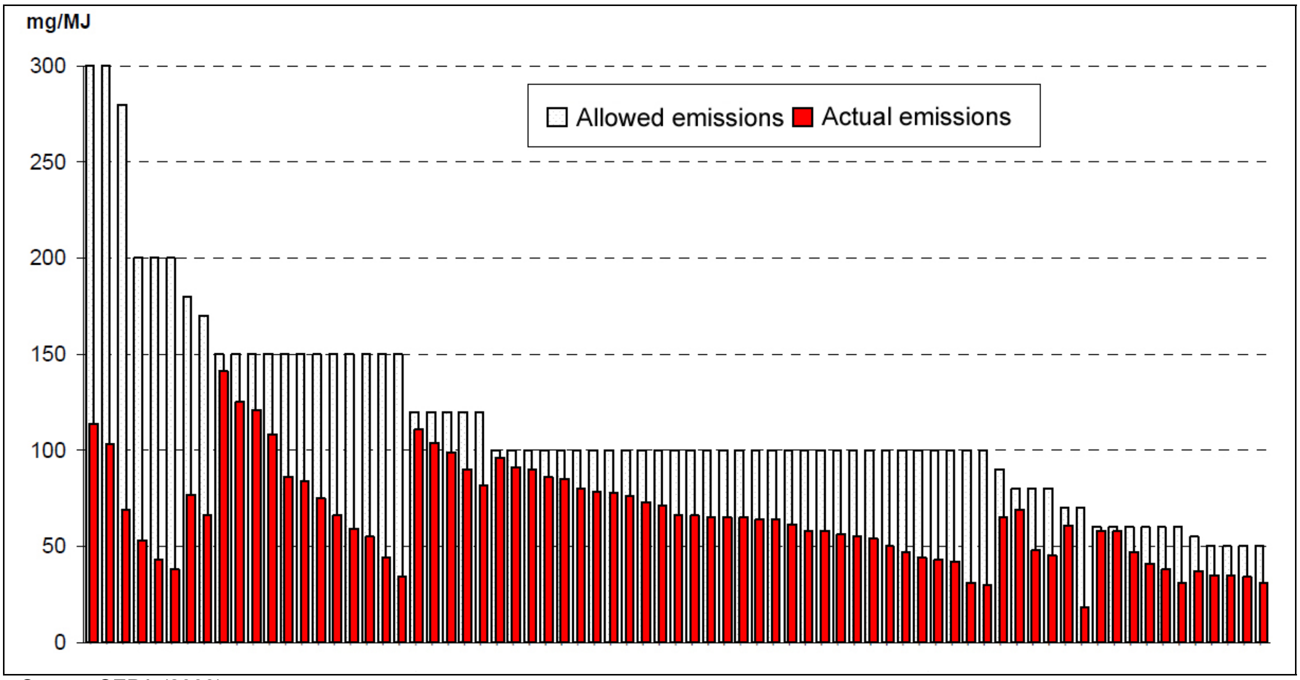
30. While only 7% of the plants subject to the $NO_x$ tax reported to SEPA that they had $NO_x$ abatement technologies installed in 1992, already one year after the introduction of the tax, the picture looked very different. In the 1993 survey, 62% of plants reported having some kind of $NO_x$ abatement technology installed, and the share increased to 72% in 1995.

31. In a survey of plants regulated in the first five years of the tax, Höglund-Isaksson (2005) found that the adoption of $NO_x$ control technologies was a combined effect of the tax and the individual emission standards that the plants had been subject to since 1988. She found that out of 162 $NO_x$-reducing measures undertaken, 47% were said *not* to have been implemented without the introduction of the tax, 22% were undertaken primarily to meet the quantitative standards, and 31% primarily for other reasons, *e.g*., improved cost-effectiveness (unrelated to $NO_x$ reductions) or compliance with emission standards for other pollutants than $NO_x$ (predominantly $SO_2$). Thus, the $NO_x$ tax appears to have been the most important, but not the *only*, factor for $NO_x$ abatement adoption during this first phase of the $NO_x$ tax and refund system.

32. The individual emission limits are determined by regional authorities on a plant-by-plant basis, with nationwide recommendations from the Swedish EPA in mind. Although the regional authority is the final decision-maker, the plants also participate in the decision process, and the resulting emission limits should *not only* take environmental aspects into account, but also consider potential effects on regional economic development and job opportunities. A complete comparison of the effectiveness of individual environmental permits and the $NO_x$ tax in reducing emission intensities of regulated plants is not possible because SEPA does not collect this information. The information is only collected by the 21 regional authorities. For an evaluation of the $NO_x$ tax, SEPA (2003) collected information on emission standards and actual emission intensities for 73 plants that were regulated by the $NO_x$ charge both in 1997 and 2001 and that had emission standards expressed in mg $NO_x$ per MJ energy produced. The results are shown in Figure 5. Worth noticing are the similarities of the emission limits across different plants, indicating that the levels have been determined following the standardised national recommendations by SEPA, rather than taking individual plant circumstances into account. The actual emission intensity levels were on average 40% below the limits specified by the quantitative standards for these plants. Also, *actual* emission intensities for plants with very generous standards were comparable with emission intensities in plants with considerably stricter limits. Thus, the $NO_x$ tax appears to have provided strong incentives to lower emission intensities well below the limits of the quantitative standards for most of the surveyed plants.[17]

17 It is also worth noticing that all the plants seem to have been in compliance with the emission limits they were facing.

**Figure 5. Quantitative emission limits and actual emission intensity for individual plants in 2001**
Plants regulated in 1997 and 2001, with emission limits specified in mg $NO_x$ per MJ.




*Source*: SEPA (2003).

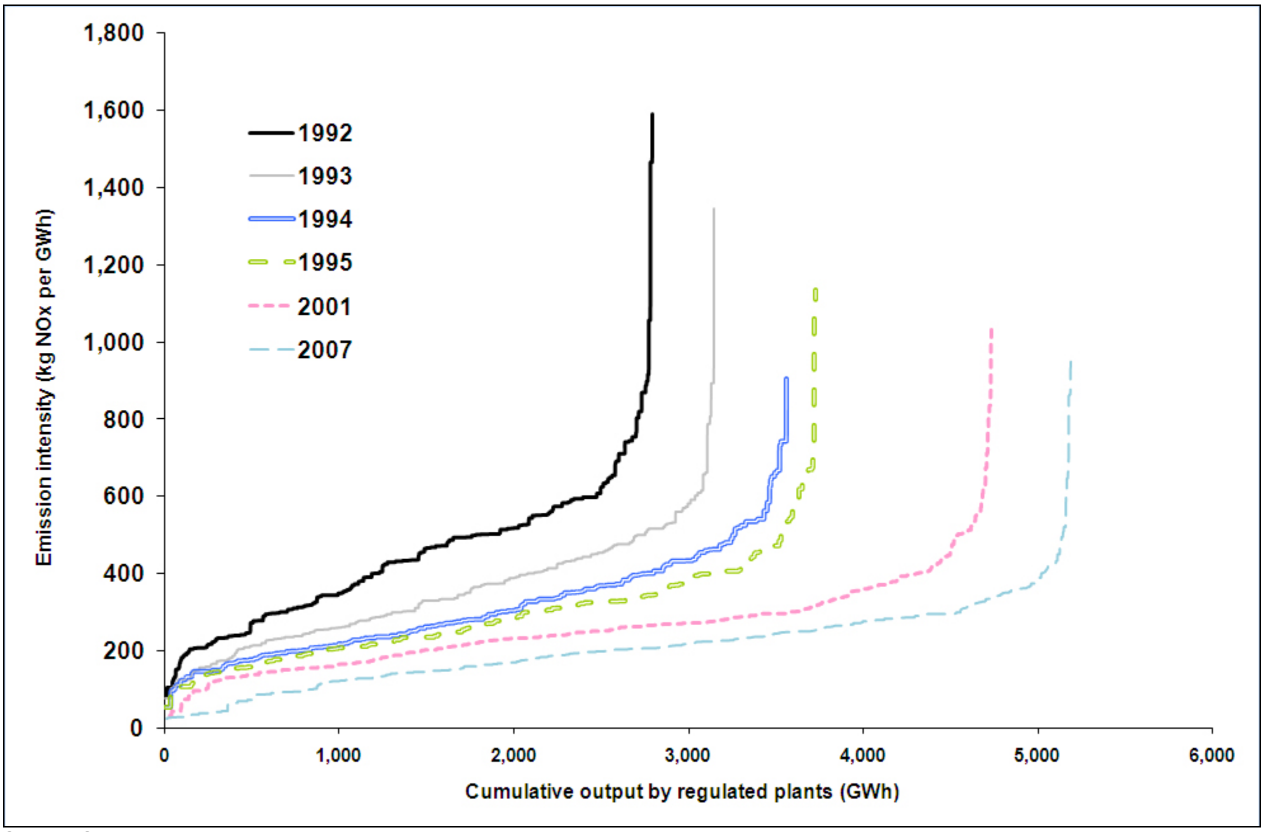
### *5.2 Impacts on abatement costs*

33. In OECD (2010a), Lena Höglund-Isaksson and Thomas Sterner analysed a sample consisting of 626 combustion plants that were regulated by the $NO_x$ tax during at least one year between 1992 and 2007. In Figure 6, the plants have been ordered by increasing emission intensities and plotted against the cumulative output of the plants. This illustrates the emission intensity attainable for a given level of cumulative output in a particular year. As shown, for a given level of cumulative output, emission intensities in later years are considerably lower than in 1992 when the tax was introduced. In 1992, the plants were *e.g.* able to produce 3 000 GWh emitting less than 550 kg $NO_x$ per GWh. Sixteen years later, in 2007, the plants were able to produce the same amount of energy emitting less than 181 kg $NO_x$ per GWh – an improvement by 67%. There are three main explanations for this:

- Cumulative output produced by the plants increased by 74% over the period. The expansion in output took to a large extent place in plants that were relatively emission-efficient or, when increases took place in new plants, these were in general more emission-efficient than old plants.
- Regulated plants invested in $NO_x$ mitigation and were therefore able to produce more output with fewer emissions.
- Innovations in mitigation technology made it possible to reach even lower emission intensity levels for the same output level.

34. All three explanations will have the effect that the slope of the curves in Figure 7 flattens over time.

**Figure 6. Emission intensity levels for given levels of cumulative output**
1992-95, 2001 and 2007

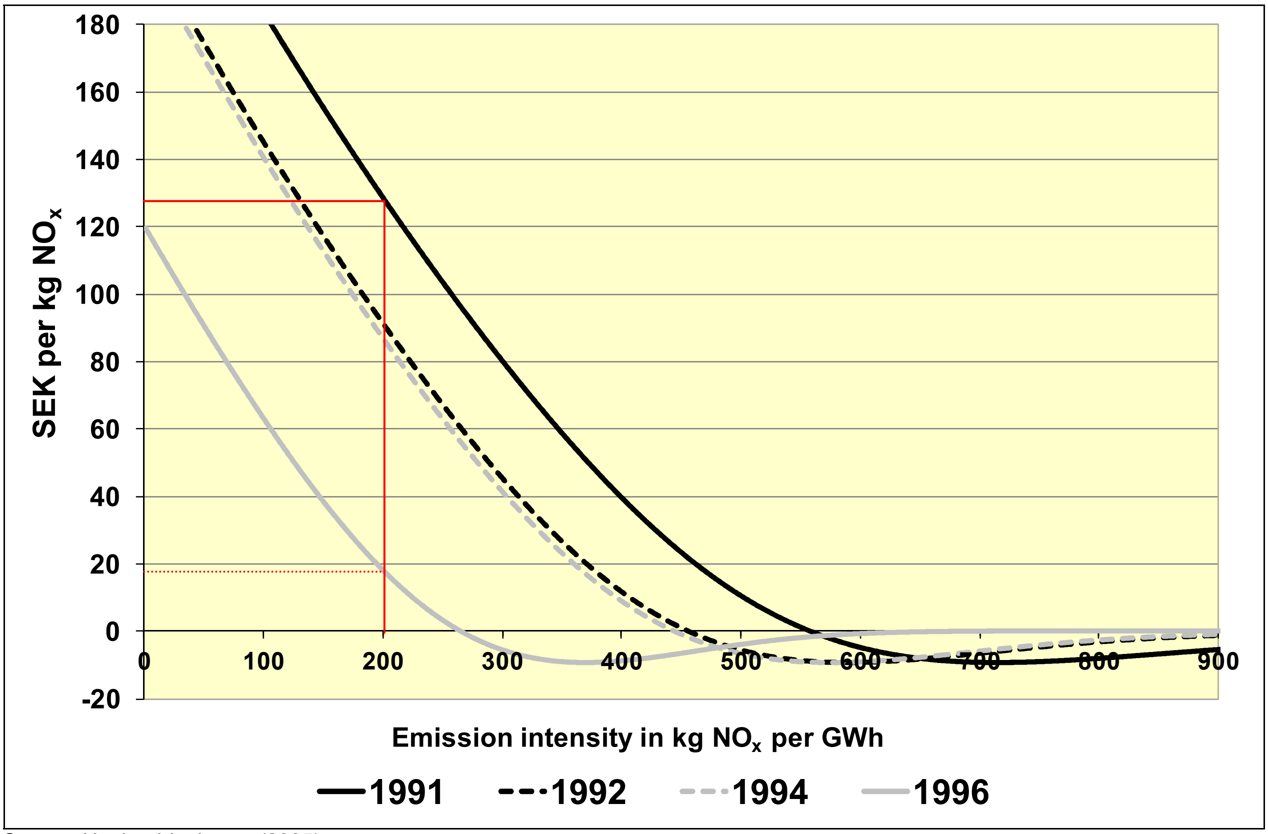



*Source*: SEPA (2008).

35. Using cost-savings in abatement for given emission intensity levels as an indicator for the occurrence of innovations in abatement technology, one could measure the incidence of innovations by measuring changes in abatement costs for given emission intensity levels over time. This, however, requires detailed information about actual investment and operation costs of abatement technologies from firms having actually installed the technologies. Systematic collection of this kind of abatement cost data is very rare. To measure effects on innovations, the data needs to encompass a very large number of abatement measures undertaken by the same firms over a longer period of time. Since abatement potentials vary considerably with plant-specific factors (in particular for $NO_x$), it is important that the same plants are followed over time.

36. Höglund-Isaksson (2005) used a survey of 114 plants regulated in 1992-96 to estimate marginal abatement cost curves, adding time as an explanatory variable, in order to capture effects of technological development. Estimations were done for the energy, pulp-and-paper and the chemical-and-food sectors. Innovation effects were measured as downward shifts of the marginal abatement cost curve from one year to the next. The energy sector was most active in abatement during 1990-96 and only for this sector was it possible to find statistically significant evidence for falling marginal abatement costs over time. Compared to 1996, marginal abatement costs were significantly higher for the same level of emission intensity in years 1991, 1992, and 1994. The predicted marginal abatement cost functions for these years are presented in Figure 7. These show *e.g.*, that the emission intensity attainable at zero abatement cost moved from 557 kg per GWh in 1991 to about 300 kg per GWh in 1996.

**Figure 7. Marginal $NO_x$ abatement costs in the energy sector in Sweden**
1991-1996




Source: Höglund-Isaksson (2005).

37. This shift likely comes from adoption of innovations in abatement technology, which made it possible to produce energy with less $NO_x$ emissions, without increasing costs. To a large extent, the effects are referred to as trimming activities. The introduction of the tax revealed opportunities to pick "low-hanging fruit" in abatement. Some of these opportunities existed also before the introduction of the tax, but the tax, with its requirement to measure $NO_x$ emissions continuously, made it possible for the firms to discover and develop them to attain even lower emission intensity levels.

38. One can also notice that for a firm having an emission-intensity of 200 kg of $NO_x$ per GWh in 1991, the cost of reducing the emissions by one kg (*i.e.* the marginal abatement cost) was close to SEK 130 (about EUR 13.5). In 1996, the cost of reducing the emissions by one kg had decreased to less than SEK 20. This is another way of highlighting the innovations that were stimulated by the $NO_x$ tax.

39. However, even if the $NO_x$ tax clearly stimulated innovation, a regulated firm's willingness to *share* innovations with other regulated plants is hampered by the refund system, since a spread of the innovation to other regulated firms will reduce the innovating firm's own refund. On the other side, for firms producing $NO_x$ emission abatement equipment – not themselves being directly affected by the $NO_x$ tax – the innovation incentives are not hampered in such a way.

## 6. Comparison with other policy instruments

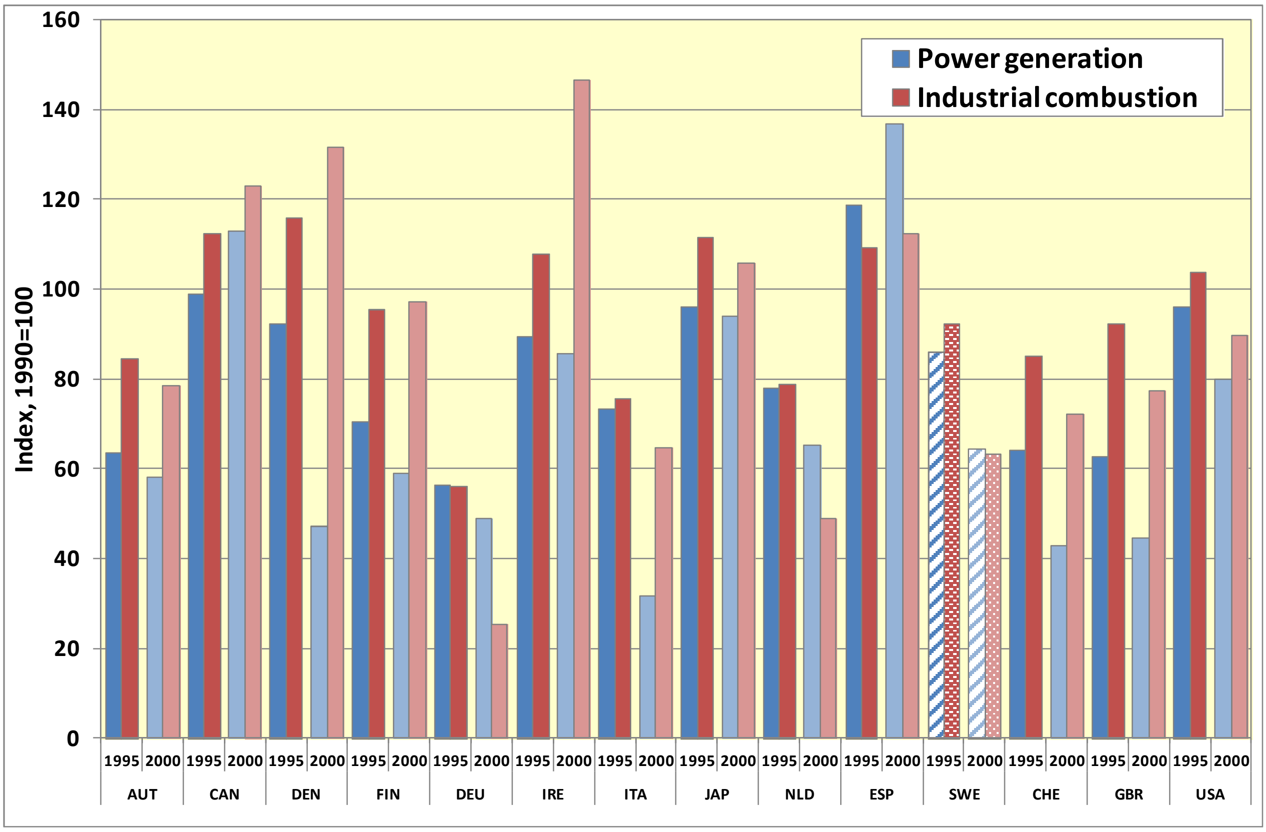
40. As mentioned in the context of Figure 5 above, the $NO_x$ tax seems to have played a larger role in triggering abatement than the individual emissions limits set according to the law on environmental protection. As highlighted in SEPA (2003), even if the emission limits are supposed to be "individual",

they tend to be set in a rather standardised way[18] – which also implies that their economic efficiency is low. The $NO_x$ tax in particular had a stronger impact on emissions than the emission limits with respect to in combined heat and power production and in waste incineration, but it is less easy to document this in the other sectors covered, according to SEPA (2003).

41. SEPA (2003) also looked at whether the individual emission limits had become stricter over time. This was found to be the case – but only to a quite limited extent.[19]

42. It would also be interesting to compare the environmental effectiveness and economic efficiency of the Swedish NOx tax with those of the policy instruments applied in other countries. While it is very difficult, and well beyond the scope of this paper, to provide a comprehensive comparison, a few illustrations can be provided.

**Figure 8. $NO_x$ emissions from electricity generation and industrial combustion in selected countries**
Levels in 1995 and 2000 compared to 1990




Source: OECD Environment Compendium.

43. Figure 8 compares $NO_x$ emissions in 1995 and 2000 from electricity generation and industrial combustion in selected countries to their respective levels in 1990. This is the breakdown of the total $NO_x$ emissions possible in OECD's Environment Compendium that comes closest to the coverage of the

18 40% of all firms included in Figure 5 had a permit to emit 100 mg $NO_x$ per MJ energy they produced.

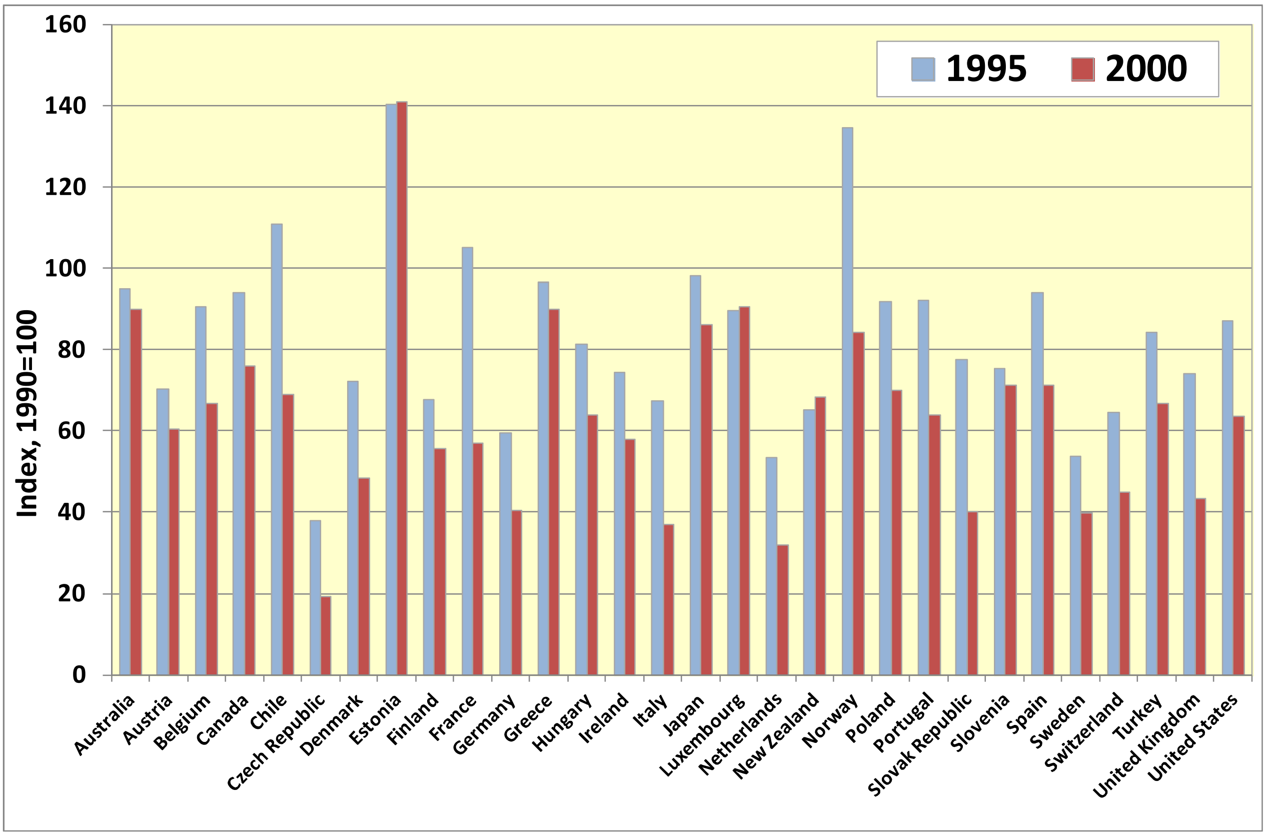
19 For 13 boilers for which emission limits were set during the period 1984 to 1991, the average limit was 125 mg $NO_x$ per MJ energy produced. For the 34 boilers that got such limits during the period 1992 to 1996, the average limit value was 120 mg $NO_x$ per MJ energy produced. For the 15 boilers that received emission limits during the period 1997 to 2001, the average emission limit was 118 mg $NO_x$ per MJ.

Swedish NOx tax, but is underlined that *not all* industrial combustion is covered by the tax. In most, but not all the countries, the emissions from these sectors had decreased since 1990 – and seemingly, developments in Sweden were not particularly "impressive": Many other countries saw significantly stronger $NO_x$ emission reductions in electricity generation and industrial combustion during the 1990s than what took place there.

44. However, this comparison doesn't take into account how the size of the sectors developed over that decade. This is done in Figure 9, where it is shown how much $NO_x$ was emitted unit electricity and heat produced by fuel combustion[20] in electricity generation and industry. Here, Sweden comes somewhat better out, especially when considering that the country's emissions per energy unit at the outset were among the lowest among all OECD.[21] Even starting from a strong position, the $NO_x$ emissions per unit energy produced in 2000 was only 40% of what they were in 1990.

**Figure 9. $NO_x$ emissions per unit of electricity and heat generated via combustion of fuels**

Index, 1990=100




Source: OECD Environment Compendium and IEA Energy Balances.

45. What is lacking in the comparison is of course information about the *costs* of the different policy measures. Unfortunately, the data necessary for a comprehensive comparison over the relevant years is not

20 The comparison only includes electricity and heat produced by combusting fuels. Hence, electricity generated by hydro power or in nuclear power plants is excluded – as this would not generate any $NO_x$ emissions.

21 A country like the Czech Republic started out with several times the $NO_x$ emissions per energy units produced of Sweden, as their emission reductions across the 1990s were facilitated by the major economic restructuring the country went through in those years.

available. What can be said is that the *marginal* abatement costs of the Swedish approach was "capped" at the tax rate of (originally) SEK 40 per kg $NO_x$, or around 4 € per kg – and that the *average* costs were estimated by Höglund (2000) to be between SEK 25 and SEK 40. Unfortunately, similar figures are not available for other countries, for a comparison to be made.

## 7. Lessons learned

46. This example demonstrates clearly that well-designed economic instruments, providing "significant" economic abatement incentives, can be effective in triggering important environmental improvements – measured *e.g.* as $NO_x$ emissions per unit of energy produced. It also demonstrates that such an instrument can have a strong impact on innovation activity – which helps to lower the costs of achieving ambitious environmental policy objectives over time.

47. The introduction of the tax was most likely helped by the good understanding many Swedes had regarding the environmental damages caused by $NO_x$ emissions. Correct and well-focused environmental information to the public at large can play an important role in this respect.

48. Many Swedes were also aware of the potential benefits of using economic policy instruments in environmental policy. All parliamentary parties had been represented in the public commission that prepared the basis for the Governments tax proposal, and it seems likely that this contributed to the broad support that the Government's proposal received.

49. The example has also demonstrated the important role that continuous (and correct) measurement of emissions can play in bringing attention to low-cost emission reductions that could be achieved simply by "trimming" the production processes better. In a number of countries, continuous measurement of a broad spectrum of pollutant emissions is now compulsory for many sources. This could form the basis for a more wide-spread use of economic instruments.

50. This is also of relevance in relation to one of the problems mentioned above, namely that measures to abate $NO_x$ emissions can contribute to increased emissions of other pollutants, such as CO, VOC, $N_2O$ and $NH_3$. It is emphasised that this is not due to the use of a tax instrument as such, but a phenomena that could occur as a result of measure taken in response to almost any type of policy instrument. While possible increases in other emissions in principle could be addressed via a number of policy instruments, a promising and consistent alternative would be to introduce a "price" on each of the measured emissions, reflecting the relative damage to society that each of the pollutants cause.

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