# Pollution Abatement in the Netherlands: A Dynamic Applied General Equilibrium Assessment

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**Summary**

This paper deals with an assessment of the economic costs of environmental policies in the Netherlands, using a dynamic Applied General Equilibrium model with bottom-up information on abatement techniques. Empirical abatement cost curves are used to determine substitution possibilities between pollution and abatement and the characteristics of abatement goods.

The results show that an absolute decoupling of economy and environment is possible. Smog formation is the most costly environmental theme, due to the absence of technical abatement options. For all environmental themes, the least-cost way to reduce emissions is via a combination of technical abatement measures and substantial economic restructuring.

**Keywords:** Applied general equilibrium, Pollution abatement, Dynamics, Environmental policy, Netherlands

**JEL Classification:** D58, H23, O41, Q28

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# 1. INTRODUCTION

The economic costs of environmental policies are determined by the direct costs of emission reductions and the indirect effects induced by these policies. The direct costs of emission reductions are given by marginal and total abatement costs. The indirect effects can be properly captured by using a multi-sectoral applied general equilibrium model. Unfortunately, most applied general equilibrium models contain abatement cost information only implicitly as the foregone profits or utility resulting from forced changes in behaviour induced by environmental policy, *cf.* Conrad (1999). Though this notion of abatement costs as foregone profits or utility is not incorrect, it disregards the micro-economic information on the available abatement technologies, which should constitute the direct costs of abatement.

At the other end of the spectrum are bottom-up models that contain detailed empirical information on the technical characteristics of specific abatement options, *e.g.* RAINS (Alcamo *et al.*, 1990). Nowadays, most of these models include estimates of the associated direct costs of the measure; they are, however, not capable of assessing the indirect economic effects. The easiest way to integrate the bottom-up model with a top-down economic model is via so-called soft-linking. In this approach, two separate models are specified, and the outcomes of one model are entered as exogenous input into the other model. The converging outcome is then achieved via an iterative procedure. An example of this approach is given in Jacobsen (1998).

Other studies aim at integrating both the bottom-up and top-down modules into one model (so-called hard-linking). Noteworthy examples of such integrated models are the NEMO energy model (Koopmans and Te Velde, 2001) and the model by Böhringer (1998).

Full-scale estimation of abatement costs is not common in top-down environmental-economic models. The detailed description of abatement processes in terms of economic inputs as used in Nestor and Pasurka (1995a) is an exception; Nestor and Pasurka (1995b) show that a proper specification of abatement costs is vital for quantitative estimates of the economic costs of environmental policy.

The vast majority of dynamic AGE models for environmental issues focus purely on climate change (for an overview see Conrad, 1999 and Harrison *et al.*, 2000). These energy-environment-economy models assume that end-of-pipe measures are not available or prohibitively costly compared to fuel switches, and therefore can be neglected in the model. Recent contributions to the field include Bye (2000),Jensen (2000), Rasmussen (2001), Wendner (2001), Dissou *et al.* (2002) and Gerlagh and Van der Zwaan (2003). Models that capture several environmental problems simultaneously are rare; a notable exception is Xie and Saltzman (2000), who distinguish between pollution abatement activities for air quality, water quality and soil quality.

The aim of this paper is to assess the long-run economic costs of current environmental policies in the Netherlands, using a dynamic AGE model augmented with several environmental themes and special attention to the (empirical) characteristics of pollution abatement. The detailed information on abatement costs, in combination with a consistent assessment of the indirect effects, provides a suitable framework for an empirical evaluation of environmental policy in the Netherlands. The novel contribution of this paper is that a consistent methodology that covers both direct and indirect effects is used, allowing for a proper assessment of the interactions between sectoral economic activity and multi-pollutant environmental policy.

The set-up of this paper is as follows. Section 2 provides an overview of the model; a more detailed description of the model and methodology to include the abatement information is given in Dellink *et al.* (2003). Section 3 deals with the data for the Netherlands. The results of the model simulations for current Dutch environmental policies are discussed in Section 4; Section 5 concludes. Information on the empirical abatement cost curves for the Netherlands and a full list of model equations are given in the Appendices.

## 2. DESCRIPTION OF THE MODEL

### 2.1. Economic activity

DEAN[1] is a forward-looking neo-classical growth model. This model type has the advantage that the specification is fully dynamic: the agents take not only the current state of the economy, but also future situations into account when making decisions that affect current and future welfare. This intertemporal aspect lacks in recursive-dynamic models. Moreover, the transition path from the original balanced growth path to a new growth path is more flexible and realistic in a model with an endogenous savings rate (Barro and Sala-i-Martin, 1995). A full set of model equations is given in Appendix II; the main features of the model will be discussed briefly below.

Consumption of different goods and environmental services are combined in a nested CES instantaneous utility function. Each level of consumption requires some combination of pollution permits and abatement, as will be explained in more detail in Section 2.2. The instantaneous utility is aggregated over time, again using CES function. Non-unitary income elasticities are specified using the Linear Expenditure System approach.

The private households have income from the sale of their endowments of capital goods and labour, reduced with lumpsum transfers to the government. The government has three sources of income: sale

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[1] Acronym for "*D*ynamic applied general *E*quilibrium model with pollution and *A*batement for the *N*etherlands".

of the pollution permits, the lumpsum transfer from the private households and tax revenues. The lumpsum transfers are endogenously adjusted to ensure budget balance for the government.

Effective labour supply grows with an exogenous rate every period. This is a combination of demographic developments and increases in labour productivity. Capital formation is based on the assumption that the interest rate is exogenously determined on the world market and that the domestic capital stock is endogenous. Investments in this period are to some extent productive in the same period and to some extent in the next period. To account for capital stocks after the model's time horizon, a transversality condition is included in the model.

Producer behaviour is specified through a nested CES production function for domestic supply and through a zero-profit condition.

World market prices are exogenously given (in foreign currency), and the international market is big enough to satisfy demand for imports and absorb supply of exports at these international prices. Under these conditions, all international trade links with other countries can be aggregated into one additional sector in the model, 'Rest of the World' (RoW). The demand by this sector represents exports and the supply are imports; the budget deficit is exogenously given and the endogenous exchange rate ensures that equilibrium is attained. The reactions on the markets to changes in domestic prices are specified by the Armington approach. This approach assumes that domestic and foreign goods are imperfect substitutes. The model is closed by the market balances for produced goods, domestic demand, the capital and labour market.

### 2.2. Pollution and abatement

Production and consumption processes lead to *pollution* (emissions). In the model specification allowances to emit polluting substances to the environment, controlled in the model via a system of pollution permits, are linked to production output and consumption. To account for the fact that different pollutants contribute to the same environmental problem, pollution is aggregated into so-called environmental themes using equivalence factors for different pollutants. For instance, all major greenhouse gases are aggregated into the environmental theme 'climate change' using the global warming potentials of the different greenhouse gases. It is assumed that the government sets the environmental policy targets exogenously by issuing a restricted number of pollution permits[2].

The proceeds from the sale of the permits are redistributed by the government to the private households in a lumpsum manner. In this way, a market for pollution permits is created, where prices

[2] For climate change, the policy target is based on the contribution of emissions to the stock of greenhouse gases and flexibility in the timing of emission reductions is allowed (see Dellink, 2003, for more details). For Acidification, Eutrophication, Smog formation and Dispersion of fine dust annual emission permits are issued. Desiccation and Soil contamination concern cleaning up past pollution and are represented by a fixed governmental expenditure on abatement, rather than a system of pollution permits. Practical considerations may lead to a different choice of policy instrument in reality. Nonetheless, the approach taken here can serve as a reference point for evaluating other policy instruments.

are determined endogenously by equating demand and supply. Polluters have the choice between paying for their pollution permits or increasing their expenditures on pollution abatement. This choice is endogenous in the model, and the polluters will always choose the cheaper of the two. A third possibility for producers and consumers is a reduction of their production and consumption of the pollution intensive good, respectively.

This becomes a sensible option when both the marginal abatement cost and the price of the permits are higher than the value added foregone in reducing production or utility foregone in reducing consumption. In the benchmark projection, the government distributes exactly the number of permits that allows the producers and consumers to maintain their original behaviour.

A key feature of the model is that the expenditures on abatement are explicitly specified to capture as much information as possible about the technical measures underlying the abatement options. For each environmental theme, abatement cost curves are constructed, using the detailed technical data for the base year (see Appendix I). This procedure involves making an inventory of all known options available to reduce pollution, including end-of-pipe measures and process-integrated measures (*e.g.* fuel-switch). Every option is characterised as a reduction measure that states how much pollution can be reduced and what the associated costs of implementation are. These detailed technical data come from existing inventories (*cf.* Dellink, 2003).

The abatement cost curves, which describe the marginal abatement costs, are translated for each environmental theme into a 'Pollution – Abatement Substitution' or PAS curve. To this end, the abatement costs are presented as a function of pollution (a downward sloping curve). Then, for each theme a CES function (the PAS curve) is estimated to best fit the abatement cost curve. The function states that different combinations of pollution and abatement allow the same level of production for firms or the same level of consumption for the households. A constant elasticity of substitution governs how much additional abatement effort is needed to reduce pollution by one additional unit. The CES-elasticity thus estimated describes the environmental theme-specific possibilities to substitute between pollution and abatement effort (hence the name Pollution – Abatement Substitution curve) and reflects the marginal abatement costs.

The existing technical potential to reduce pollution through abatement activities, *i.e.* without economic restructuring, provides an absolute upper bound on technical abatement in the model. This is a clear difference with the traditional quadratic abatement cost curves, where no true upper bound on abatement activities exists (the abatement costs will always be finite, no matter how much pollution is abated). The empirical importance of an absolute limit on environmental technology has been emphasised by Hueting (1996). The upper bound on abatement is implemented by assuming that part of the pollution ('technically abatable pollution') can be reduced as a result of abatement activities, and the remaining part of pollution is directly coupled with the production quantity of the producers, and with income of the private households. This remaining, ‘technically unabatable’, pollution can only be reduced via reduction in economic activity of these polluting sectors.

The abatement sector is modelled as a separate producer that produces ‘abatement goods’ using both produced goods and primary production factors as inputs. In the model presented here, an abatement sector production function is calibrated on data that are derived from abatement cost curves. The inputs in the CES production function of the abatement sector represent the cost components of the underlying technical measures, including capital costs and operational costs like energy and labour costs. This implies that at original prices, the cost estimates match the original data, which is based on partial analysis, while the effects of endogenous price changes on the abatement costs are fully taken into account in the model simulations.

The output of the abatement sector is demanded by the other producers and by consumers, that have a common set of abatement technologies available. The total costs of abatement will differ between the producers, as they have different initial combinations of abatement costs and pollution levels. Hence, they demand different amounts of abatement and initial *marginal* abatement costs differ (*i.e.* the trade-off as described by the PAS curve differs). The sectoral *marginal* abatement costs will, however, be equalised in the policy simulations, because the resulting equilibrium is characterised by cost-effectiveness. The marginal abatement costs in the new equilibrium will equal the price of the pollution permits. Hence, all polluters are indifferent at the margin between polluting and increasing their expenditures on abatement.

Autonomous pollution efficiency improvements result in a relative decoupling of economic growth and pollution. The development of abatement possibilities and abatement costs over time are captured via specific parameters that govern the changes in the technical potential for pollution reduction over time, and efficiency improvements in the abatement sector. In the current specification of the model, these developments in the abatement possibilities and costs, *i.e.* innovation of new abatement measures, are driven by exogenous parameters. Nonetheless, the model does contain endogenous diffusion of existing abatement technology.

## 3. DATA

### 3.1. The benchmark projection

The base year data are taken from historical data for 1990 for the Netherlands, as reported in Dellink *et al.* (2001)[3]. The Netherlands is chosen because of the wide availability of data. More recent data that is available for economic activity and emissions is used to calibrate the model parameters. On the production side, 27 producers of private goods are identified; this allows for a moderate degree of

[3] Consequently, this section draws heavily on Dellink *et al.* (2001). Statistics Netherlands have adjusted some numbers since then, and hence the numbers used here may differ from Dellink *et al.* (2001).

detail on the side of economic and environmental diversity. A more disaggregated set-up was not feasible due to environmental data limitations. There are two consumer groups: private households and the government. The largest sectors in terms of production value, value added and consumption are Non-commerical services (23% of total value added) and Commercial services (22% of total value added).

For Climate change, the shares of the largest 3 polluters is relatively small (just over fifty percent of total) and emissions are rather evenly spread across sectors. This is in line with the intuition that energy use is widespread across all sectors. Another relatively even spread environmental theme is Dispersion of fine dust. Other environmental themes are much more concentrated. For example, Acidification and Eutrophication are concentrated to a large extent in the Agricultural sector. Agriculture and Private households are among the largest polluters for several environmental themes in absolute terms. The agricultural sector is well known for its environmental impact, though it may seem surprising that it is also the largest polluter for climate change (caused primarily by $CH_4$ and to some extent by $N_2O$ emissions).

In 1990, total output or supply of the abatement sector equals almost 200 million Euro, excluding public environmental expenditures. Including these, the abatement sector amounts to around 9.7 billion Euro.

### 3.2. Economic parameter values

In this section, the most important economic parameters are discussed; together with the data for the base year they govern the benchmark projection of the economy.

The value of the labour supply growth rate is based on the average annual realised growth rate of the Dutch economy in the period 1990 – 2000 and equals 2 percent.

In principle, the benchmark accounting data on depreciation can be used directly to calculate the annual depreciation rate of capital. However, the economic situation in the Netherlands in 1990 was not very favourable, reflected in relatively low savings and investments. Moreover, depreciation data in the National Accounts are notorious for their low quality. Therefore, the steady-state relationship between investments and capital is used to calculate depreciation. This procedure results in a depreciation rate of 3 percent.

The annual interest rate is calibrated to the long-term interest rate on government bonds, as these have no risk premium. This interest rate has in the 1990s steadily declined to below 5% (De Nederlandsche Bank, 2002). For practical reasons, a stable annual interest rate of 5% is used.

The values for the substitution elasticities and the nesting structure for the production functions, the utility function and the international trade functions are taken from Gerlagh *et al.* (2002) and represent adaptation possibilities for the medium term. The intertemporal elasticity of substitution has to be calibrated only for the private households; the value equals 0.5, based on Hall (1988).

### 3.3. Environmental parameter values

The pollution-abatement-substitution (PAS) curves that are derived from the abatement cost curves are characterised by a constant elasticity, the so-called PAS-elasticity. The abatement cost curves and the associated PAS-curves are discussed in Appendix I. The benchmark price of the emission permits can also be derived from the PAS curves using duality theory. For Climate change, the price of the stock addition permits equals zero in the benchmark, since there is no restrictive Climate policy in the benchmark.

The technical potential for pollution reduction cannot be specified on a sectoral basis due to lack of data. The economy-wide technical potential for each environmental theme for 1990 can be directly derived from the abatement cost curves.The growth rate of the technical potential for pollution reduction is based on a comparison of the abatement cost curves for 1990 and 1995. The curves for 1995 are taken from Hofkes *et al.* (2002).

The autonomous pollution efficiency improvement parameter describes the difference between the growth rate of the economy and the growth rate of emissions in the benchmark projection. This difference may be the result of free efficiency improvements as some sort of 'manna from heaven', but also captures the impacts of any abatement activities in the benchmark projection. The autonomous pollution efficiency improvements are calibrated for each environmental theme separately using the realised development of emission levels between 1990 and 2000. It is unrealistic to assume that high autonomous pollution efficiency improvements can be sustained in a growing economy without additional abatement efforts. Therefore, the *ad-hoc* assumption is made that the efficiency improvements gradually change over time to the common benchmark growth rate of 2%, such that benchmark emissions are stabilised in 2030 and beyond.

Honig *et al.* (2000) carried out a study to get a tentative estimate of the decrease of environmental costs over time as the result of decreasing real marginal abatement costs. They conclude that a reduction of total abatement costs with 10 percent in 20 years is not unlikely. Using the bold assumption that this 10 percent decrease in 20 years applies to all abatement costs and all periods, the autonomous abatement efficiency improvement is calibrated to 0.5 percent per year.

### 3.4. Environmental policy scenarios for the Netherlands

Dutch environmental policy targets are based on the National Environmental Policy Plan 4 (NEPP4; VROM, 2001) and summarised in Table 1.

*Table 1. Policy targets for environmental themes in the Netherlands for 2010 and 2030*

| | reduction target 2010 (%-change compared to 1990)[1] | reduction target 2030 (%-change compared to 1990)[2] |
|---|---|---|
| Climate change[3] | -8% | -50% |
| Acidification | -75% | -85% |
| Eutrophication | -65% | -75%[4] |
| Smog formation | -75% | -85% |
| Fine particles in air | -75%[5] | -90% |

[1]: Source NEPP3, except for Fine Particles; [2]: Source NEPP4, except for Eutrophication; [3]: Targets are for emissions of GHGs, not for the associated stock; [4]: Expert judgement; [5]. Based on targets for related themes.

As the table shows, including the intermediate targets for 2010 implies that the path between introduction of the policy and 2030 is non-linear. For most themes, relatively much pollution has to be reduced before 2010.

Three policy scenarios are constructed and analysed: (i) *NEPP2030*, (ii) *Delay* and (iii) *NEPP2010*. In all three scenarios, national emission targets are set for each environmental theme. The only difference between the scenarios is the timing of the environmental policy. In the NEPP2030 scenario, the policy targets have to be met in the year 2030. In the Delay scenario, the same targets are set, with a delay of 10 year. The NEPP2010 scenario consists of the targets from NEPP2030, with additional intermediate targets for the year 2010.

For the themes Acidification, Eutrophication, Smog formation and Fine Particles, the policy targets act as a restriction on the maximum allowable emissions in the target year. For the policy simulations with DEAN, these targets have to be translated into maximum allowable emission paths. In other words, an emission ceiling has to be imposed for all periods in the model horizon. Since no explicit goals exist for periods before or after the policy target year, the *ad hoc* assumptions are made that (i) in the first three periods (1990 - 2004), there is no additional environmental policy; (ii) from 2005, a reduction path towards the target is imposed that is linear in terms of reduction percentages, as this allows for a gradual adjustment process, and (iii) after the policy target is reached, emissions cannot increase again.

For Climate change, the emission target as laid down in the environmental policy plans has to be translated into a target for the total allowable addition to the stock of greenhouse gasses over the model horizon. This is done in two steps. First, a proposed path of greenhouse gas (GHG) emissions that is consistent with the emission policy target of NEPP2030 is formulated, analogue to the maximum allowable emission paths for the other environmental themes. Second, the stock addition over the model horizon that would result from this emission path is calculated. This calculated stock addition is then taken as the maximum allowable stock addition in the NEPP230 scenario. The proposed emission path is not imposed by government to allow flexibility in the timing of reduction efforts. For the Delay scenario and NEPP2010 scenario, the same maximum allowable stock addition is imposed as in the NEPP2030 scenario, so that greenhouse gas concentrations at the end of the model horizon are identical across the scenarios.

It should be emphasised that the environmental quality that is reached differs between the scenarios. For environmental themes that have some stock characteristics, such as Acidification and Eutrophication, environmental quality at the end of the 21st century depends not only on emissions in the last period, but also on emission levels in earlier periods. For the environmental themes Smog formation and Dispersion of fine dust, the duration of environmental effects of emissions is much smaller, and therefore long run environmental quality for these themes does not depend as much on earlier emissions. Total emission reductions are largest in the NEPP2010 scenario and smallest in the Delay scenario, implying a better environmental quality in the NEPP2010 scenario for Acidification and Eutrophication.

# 4. RESULTS

## 4.1. Results for the *NEPP2030* scenario

The impact of the NEPP2030 scenario on the main economic and environmental variables is presented in Table 2. In 1990, emissions do not have to decrease compared to the benchmark projection. It is therefore not surprising that Gross Domestic Product (GDP) is hardly affected. However, the composition of GDP and Net National Income (NNI) changes already in this first year: consumption by private households increases with 1 percent while savings (and investments) decrease with almost 2 percent compared to the benchmark. This indicates that consumers are anticipating the stricter future environmental policy and react by placing more emphasis on current consumption and accepting lower consumption levels in later periods.

The higher consumption levels do not imply that production levels are also higher. The negative impact of lower investments on the demand for produced goods outweighs the positive impact of increased demand by the private households.

*Table 2. Results of the NEPP2030 scenario with the base specification of DEAN*

| | 1990 | 2010 | 2030 | 2050 |
|---|---|---|---|---|
| *Macroeconomic results (%-change in volumes compared to benchmark projection)* | | | | |
| GDP | -0.02 | -1.35 | -8.45 | -10.21 |
| NNI | 0.33 | -0.26 | -6.26 | -8.55 |
| Total private consumption | 0.96 | 1.10 | -6.12 | -10.35 |
| Savings / capital investment | -1.85 | -7.11 | -20.00 | -19.00 |
| Trade balance (% of GDP; in benchmark 0.99%) | 0.99 | 1.01 | 1.09 | 1.11 |
| *Sectoral[1] results (%-change in volumes compared to benchmark projection)* | | | | |
| Sectoral production Agriculture | -1.09 | -7.46 | -32.64 | -34.58 |

*Table 2. Results of the NEPP2030 scenario with the base specification of DEAN*

| | 1990 | 2010 | 2030 | 2050 |
|---|---|---|---|---|
| Sectoral production Industry | -0.60 | -3.25 | -35.05 | -30.64 |
| Sectoral production Services | 0.09 | -0.64 | 0.49 | -3.74 |
| Sectoral production Abatement services | -0.03 | 4.23 | 16.59 | 15.81 |
| *Environmental results (%-change in volumes compared to benchmark projection)* | | | | |
| Emissions Climate change | -1.06 | -13.36 | -45.24 | -50.06 |
| Emissions Acidification | 0.00 | -21.84 | -65.52 | -65.52 |
| Emissions Eutrophication | 0.00 | -16.40 | -49.21 | -49.21 |
| Emissions Smog formation | 0.00 | -17.32 | -51.96 | -51.96 |
| Emissions Dispersion of fine dust | 0.00 | -20.98 | -62.93 | -62.93 |
| *Prices of tradable permits (constant 1990 prices)* | | | | |
| Price Climate change permits[2] (Euro / ton $CO_2$-eq.) | 2.2 | 7.1 | 22.6 | 71.3 |
| Price Acidification permits (Euro / acid-eq.) | 3.9 | 25.8 | 1234.7 | 1731.1 |
| Price Eutrophication permits (Euro / P-eq.) | 0.6 | 2.5 | 10.0 | 17.9 |
| Price Smog formation permits (Euro / kilogram) | 0.1 | 1.4 | 1696.0 | 2156.0 |
| Price Fine particles permits (Euro / kilogram) | 0.1 | 0.9 | 109.5 | 164.6 |

[1]: The results for the 27 production sectors are grouped into 3 categories. [2]: Expressed in terms of emissions.

Over time, the negative impact of the environmental policy on the economy becomes more significant. By 2050, GDP has dropped 10 percent compared to the benchmark projection. The lower savings induce a lower growth rate of the economy and it is therefore not surprising that the long run levels of NNI, consumption and production are all well below the benchmark.

Note that this drop in GDP does not mean that absolute GDP levels are declining over time. In comparison to the growth of GDP with 2 percent in the benchmark, the reductions compared to the benchmark are minor. In fact, the growth rate of the economy comes very close to the benchmark level in the second half of the century, implying that the environmental policy, which has constant emission reduction percentages in the long run, has only a temporary effect on the growth rate of the economy. The decrease in the absolute level of GDP is however lasting.

One of the strong points of the AGE framework that forms the basis of the DEAN model is that it allows a detailed analysis of the impact of the policy on different sectors in the economy. In Table 2 the sectors are aggregated into three categories. The impacts of environmental policy on individual sectors are much more diverse than the macro-economic results suggest, as shown in Figure 1.

This diversity arises from differences in pollution intensities, substitution possibilities and income elasticities of the various goods and services. A shift occurs from relatively polluting sectors to relatively clean sectors. This shift is even more important in the DEAN model than in most other models, as the possibilities to reduce emissions via technical abatement measures is limited in DEAN.

In the first few periods, the costs of environmental policy are the most problematic for the agricultural sector. The production volume of the sector drops significantly right from the first period, because on the one hand the agricultural sector is characterised by relatively large emissions: 20 percent of greenhouse gas emissions, 42 percent of acidifying emissions and 68 percent of eutrophying emissions are attributed to agriculture. On the other hand, the contribution of agriculture to GDP is relatively small. Very severe reductions in agricultural production are prevented by the low income elasticity for agricultural goods .

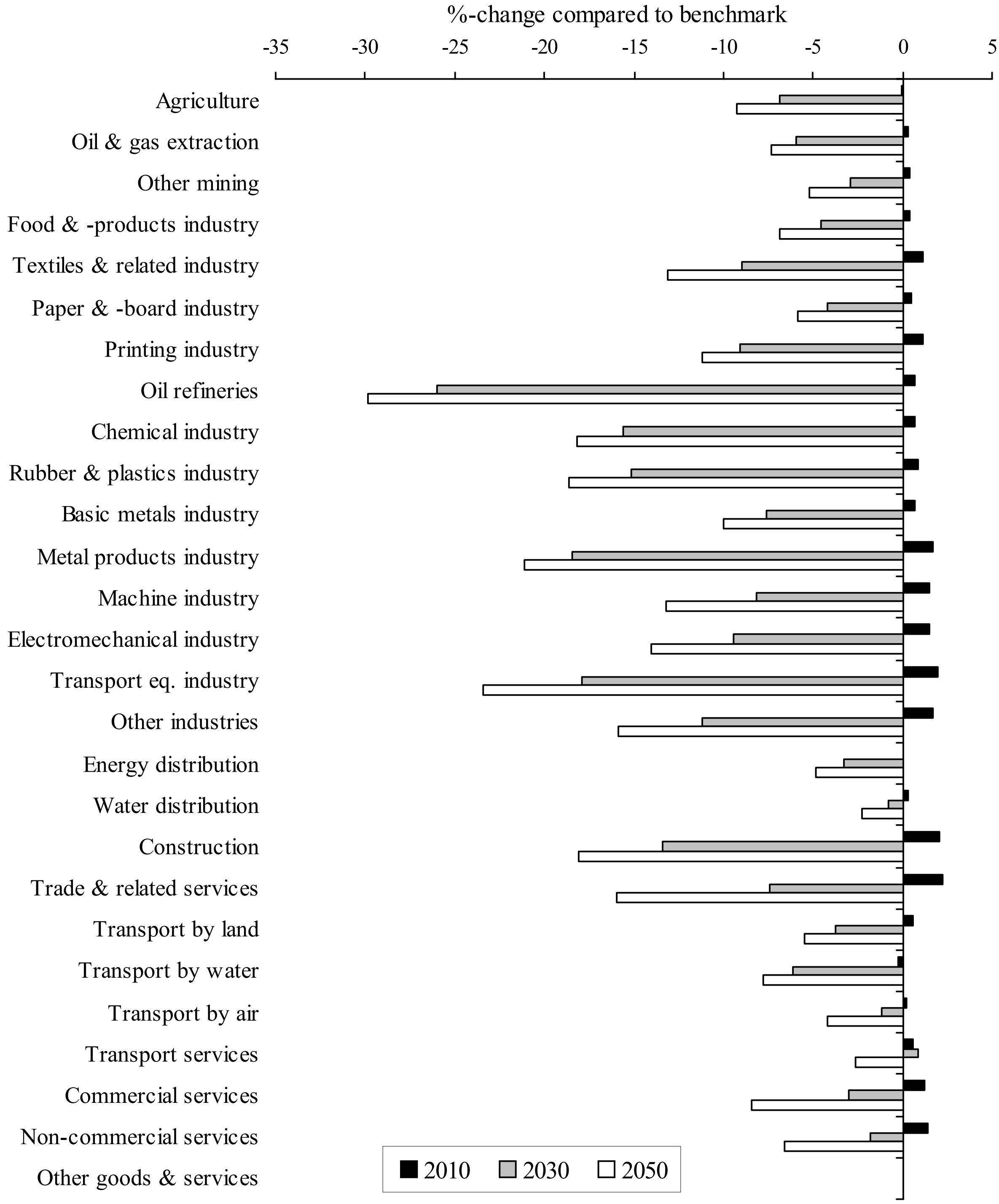


*Figure 1. Results of the NEPP2030 scenario on sectoral consumption for selected years for the base specification of DEAN*

Not surprisingly, the demand for abatement services increases substantially as environmental policy becomes stricter; see Table 2. These numbers may seem small, but one has to remember that by far the largest part of the demand for abatement services (98% in the benchmark) is constituted by the government sector for the public environmental expenditures. The demand for abatement services in 2010 by the other sectors is 5 times higher in the NEPP2030 scenario than in the benchmark. As environmental permits become more expensive it is cheaper to spend more on abatement and reduce the level of emissions. However, marginal abatement costs are also increasing as more emissions are abated. In the end, there is a new equilibrium where the marginal abatement costs equal the price of the environmental permits and the polluters are indifferent between buying more pollution permits or demanding more abatement services.

The decrease in emissions is in accordance with environmental policy. For Climate change, the path of emission reductions is endogenous, *i.e.* determined by the individual polluters, not imposed by government. Emissions are however bounded by the restriction on the total allowable addition to the stock of GHGs. Some emissions are reduced in 1990, even though the assumption is made that between 1990 and 2000 no technical abatement measures are available. The 1 percent reduction in GHG emissions is therefore fully achieved via a restructuring of the economy, *i.e.* via the reduction of agricultural and industrial production. For the other environmental themes, the path of emission reduction is exogenously given, and therefore the numbers in Table 2 reflect the difference between benchmark emissions and the number of emission permits auctioned by government.

The decline in emissions is much larger than the decline in GDP, and absolute economic growth levels are positive. Therefore, the conclusion can be drawn that in the coming decades a decoupling of economic growth and environmental pressure is possible, given the availability of abatement measures.

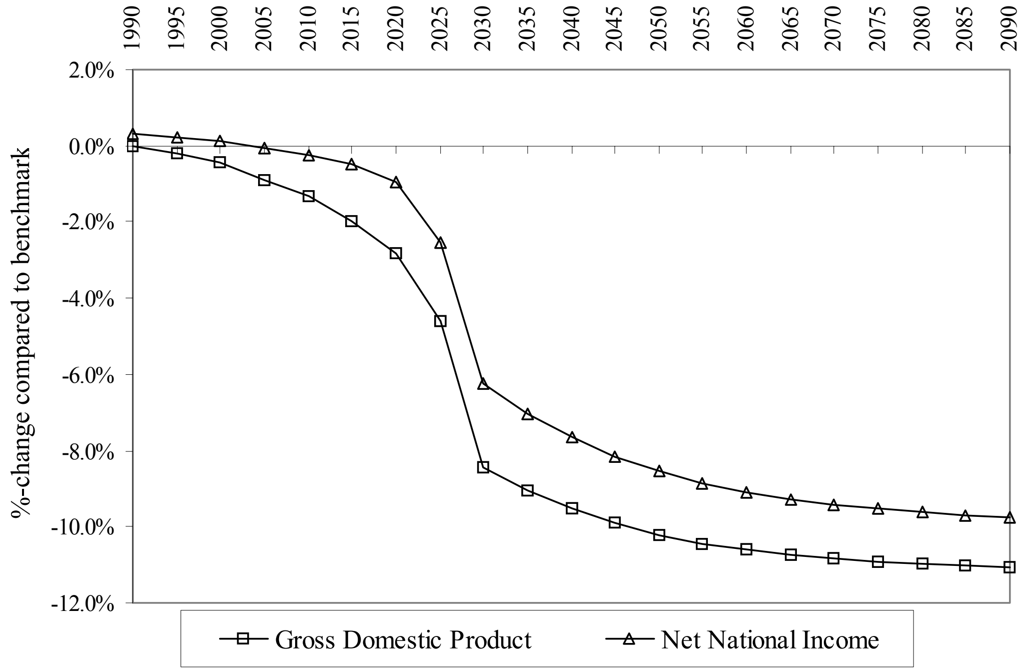


*Figure 2. Results of the NEPP2030 scenario on the development of GDP and NNI for the base specification of DEAN*

To get a better insight into the economic transition paths that are induced by the environmental policy, it is useful to look at the development of GDP and NNI over the periods. These are shown in Figure 2. Both measures of the size of the economy are closely related, and it is therefore not surprising that their development is very similar. For all periods, the impact of the policy on GDP is more negative than on NNI. This reflects the decreased replacement investments (less depreciation of capital).

Though the private households have perfect foresight on the future level of environmental policy, and know the future prices of environmental permits, the path of GDP and NNI is not completely smooth. The extent to which consumers switch between current and future consumption is limited by the intertemporal elasticity of substitution. The foregone utility increases more than proportionately if more consumption is shifted intertemporally. In effect, the development of GDP and NNI over time reflects a combination of the required emission reductions and a temporary slowdown of the economic growth rate.

Extrapolating the GDP-curve, one may draw the conclusion that a structural reduction of emissions of 50 percent or more for all environmental themes covered in the DEAN model will lead to an economy that is structurally around 10 to 11 percent below what it would have been without the environmental policy. Since the monetarised benefits of this environmental policy are not included in the analysis, it is impossible to say whether these costs are justified.

The assumptions on international trade prescribe how the aggregates of imports and exports react on the environmental policy. There is however scope for sectoral variation in both imports and exports, though relative prices on the world market are exogenous. For the industrial sectors, the decrease in exports is larger than the decrease in imports. For most services sectors, the exports increase while imports decrease. This allows for a large restructuring of the domestic economy in terms of production, while keeping the changes in domestic consumption relatively small. Domestic emissions can be reduced significantly through this 'leakage effect'. For local pollutants, this does not have to be a problem. For transboundary environmental problems, environmental quality may not improve from such a transfer of emissions to a different geographical location. In policy discussions, the prevailing argument against unilateral environmental policy is that it would affect the competitive position of the domestic production sectors. In standard AGE models, including DEAN, this effect is dominated by the ability to specialise in clean production sectors.

*Environmental results*

For each environmental theme, the reduction in emissions can be broken up into a reduction in emissions via the implementation of technical abatement measures and a reduction in emissions due to economic restructuring. The concept of 'technically abatable emissions', that can be reduced by technical abatement measures, and 'technically unabatable emissions' that cannot, is very helpful in analysing the emission reductions in more detail. The ratio between technically abatable and technically unabatable emissions differs between the environmental themes. For instance, almost two-thirds of acidifying emissions can be reduced via technical abatement measures, while only roughly one-third of the VOC emissions can be reduced in this way. The contribution of technical measures and economic restructuring to total emission reductions are represented in Table 3.

The emission reductions due to economic restructuring are especially large for Climate change and Eutrophication. For Eutrophication this is expected, as emissions are to a large extent concentrated in a few sectors (mainly Agriculture). For Climate change, this effect is related to the timing of emission reductions: emission reductions are to some extent postponed to later periods, thereby reducing the need to implement technical measures in 2030. For Smog formation, the contribution of technical measures is limited, even though virtually all available technical measures are implemented. These are, however, insufficient to achieve the emission reduction target and therefore large emission reductions through economic restructuring are required.

*Table 3. Contributing parts to emission reductions in year 2030 in the NEPP2030 scenario for the base specification of DEAN*

| | Techn. measures | | Economic restructuring | | Total | |
|---|---|---|---|---|---|---|
| | absolute | (%) | absolute | (%) | absolute | unit |
| Climate change | 46.1 | (38%) | 76.1 | (62%) | 122.3 | mln ton $CO_2$ equiv. |
| Acidification | 6.6 | (57%) | 4.9 | (43%) | 11.5 | mln acid equivalents |
| Eutrophication | 16.9 | (36%) | 29.7 | (64%) | 46.6 | mln P-equivalents |
| Smog formation | 42.4 | (50%) | 43.1 | (50%) | 85.5 | mln kilograms |

| | | | |
|---|---|---|---|
| Fine dust | 7.1 (53%) | 6.2 (47%) | 13.3 mln kilograms |

The upper limit on technical abatement, or technical potential, for each environmental theme, has major impacts on the model results. Since the costs of economic restructuring are relatively high compared to the marginal abatement costs for most of the available abatement measures, the low technical potential for Smog formation implies that emission permits for this theme become very expensive.

The environmental permit prices in Euro per theme-equivalent are not directly comparable across environmental themes, as the physical units differ. Therefore, it makes sense to express the total environmental permit values in billion Euro. These permit values give insight into the direct economic costs of environmental policy per environmental theme. Table 4 reveals that in the long run the permit value for Smog formation is clearly dominant.

*Table 4. Direct environmental expenditures in the NEPP2030 scenario for the base specification of DEAN (undiscounted values in billion Euro)*

| | 1990 | 2010 | 2030 | 2050 |
|---|---|---|---|---|
| Climate change | 0.55 | 1.64 | 3.34 | 9.62 |
| Acidification | 0.16 | 0.42 | 7.44 | 10.43 |
| Eutrophication | 0.11 | 0.23 | 0.48 | 0.86 |
| Smog formation | 0.07 | 0.25 | 134.09 | 170.46 |
| Fine particles to air | 0.01 | 0.02 | 0.86 | 1.29 |
| Desiccation | 0.25 | 0.37 | 0.50 | 1.01 |
| Soil contamination | 8.77 | 13.02 | 17.47 | 35.54 |
| Total environmental expenditures | 9.92 | 15.95 | 164.18 | 229.22 |
| *in percentage of GDP* | *4%* | *5%* | *35%* | *33%* |

It should be noted that for the emission-related environmental themes, these environmental expenditures are also accounted as income for the government, who recycles these revenues to the private households. For Desiccation and Soil contamination, the environmental expenditures are a public demand for abatement services. Indirectly, these expenditures generate value added and hence contribute to GDP. Therefore, the macro-economic costs of environmental policy are smaller than Table 4 suggests.

The permit prices for Climate change are reported per ton $CO_2$-equivalents emitted. Over time, the Climate permits become more and more expensive, which is in line with the declining GHG emission levels for later periods. Expressed as a percentage of GDP, the costs of Climate change permits increase from 0.2 percent in 1990 to 1.4 percent in 2050 and 5 percent in 2090. The price of the “GHG stock addition” permits increases exponentially over time, in line with the Hotelling rule.

The environmental theme with the lowest direct cost is Eutrophication. There are several reasons why the permits for this theme are relatively cheap. First, the emissions are concentrated in a few sectors (more than two-thirds are attributed to the agricultural sector), implying that a restructuring of the economy to reduce emissions is relatively easy. Second, the substitution elasticity between emissions and abatement (the PAS-elasticity) is higher than for other themes, indicating relatively easy abatement options. Third, a relatively large share of eutrophying emissions can be reduced via low-cost technical abatement measures. Fourth, the policy target in percentages of emissions is not as stringent as for most other themes.

The total costs for Soil contamination dominate environmental expenditures in the first decades, constituting a little less than 4 percent of GDP. The public environmental expenditures on Desiccation and Soil contamination are exogenously given and are assumed to increase with 2 percent per year. As the expenditures on the other environmental themes increase much more, especially around 2030, the relative importance of Soil contamination decreases over time.

### 4.2. Results for alternative policy scenarios

In order to analyse the impact of the timing of environmental policy on the economy and on abatement, two alternative scenarios are constructed. In the *Delay* scenario the policy targets of NEPP2030 are implemented with a delay of 10 years, *i.e.* in 2040. This means that the adjustment path to the target is longer, and policy targets for the period 2000 – 2040 are less ambitious. Instead of slowing down the implementation of environmental policy, government can also choose to implement intermediate targets in 2010 (*NEPP2010* scenario). Both alternative scenarios have no impact on the target for Climate change, as that is implemented as a maximum allowable addition to the stock of GHGs, which is assumed equal across the scenarios.

Figure 3 displays the development of GDP for the different policy scenarios. The graph shows that the impacts of environmental policy on the development of GDP are relatively smooth, though there is a kink in the curves in 2030 for NEPP2030 and NEPP2010 and in 2040 for the Delay scenario[4]. It is not difficult to recognise the parallel between the development of environmental policy and the GDP graph.

[4] The kink in the curve reflects a kink in the relative strictness of environmental policy.

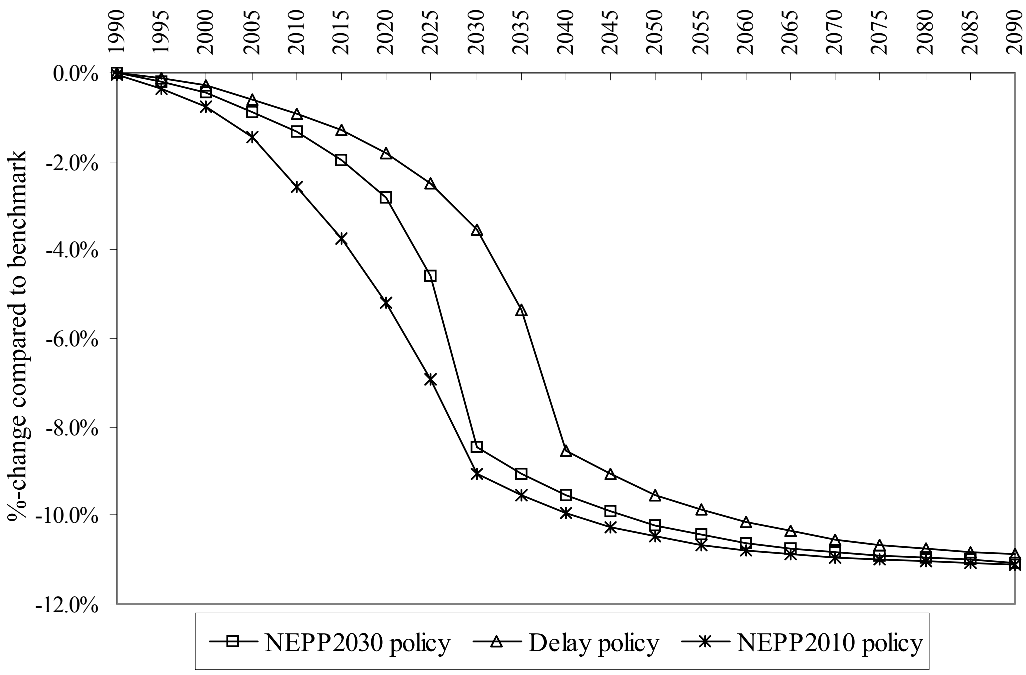


*Figure 3. Results of the policy scenarios on the development of GDP for the base specification of DEAN*

The tendency to place more emphasis on current consumption at the expense of future consumption is less strong in the Delay scenario than in NEPP2030. In 2050, the GDP loss is still more than half a percent-point less than in the NEPP2030 scenario. The slower adjustment path does, however, lead to a lower growth rate of the economy in 2050. Hence, the alternative scenario is characterised by lower economic costs in the first half of the decade, but also by a longer period of economic adjustment costs.

To a large extent, the differences between NEPP2010 and NEPP2030 are opposite to those between Delay and NEPP2030. When the NEPP2010 policy targets are implemented, GDP levels are more severely affected in 2010 and 2030, and to a lesser extent still in 2050. In the long run, the GDP losses converge for all three scenarios to around 11 percent below the benchmark projection, and the growth rate of GDP is restored at 2 percent. This implies that a temporary difference in environmental policy will lead to a temporary difference in economic costs between the scenarios. The implications of the scenarios on environmental quality are however permanently different between the scenarios, as greenhouse gasses, acidifying emissions and eutrophying emissions have characteristics of stock pollutants.

Figure 4 shows the endogenous path of emission reductions for greenhouse gasses. At first glance, it may seem surprising that the emission path of GHGs is similar to the paths of the other environmental themes. Moreover, even though the policy target in terms of the maximum allowable stock addition is identical across the policy scenarios, the scenarios give differences in the optimal path of GHG emissions that resemble the differences in emission paths between the scenarios for the other environmental themes. This result is primarily caused by the economic restructuring induced by the other themes. In the Delay scenario, the economy adapts slower to the environmental policy, and hence it makes sense for the polluters to time their GHG emissions to coincide with that development. The path of GHG emissions is determined by a (discounted) balancing of the costs of technical abatement measures, the costs of environmental permits and the costs of economic restructuring.

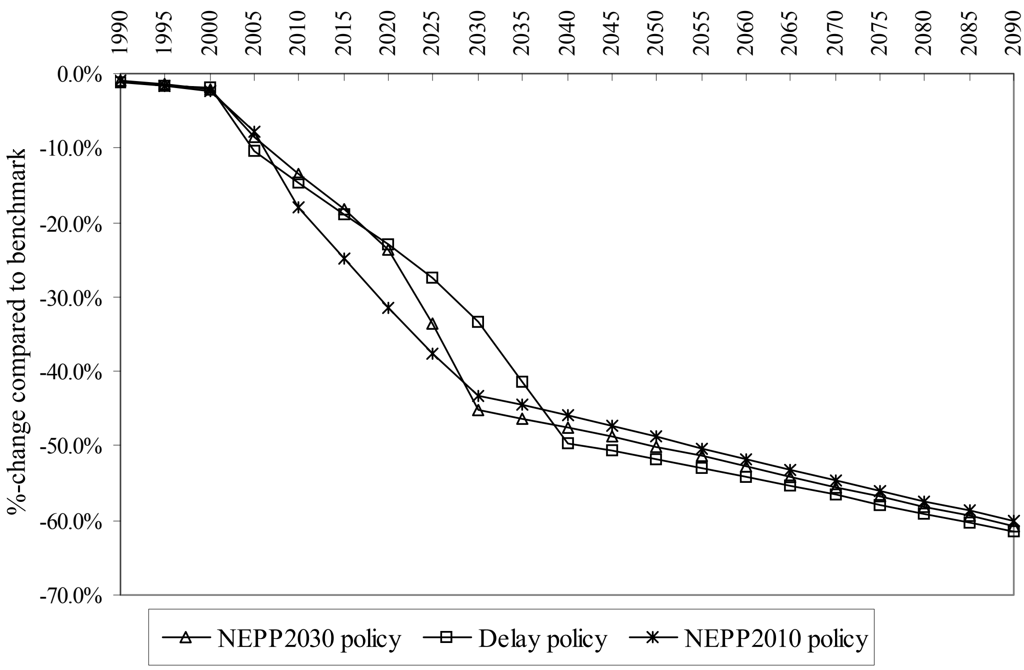


*Figure 4. Results of the policy scenarios on the reduction of GHG emissions for the base specification of DEAN*

## 4.3. Sensitivity analysis

### *4.3.1. Changing the technical potential for emission reduction*

One parameter that is expected to have significant effects on the model outcomes is the technical potential for emission reduction, that limits how much abatement is possible via implementation of technical measures. Since this form of emission reduction is almost always cheaper than the costs of economic restructuring, the likely impact of increasing the technical potential is that economic costs of environmental policy are smaller. In the sensitivity analysis, the technical potential is increased with 0.05 for one environmental theme at a time, see Table 5.

Table 5 presents the results for the base specification and for the alternative values of the technical potentials for the NEPP2030 scenario for the year 2030. Only the technical potential for VOC emission reductions influences GDP substantially: a shift from –8.45 percent in the base specification to –6.06 percent in the sensitivity analysis. For a highly binding constraint that the environmental policy for Smog formation apparently constitutes, any additional abatement opportunity leads to a substantial decrease in the economic costs of the environmental policy. For the other environmental themes, the increase in technical potential matters much less, as the restrictions on emissions are less binding for these themes than for Smog formation. This confirms the conclusion that the significant reduction in the long run level of GDP can be attributed to a large extent to a lack of VOC abatement measures. In reality, it is likely that these high economic costs of environmental policy will induce innovations that can reduce VOC emissions further at relatively low costs. This effect is not present in the current paper and warrants further research.

*Table 5. Results of the NEPP2030 scenario for year 2030 for alternative values of the technical potentials for emission reduction – per environmental theme*

| | | High technical potential | | | | |
|---|---|---|---|---|---|---|
| | Base spec. | Climate from 0.414 to 0.464 | Acidific. from 0.633 to 0.683 | Eutroph. from 0.624 to 0.674 | Smog f. from 0.344 to 0.394 | Fine dust from 0.545 to 0.595 |
| *Macroeconomic results (%-change in volumes compared to benchmark projection)* | | | | | | |
| GDP | -8.45 | -8.43 | -8.37 | -8.46 | -6.06 | -8.44 |
| NNI | -6.26 | -6.24 | -6.21 | -6.27 | -4.40 | -6.26 |
| Total private consumption | -6.12 | -6.09 | -6.10 | -6.13 | -4.17 | -6.12 |
| Savings / capital investment | -20.00 | -20.00 | -19.77 | -20.03 | -14.79 | -19.98 |
| Trade balance (% GDP) | 1.09 | 1.09 | 1.08 | 1.09 | 1.06 | 1.09 |
| *Sectoral results (%-change in volumes compared to benchmark projection)* | | | | | | |
| Production Agriculture | -32.64 | -32.64 | -29.81 | -32.90 | -29.63 | -32.82 |
| Production Industry | -35.05 | -35.10 | -35.16 | -35.06 | -25.84 | -35.08 |
| Production Services | 0.49 | 0.58 | 0.81 | 0.47 | -0.52 | 0.59 |
| Production Abatement serv. | 16.59 | 16.42 | 16.72 | 16.69 | 18.19 | 16.62 |
| *Prices of tradable permits (constant 1990 prices)* | | | | | | |
| Price Climate change permits | 22.6 | 19.1 | 23.6 | 22.5 | 28.0 | 22.6 |
| Price Acidification permits | 1234.7 | 1265.2 | 912.5 | 1258.8 | 1192.3 | 1270.0 |
| Price Eutrophication permits | 10.0 | 10.0 | 12.4 | 8.9 | 13.2 | 9.9 |
| Price Smog formation permits | 1696.0 | 1698.1 | 1696.0 | 1697.0 | 1123.8 | 1699.2 |
| Price Fine particles permits | 109.5 | 110.8 | 194.3 | 109.1 | 243.4 | 29.8 |

From an empirical point of view, the robustness of the model results for changes in the specification of Climate change may seem surprising. Most of the environmental-economic literature focuses on Climate change, which is deemed to be the most important environmental problem society is currently facing. In a national model like DEAN, however, regional pollutants have relatively more weight. Moreover, the significance of the environmental theme Smog formation is caused primarily by a lack of available technologies to reduce VOC emissions. There seems to be a feedback mechanism that environmental technicians put most of their effort in specifying reduction measures for those environmental themes that are in the centre of attention of policy makers. In the 1980s, acid rain was the ‘hot topic’, and many technical abatement measures for acidifying substances were specified, and partially implemented. In the 1990s, the focus shifted towards Climate change, both for scientists and policy makers.

An increase in technical potential for a certain environmental theme will likely result in a lower associated permit price. As shown in Table 5, this is indeed the case. The prices of Fine particles and Eutrophication permits are also sensitive to the parameter value of the technical potential for the other environmental themes: an increase in technical potential for Acidification or Smog formation leads to an increase in the permit price for Eutrophication and Fine particles. This implies that the higher technical potential induces less reduction in production of the sectors that are also environmentally intensive with respect to Eutrophication and Fine particles. In other words, there is a complementarity between these environmental themes so that reducing the implicit strictness of environmental policy for one theme increases the implicit strictness of environmental policy for the other theme.

*4.3.2. Changing the PAS-elasticity*

A key parameter of the DEAN model is the estimated elasticity of substitution between pollution and abatement, the PAS elasticity. Therefore, this parameter is also subjected to sensitivity analysis. Per environmental theme, the value of the elasticity is increased with 0.1, see Table 6. Again, the sensitivity analysis is carried out for one theme at a time, not for all themes simultaneously.

As in the other sensitivity analyses, the largest impact is caused by the elasticity for Smog formation, but the impact of the change in the value of the PAS elasticity is very small for all themes. The higher elasticity implies that it is easier for the polluters to switch between buying emission permits and buying abatement services. But for Smog formation, virtually all available technical abatement measures are already implemented in the base specification. Therefore, increasing the substitutability between emissions and abatement can only have a minor impact on the economic costs of environmental policy.

The higher PAS-elasticity for Acidification has an impact on the sectoral structure of the economy: the reductions in production and consumption of agricultural goods are limited, while the results for the other production sectors are hardly influenced by the PAS-elasticity.

*Table 6. Results of the NEPP2030 scenario for year 2030 for alternative values of the PAS elasticities – per environmental theme*

| | | High PAS elasticity | | | | |
|---|---|---|---|---|---|---|
| | Base spec. | Climate from 1.240 to 1.340 | Acidific. from 1.416 to 1.516 | Eutroph. from 1.388 to 1.488 | Smog f. from 1.186 to 1.286 | Fine part. from 1.264 to 1.364 |
| *Macroeconomic results (%-change in volumes compared to benchmark projection)* | | | | | | |
| GDP | -8.45 | -8.44 | -8.37 | -8.44 | -8.31 | -8.44 |
| NNI | -6.26 | -6.25 | -6.21 | -6.26 | -6.15 | -6.26 |
| Total private consumption | -6.12 | -6.10 | -6.09 | -6.12 | -5.99 | -6.12 |
| Savings / capital investment | -20.00 | -20.02 | -19.77 | -19.99 | -19.75 | -19.99 |
| Trade balance (% GDP) | 1.09 | 1.09 | 1.08 | 1.09 | 1.08 | 1.09 |
| *Sectoral results (%-change in volumes compared to benchmark projection)* | | | | | | |
| Production Agriculture | -32.64 | -32.64 | -29.85 | -32.45 | -32.11 | -32.73 |
| Production Industry | -35.05 | -35.09 | -35.07 | -35.04 | -34.73 | -35.07 |
| Production Services | 0.49 | 0.56 | 0.68 | 0.47 | 0.45 | 0.55 |
| Production Abatement serv. | 16.59 | 16.49 | 16.32 | 16.60 | 15.04 | 16.59 |
| *Prices of tradable permits (constant 1990 prices)* | | | | | | |
| Price Climate change permits | 22.6 | 19.6 | 23.7 | 22.6 | 22.8 | 22.6 |
| Price Acidification permits | 1234.7 | 1261.2 | 992.1 | 1239.4 | 1239.5 | 1254.9 |
| Price Eutrophication permits | 10.0 | 10.0 | 11.9 | 8.9 | 10.3 | 10.0 |
| Price Smog formation permits | 1696.0 | 1697.6 | 1695.5 | 1696.6 | 1674.9 | 1697.8 |
| Price Fine particles permits | 109.5 | 110.6 | 160.2 | 109.2 | 112.2 | 62.6 |

The prices of emission permits react on the sensitivity analyses in accordance with expectations: a higher PAS-elasticity leads to a lower associated permit price. But this impact is rather small. As in the other sensitivity analysis, there are some cross-theme effects on the permit prices: the sensitivity analysis on Acidification changes the permit price for Climate change and *vice versa*. A similar effect holds for Acidification and Fine particles.

## 5. DISCUSSION AND CONCLUSIONS

This paper presented an empirical evaluation of the economic costs of environmental policy in the Netherlands, using the multi-sectoral dynamic applied general equilibrium model DEAN. The model pays specific attention to the empirical options to reduce pollution via abatement. In the model, there is a separate 'abatement production sector' that provides the abatement techniques to the producers and consumers and that has specific characteristics associated with the cost components of abatement techniques. Polluters have the endogenous choice between paying for pollution permits and increasing their expenditures on abatement. The extent to which this substitution is possible and the characteristics of producing abatement are derived from empirical abatement cost curves. Data limitations[5] imply, however, that the results have to be interpreted with sufficient caution.

The enforcement of the environmental policy targets as laid out in the latest National Environmental Policy Plan (the *NEPP2030* scenario), via a system of tradable emission permits, leads to a reduction of economic activity: GDP levels drop in the long run to around 10 to 11 percent below the benchmark projections. This does not mean that absolute levels of GDP are declining; the annual growth rate of GDP stays above one percent for all periods. In the second half of the 21st century, the growth rate of the economy comes back to the level of the benchmark projection, implying that there is only a temporary impact of environmental policy on economic growth. The decline in GDP levels compared to the benchmark projection is however lasting.

The consumers anticipate on the stricter future environmental policy by placing more emphasis on current consumption at the expense of future consumption. Comparison of scenarios with different timing of the environmental policy suggests that the stricter the environmental policy is, and the sooner it is imposed, the bigger this intertemporal shift in consumption is. The resulting path of consumption is however not completely smooth, as emission targets are imposed for every period and there is a relatively low substitution elasticity between current and future consumption.

The sectoral impacts of environmental policy are much more diverse than the macro-economic results. There is a substantial shift in production from the relatively dirty agricultural and industrial sectors, to the relatively clean services sectors. Consumption patterns are adjusting much less than production, because part of the environmental problems can be “transferred abroad” by importing more dirty goods and exporting more clean goods. Domestic emissions can be reduced substantially through this leakage effect, but in the case of transboundary environmental problems this may not be desirable from an environmental point of view. The shift from dirty to clean sectors is relatively important in the DEAN model as, in contrast to most other models, the possibilities to reduce emissions via technical abatement measures are limited.

The percentage decline in emissions is much larger than the percentage decline in GDP, and absolute economic growth levels are positive. Hence, according to the model it will be possible for the Netherlands in the coming decades to decouple environmental pressure and economic growth, given the empirical availability of technical abatement measures and substitution possibilities within the economy. The DEAN model cannot be used to assess whether the economic costs of environmental policy are justified, as the benefits of the policy in terms of better environmental quality are not taken into account. Hence, the optimal policy level cannot be inferred and the analysis has to be confined to an evaluation of the cost-effectiveness of exogenously given policy scenarios.

[5] One major limitation is that only average data on cost components of abatement measures could be used.

The model contains two sources to reduce emissions. First, emissions can be reduced via the implementation of technical abatement measures. These measures describe all available end-of-pipe and process-integrated options and can only reduce a certain amount of emissions. Second, economic activity in a polluting sector can be reduced, *i.e.* the economy can be restructured. For most environmental themes included in the model, environmental policy results in the implementation of almost all technical abatement options, except for the ones that are extremely expensive. The reason for this is that most abatement options are cheaper than the social cost of restructuring the economy.

The economic costs of environmental policy can be attributed to the policies for the different environmental themes. Since the model equates the marginal costs of all available options to reduce emissions, the price of the emission permits both equals the marginal abatement costs and the cost of economic restructuring. In 2030 and later periods, the emission permit costs for the theme Smog formation are much higher than the permit costs for the other environmental themes. This is primarily due to the shortage of technical abatement options for this theme: only one third of all VOC emissions can be reduced via technical abatement measures.

Climate change policy also brings about significant economic costs. The modelling of Climate change differs from the other emission-related themes in the sense that for Climate change, the path of emissions is endogenous and Climate change policy is implemented via tradable permits that allow some addition to the stock of greenhouse gasses. For the other emission-related themes annual tradable emission permits are auctioned by the government. The flexibility in the timing of GHG emission reduction is used by the polluters to place some more emphasis on reductions in the later periods, allowing higher emissions in the early periods. There are many mechanisms that influence this result, which can be summarised by observing that the optimal path of GHG emission reductions is characterised by minimising the net present value of all abatement costs associated with the theme. A relatively smooth path emerges, that tends to follow the path for the other environmental themes, with an additional emphasis on emission reductions in the later periods. The undiscounted price of Climate change permits increases exponentially over time, reflecting an equalisation of discounted costs for Climate change permits (Hotelling rule).

The sensitivity analysis shows that the results are particularly sensitive to the parameter values for the environmental theme Smog formation. Given the absence of endogenous environmental innovation in the model, the possibilities to reduce VOC emissions via technical abatement measures are strictly limited. It is likely that the high permit price for Smog formation permits will induce the innovation of new VOC abatement techniques. Hence, the high economic costs shown in this paper are likely to be exaggerated. The results do show, however, that substantial additional efforts in combatting this environmental problem are needed.

This paper contributes to the understanding of the dynamic feedback mechanisms between environmental activity and abatement in the context of multi-pollutant environmental policy. The consistent integration of essential bottom-up information on abatement measures in a top-down framework has been shown to be both implementable and applicable. In this way, a better assessment can be made of both the direct and indirect economic effects of environmental policy for several major environmental themes. The empirical application to The Netherlands shows that if environmental policies can be implemented simultaneously and in a cost-effective manner, the economic costs of these policies can be limited via a mixture of adoption of technical abatement measures, economic restructuring and a temporary slowdown of economic growth.

Several caveats remain with respect to methodology and data. These hopefully provide a stimulus for further research in this field, as an improved comprehension of the interactions between economic growth, sectoral structure, pollution and abatement can lead to better environmental policies. It is evident that such improved understanding is essential; there are significant direct and indirect economic costs of environmental policies, which undoubtedly await in the coming decades, as illustrated in this paper.

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## APPENDIX I. ABATEMENT COST CURVES FOR THE NETHERLANDS

**Introduction**

The inventory of technical abatement measures contains many different types of reduction possibilities. End-of-pipe measures are included, as well as process-integrated options, including substitution between different inputs (*e.g.* fuel-switch). Though the set-up of the model disregards the impact of the abatement measures on the other inputs in the production functions, all direct environmental and economic effects of the measures are captured in this framework. For instance, the reduced costs due to energy conservation as result of some abatement measure are subtracted from the gross cost of the measure, though the reduced input of energy in the production function is not taken into account. The cost of an individual measure effectively reflects the total net costs of adopting the measure at given prices. Note that pollution can also be reduced by means of a reduction in economic activity. This is fully endogenised in the model by linking pollution to economic activity. Hence, these so-called 'volume measures' (Hueting, 1996) should not be included in the abatement cost curves.

In the abatement cost curve all measures are ranked by cost-effectiveness. This requires solving some methodological and practical issues such as how to deal with measures that exclude each other or that have to be taken in a fixed order (for details, see Dellink, 2003). In the construction of the abatement cost curves, all costs are transformed into annual costs, including the capital costs (annuity interest and depreciation payments) of the investments. In the model, these capital costs of abatement investments are treated similar to 'conventional' man-made capital, *i.e.* the firms pay the capital costs while the households provide the means necessary for investments (in the form of savings)[6]. This means that the order in which the measures are represented in the abatement cost curve is consistent with the way rational firms decide upon the adoption of a measure.

Major data limitations lead to a high level of aggregation in the calibration of the abatement cost curves. Many refinements can be made to the abatement cost curves, both methodologically as well as with respect to the data. This warrants further study, but that task goes beyond the scope of this paper. Nonetheless, the current procedure and data do give insight in the (bottom-up) possibilities for pollution abatement, and its limitations.

**Climate change**

The greenhouse gases (GHGs) that cause Climate change are mainly: carbon dioxide; methane; nitrous oxide; CFCs and halons. The effects of these substances on Climate change, as well as the duration of their effects, vary. The way in which these GHGs can be aggregated into $CO_2$ equivalents is not unambiguous, but depending on the mix of emissions (and emission reductions). The coefficients that

[6] As capital is assumed mobile across sectors, this means that capital expenditures for abatement purposes are in full competition with capital expenditues in other sectors.

were chosen to aggregate the GHGs into $CO_2$ equivalents are based on the long-term Global Warming Potentials of the substances. The construction of the abatement cost curve for Climate change is discussed in detail in De Boer (2000). The curve of total costs is depicted in Figure 5, together with the approximation by a CES curve. In total, just over 87 billion kg $CO_2$-equivalents can be reduced at annual costs of a little more than 1.6 billion Euro.

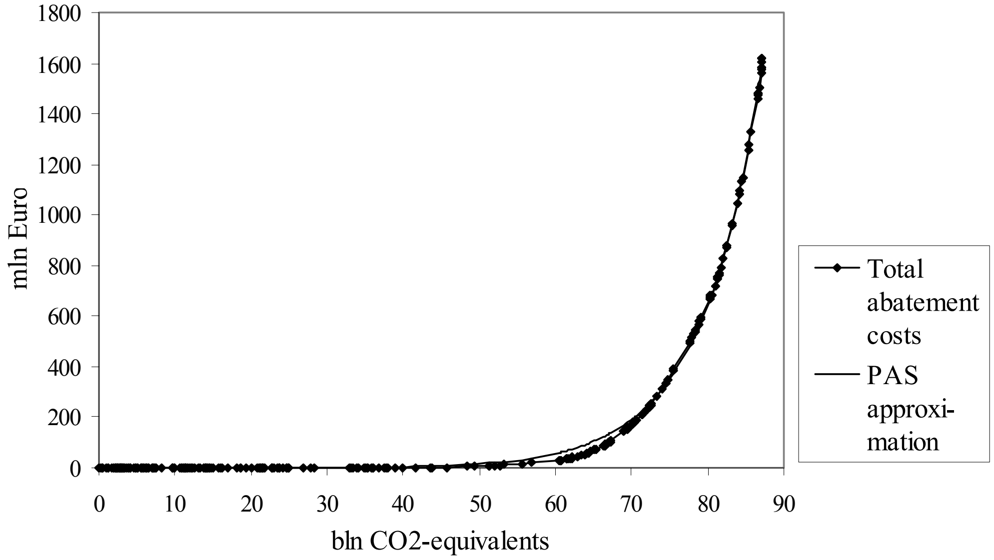


*Figure 5. Total annual costs of reduction of greenhouse gases for 1990*

**Acidification**

The substances that cause Acidification are $NO_x$, $SO_2$ and $NH_3$. The first two are mainly related to the combustion of fossil fuels, the last one to agriculture. Emissions of the three substances can be aggregated into acid equivalents as follows: 1 kilogram $NO_x$ = 0.022 acid equivalents, 1 kilogram $SO_2$ = 0.031 acid equivalents, and 1 kilogram $NH_3$ = 0.059 acid equivalents.

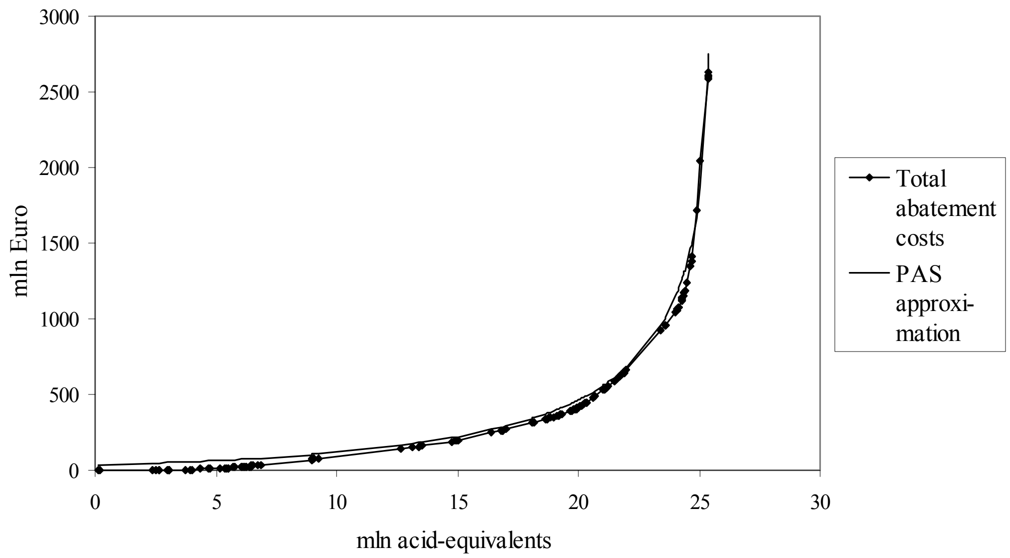


*Figure 6. Total annual costs of reduction of acidifying emissions for 1990*

The measures to reduce acidification were taken from Dellink and Van der Woerd (1997) and comprise about 170 options. The cost curve for reduction of Acidification and the approximation with a CES function are given in Figure 6. Combining all available measures, 25.5 million acid equivalents can be prevented at a total cost of 2.7 billion Euro.

**Eutrophication**

The substances that cause Eutrophication are phosphorus (P) and nitrogen (N). They mainly stem from agricultural use of fertiliser and manure in agriculture, but emissions of $NH_3$ and $NO_x$ contribute as well. The substances can be aggregated into phosphor equivalents as follows: 1 kg P= 1 P equivalent; 10 kg N= 1 P equivalent. The measures to reduce Eutrophication, as well as their costs, are taken from Dellink and Van der Woerd (1997), and amount to 145 options, of which 125 are also present in the cost curve of reduction of acidification. The curve, together with the CES approximation, is given in Figure 7. For somewhat more than 3 billion Euro annually, 120 million P equivalents can be reduced.

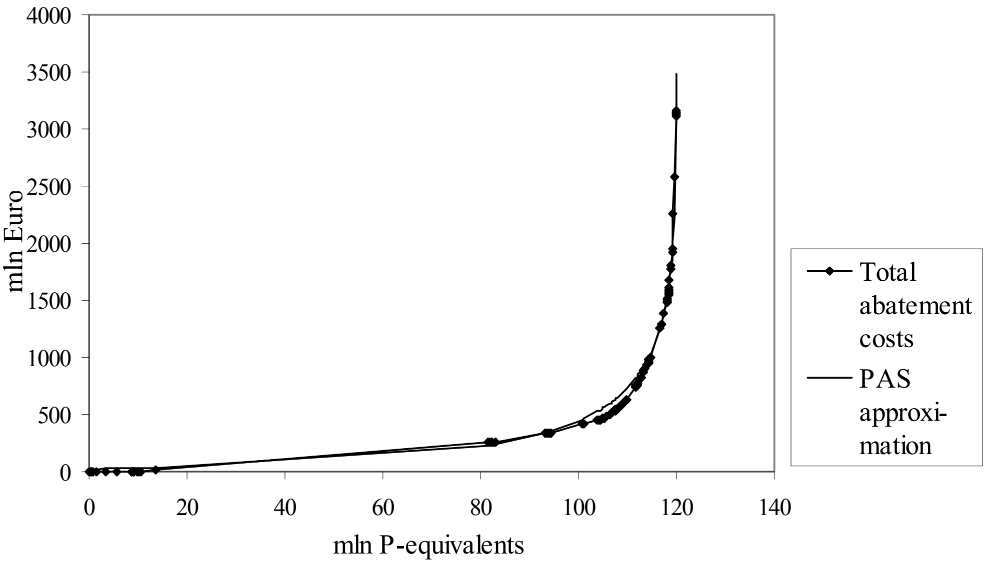


*Figure 7. Total annual costs of reduction of eutrophying emissions for 1990*

**Smog formation**

For the cost curve of Smog formation (Volatile Organic Components, in particular hydrocarbons), 39 measures were identified, of which 8 were deleted because they were excluded by other measures, while at two occasions measures had to be combined due to sequentiality. This results in 29 points on the curve, with a maximum reduction of almost 175 million kg at annual costs of less than 1.5 billion Euro. The cost curve and its approximation by a CES curve are given in Figure 8.

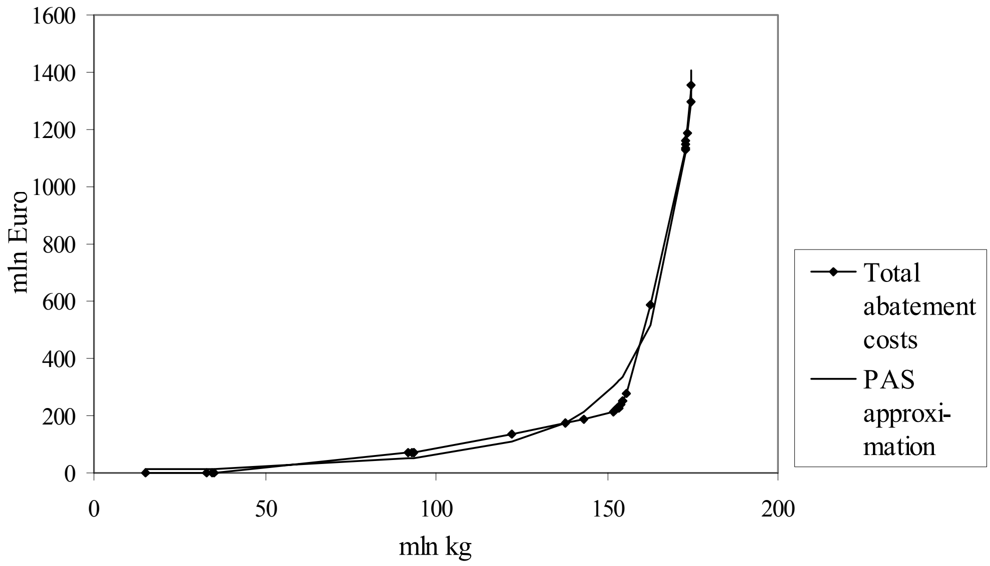


*Figure 8. Total annual costs of reduction of VOC emissions for 1990*

**Dispersion of fine dust**

Dispersion of fine dust to air is measured by the emissions of fine particles ($PM_{10}$) to air. The curve contains 36 measures, starting with 3 measures that are relatively cheap and are specifically aimed at reducing $PM_{10}$-pollution, and furthermore containing measures that are primarily aimed at reducing $NO_x$, but also reduce pollution of Fine particles. As shown in Figure 9, the curve can reduce almost 44 million kilograms of $PM_{10}$ at a cost of around 1.15 billion Euro annually.

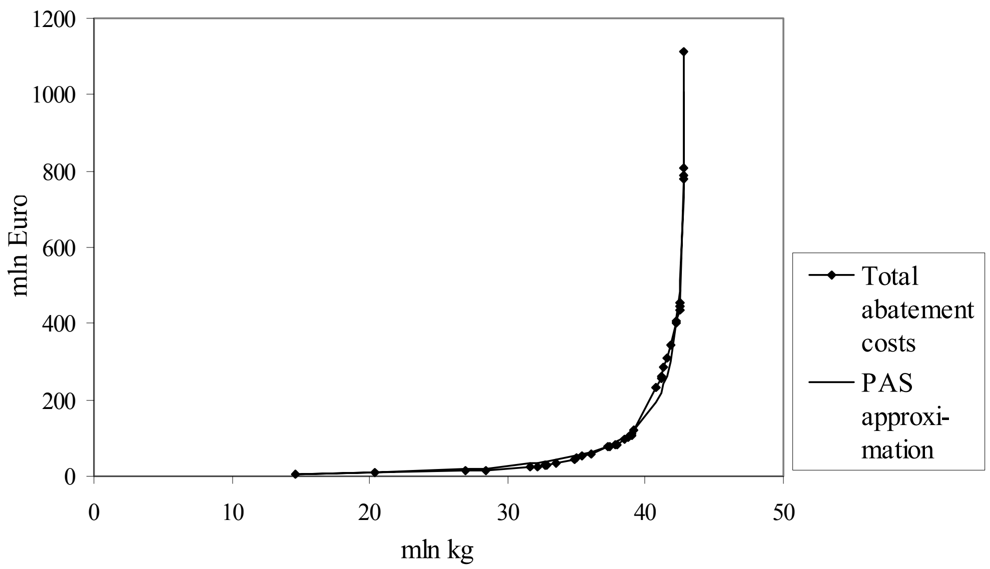


*Figure 9. Total annual costs of reduction of fine particles to air for 1990*

**Public environmental expenditures**

For the environmental themes Desiccation and Soil Contamination no abatement cost curves are constructed. For the estimation of costs to reduce the arid/dehydrated area, use was made of a study of policy scenarios (RIZA, 1996). Table 7 depicts the annual costs of reduced desiccation. The *ad-hoc* assumption is made that these costs will have to be borne throughout the model horizon.

Estimation of the cost curve of cleaning up of contaminated soil from the past is a heroic effort. Data is weak or lacking and the estimation should be interpreted, at most, as an indication of the order of magnitude. The first and possibly largest problem is that no complete inventory of contaminated locations is available. In recent years, the number of suspect locations grew with a factor 200 from about 3 thousand to 600 thousand. The estimation of costs for complete cleaning of all contaminated sites to full, multifunctional, “sustainable” use is in the range of 105 - 205 billion Euro (total, not yearly costs). More details on this estimate can be found in Dellink and Van der Woerd (1997). To convert the total costs into annual costs, an everlasting annuity payment is calculated at 5% interest. This leads to expected annual payments of 8.8 billion Euro, as shown in Table 7.

*Table 7. Annual costs for Desiccation and Soil contamination.*

| | Annual costs |
|---|---|
| | (Million Euro/yr) |
| Desiccation | 250 |
| Soil contamination | 8800 |
| *Total public environmental expenditures* | *9050* |

## Appendix II. DEAN model equations

*Consumers*

$$W_{h,t} = CES(C_{1,h,t},...,C_{J,h,t},ES_{1,h,t},...,ES_{E,h,t};\sigma_h^1,...,\sigma_h^V) \quad \forall (h,t)^{7,8} \qquad \text{(DEAN-1)}$$

$$U_h = CES(W_{h,1},...,W_{h,T};\sigma_h^{Util}) \quad \forall h \qquad \text{(DEAN-2)}$$

$$p_{h,t}^W \cdot W_{h,t} = \sum_{j=1}^{J}(1+\tau_{j,h}\cdot\alpha_t)\cdot p_{j,t}\cdot C_{j,h,t} + p_{A,t}\cdot C_{A,h,t} + \sum_{e=1}^{E} p_{e,t}\cdot E_{e,h,t} \quad \forall (h,t) \qquad \text{(DEAN-3)}$$

$$\sum_{t=1}^{T} p_{h,t}^W \cdot W_{h,t} + p_{K,T}\cdot \bar{K}_T = p_{K,1}\cdot \bar{K}_1 + \sum_{t=1}^{T}\left\{p_{L,t}\cdot \bar{L}_t - \tau_h^{LS}\cdot\alpha_t^{LS} - \gamma_{h,t}^{LS} - \overline{BD}_{h,t}\right\} \quad h=priv \qquad \text{(DEAN-4)}$$

$$p_{'subs',t}^W \cdot W_{'subs',t} = \gamma_{'subs',t}^{LS} \quad \forall t \qquad \text{(DEAN-5)}$$

$$p_{'govt',t}^W \cdot W_{'govt',t} = \sum_{e=1}^{E} p_{e,t}\cdot \bar{E}_{e,t} - \tau_{'govt'}^{LS}\cdot\alpha_t^{LS} + TR_t \quad \forall t \qquad \text{(DEAN-6)}$$

$$W_{'subs.',t} = \bar{W}_{'subs.',t} \quad \forall t;\ \text{determines } \gamma_{h,t}^{LS} \qquad \text{(DEAN-7)}$$

$$W_{'govt',t} = \bar{W}_{'govt',t} \quad \forall t;\ \text{determines } \alpha_t \text{ and } \alpha_t^{LS} \qquad \text{(DEAN-8)}$$

$$C_{j,'subs.',t} = \left(1-\frac{\eta_j}{Max_k\{\eta_k\}}\right)\Big/\left(\frac{\eta_j}{Max_k\{\eta_k\}}\right)\cdot C_{j,'priv.',t} \quad \forall (j,t) \qquad \text{(DEAN-9)}$$

*Demographic developments and labour supply*

$$\bar{L}_{t+1} = \bar{L}_t\cdot(1+g_L) \quad \forall t \qquad \text{(DEAN-10)}$$

*Capital accumulation*

$$\bar{K}_{t+1} = (1-\delta_K)\cdot\left(\bar{K}_t + \iota^C\cdot I_t\right) + \iota^N\cdot I_t \quad \forall t \qquad \text{(DEAN-11)}$$

$$\iota^C = \left(\frac{1}{g_L - r}\right)\cdot\left\{\left(\frac{g_L+\delta_K}{g_L^a+\delta_K^a}\right) - \left(\frac{r+\delta_K}{r^a+\delta_K^a}\right)\right\} \qquad \text{(DEAN-12)}$$

$$\iota^N = \left(\frac{-1}{g_L - r}\right)\cdot\left\{\left(\frac{g_L+\delta_K}{g_L^a+\delta_K^a}\right)\cdot(1+r) - \left(\frac{r+\delta_K}{r^a+\delta_K^a}\right)\cdot(1+g_L)\right\} \qquad \text{(DEAN-13)}$$

$$\bar{K}_T = (1+g_L)\cdot\bar{K}_{T-1} \qquad \text{(DEAN-14)}$$

*Producers*

$$Y_{j,t}^{DS} = CES(Y_{1,j,t}^{ID},...,Y_{J,j,t}^{ID},K_{j,t},L_{j,t},ES_{1,j,t},...,ES_{E,j,t};\sigma_j^1,...,\sigma_j^V) \quad \forall (j,t) \qquad \text{(DEAN-15)}$$

$$\begin{aligned} 0 = \Pi_{j,t} = \ & p_{j,t}\cdot Y_{j,t}^{DS} - \sum_{jj=1}^{J}(1+\tau_{jj,j})\cdot p_{jj,t}\cdot Y_{jj,j,t}^{ID} - (1+\tau_{A,j})\cdot p_{A,t}\cdot Y_{A,j,t}^{ID} \\ & -(1+\tau_{L,j})\cdot p_{L,t}\cdot L_{j,t} - (1+\tau_{K,j})\cdot r_{K,t}\cdot K_{j,t} - \sum_{e=1}^{E} p_{e,t}\cdot E_{e,j,t} \end{aligned} \quad \forall (j,t) \qquad \text{(DEAN-16)}$$

---

[7] As usual, '…' is used to indicate all items within the range as given by the items listed before and after. A general nested CES production function with for example 4 inputs and 2 levels can be written as: $Y = (a_1X_1^{\rho} + a_2X_2^{\rho} + a_{34}X_{34}^{\rho})^{1/\rho}$ , and $X_{34} = (a_3X_3^{\psi} + a_4X_4^{\psi})^{1/\psi}$ for some parameters $a_1$, $a_2$, $a_{34}$, $a_3$, $a_4$, where $\rho=(\sigma-1)/\sigma$ and $\psi=(\varphi-1)/\varphi$. A convenient notation is: $Y = \text{CES}(X_1, X_2, X_{34}; \sigma)$; $X_{34} = \text{CES}(X_3, X_4; \varphi)$.

[8] The domain and meaning of the indices are given in the appendix.

*International trade*

$$Y^{TS}_{j,t} = CES(Y^{DS}_{j,t}, M_{j,t}; \sigma^{imp}) \quad \forall (j,t) \qquad \text{(DEAN-17)}$$

$$Y^{TS}_{'ncm',t} = M_{'ncm',t} \quad \forall t \qquad \text{(DEAN-18)}$$

$$CET(Y^{DD}_{j,t}, X_{j,t}; \sigma^{exp}) = Y^{TS}_{j,t} \quad \forall (j,t) \qquad \text{(DEAN-19)}$$

$$CET(Y^{DD}_{'ncm',t}, X_{'ncm',t}; \sigma^{exp}) = Y^{TS}_{'ncm',t} \quad \forall t \qquad \text{(DEAN-20)}$$

$$\sum_{j=1}^{J} p_{x,t} \cdot \left(M_{j,t} - X_{j,t}\right) + p_{x,t} \cdot \left(M_{'ncm',t} - X_{'ncm',t}\right) = \sum_{h=1}^{H} \overline{BD}_{h,t} \quad \forall t \qquad \text{(DEAN-21)}$$

*Market clearance*

$$Y^{DS}_{j,t} + M_{j,t} = Y^{TS}_{j,t} = Y^{DD}_{j,t} + X_{j,t} \quad \forall (j,t) \qquad \text{(DEAN-22)}$$

$$Y^{DD}_{j,t} = \sum_{jj=1}^{J} Y^{ID}_{j,jj,t} + Y^{ID}_{j,A,t} + I_{j,t} + \sum_{h=1}^{H} C_{j,h,t} \quad \forall (j,t)\text{; determines } p_{j,t} \qquad \text{(DEAN-23)}$$

$$\sum_{j=1}^{J} K_{j,t} + K_{A,t} = \overline{K}_t \quad \forall t\text{; determines } p_{K,t} \qquad \text{(DEAN-24)}$$

$$\sum_{j=1}^{J} L_{j,t} + L_{A,t} = \overline{L}_t \quad \forall t\text{; determines } p_{L,t} \qquad \text{(DEAN-25)}$$

$$S_t = \sum_{j=1}^{J} p_{j,t} \cdot I_{j,t} \quad \forall t \qquad \text{(DEAN-26)}$$

*Emissions and abatement*

$$ES_{e,jh,t} = CES(E^{U}_{e,jh,t}, CES(E^{A}_{e,jh,t}, A_{e,jh,t}; \sigma^{A}_{e,jh}); \sigma^{ES}_{e,jh}) \quad \forall (e,jh,t)\text{, with } \sigma^{ES}_{e,jh} = 0 \qquad \text{(DEAN-27)}$$

$$E^{A}_{e,jh,t} \big/ E_{e,jh,t} = \mu_{e,jh,t} \quad \forall (e,jh,t) \qquad \text{(DEAN-28)}$$

$$\sum_{jh=1}^{JH} E^{U}_{e,jh,t} + \sum_{jh=1}^{JH} E^{A}_{e,jh,t} \equiv \sum_{jh=1}^{JH} E_{e,jh,t} = \overline{E}_{e,t} \quad \forall (e,t)\text{; determines } p_{e,t} \qquad \text{(DEAN-29)}$$

$$Y_{A,t} = \sum_{jj=1}^{J} Y^{ID}_{A,jj,t} + \sum_{h=1}^{H} C_{A,h,t} \equiv \sum_{jh=1}^{JH} \sum_{e=1}^{E} A_{e,jh,t} \quad \forall t\text{; determines } p_{A,t} \qquad \text{(DEAN-30)}$$

$$EM_t = \left(1 - \delta_{EM}\right) \cdot EM_{t-1} + \varepsilon_{EM} \cdot \sum_{jh=1}^{J+H} E_{'climate',jh,t} \quad \forall t \qquad \text{(DEAN-31)}$$

*Environmental technological progress*

$$E_{e,jh,t+1} = \left(1 + g_L - \varphi_e\right) \cdot E_{e,jh,t} \quad \forall (e,jh,t) \qquad \text{(DEAN-32)}$$

$$\mu_{e,jh,t+1} = \mu_{e,jh,t} \cdot (1 + g_{\mu}) \quad \forall (e,jh,t) \qquad \text{(DEAN-33)}$$

$$Y_{A,t+1} = \left(1 + g_L + \varphi_A\right) \cdot Y_{A,t} \quad \forall t \qquad \text{(DEAN-34)}$$

$$p_{A,t+1} = \left(\frac{1 + g_L}{1 + g_L + \varphi_A}\right) \cdot p_{A,t} \quad \forall t \qquad \text{(DEAN-35)}$$

*Indices*

| Label | Entries | Description |
|---|---|---|
| $v_J$ | 1,…,$V_J$ | 'CES-knots' in production functions |
| $v_H$ | 1,…,$V_H$ | 'CES-knots' in instantaneous utility functions |
| *e* | 1,…,E | Environmental themes |
| *h* | 1,…,H | Consumer groups |
| *j* and *jj* | 1,…,J,A | Production sectors, including Abatement sector (A) |
| *jh* | (JxH) | Combination of production sectors and consumer groups |
| *t* | 1,…,T | Time periods (of 5 years each) |

*Parameters*

| Symbol | Description |
|---|---|
| $\delta_{EM}$ | Decay rate of greenhouse gas stock additions |
| $\delta_K^a$ | Annual depreciation rate |
| $\delta_K$ | Per period depreciation rate: $(1-\delta_K)=(1-\delta_K^a)^5$ |
| $\varepsilon_{EM}$ | Marginal atmospheric retention rate of greenhouse gasses |
| $\varphi_e^a$ | Annual autonomous pollution efficiency improvement for environmental theme *e*; assumed equal across all agents |
| $\varphi_e$ | Per period autonomous pollution efficiency improvement for environmental theme *e*: $(1+g_L-\varphi_e)=(1+g_L^a-\varphi_e^a)^5$ |
| $\varphi_A^a$ | Annual autonomous abatement efficiency improvement |
| $\varphi_A$ | Per period autonomous abatement efficiency improvement: $(1+g_L+\varphi_A)=(1+g_L^a+\varphi_A^a)^5$ |
| $\eta_j$ | Income elasticity for good *j* for private households and subsistence consumer |
| $\sigma_h^v$ | Substitution elasticities between consumption goods combined in knot $v_H$ in instantaneous utility function for consumer *h* |
| $\sigma_j^v$ | Substitution elasticities between inputs combined in knot $v_J$ in production function for sector *j* |
| $\sigma_{e,h}^A$ | Substitution elasticities between pollution and abatement (PAS elasticity) for environmental theme *e* in instantaneous utility function for consumer *h* |
| $\sigma_{e,j}^A$ | Substitution elasticities between pollution and abatement (PAS elasticity) for environmental theme *e* in production function for sector *j* |
| $\sigma_{e,jh}^{ES}$ | Substitution elasticity between technically unabatable pollution and technically abatable pollution / abatement aggregate for environmental theme *e* for sector *j* / consumer *h* (always equal to zero) |
| $\sigma^{exp}$ | Transformation elasticity between domestic demand and exports |
| $\sigma^{imp}$ | Substitution elasticity between domestic production and imports |
| $\sigma_h^{Util}$ | Intertemporal substitution elasticities in utility function for consumer *h* (between time periods) |
| $\tau_{j,h}$ | Tax rate on consumption of good *j* by consumer *h* |
| $\tau_{jj,j}$ | Tax rate on input of good *jj* by sector *j* |

| Symbol | Description |
|---|---|
| $\tau_{K,j}$ | Tax rate on capital demand by sector *j* |
| $\tau_{L,j}$ | Tax rate on labour demand by sector *j* |
| $\tau_h^{LS}$ | Lumpsum transfer from government to consumer *h*, with $\sum_{h=1}^{H} \tau_h^{LS} = 0$ |
| $\mu_{e,jh,t}$ | Benchmark share of technically abatable emissions in total emissions for environmental theme *e* (technical potential parameter) for sector *j* / consumer *h* in period *t* |
| $\overline{BD}_{h,t}$ | Annual budget deficit for consumer *h* in period *t* |
| $\bar{E}_{e,t}$ | Annual endowments of pollution permits for environmental theme *e* in period *t* |
| $g_\mu^a$ | Exogenous annual growth rate of technical potential parameter |
| $g_\mu$ | Per period growth rate of technical potential parameter: $(1+g_\mu) = (1+g_\mu^a)^5$ |
| $g_L^a$ | Exogenous annual growth rate of labour supply |
| $g_L$ | Per period growth rate of labour supply: $(1+g_L) = (1+g_L^a)^5$ |
| $\bar{L}_t$ | Exogenous annual labour supply in period *t* |
| $r^a$ | Annual steady-state interest rate |
| $r$ | Per period steady-state interest rate: $(1+r) = (1+r^a)^5$ |
| $\bar{W}_{'govt',t}$ | Annual benchmark size of government sector in period *t* |
| $\bar{W}_{'subs.',t}$ | Annual benchmark size of subsistence consumer in period *t* |

*Variables*[9]

| Symbol | Description |
|---|---|
| $\alpha_t$ | Endogenous change in existing tax rates to offset changes in government income in period *t* |
| $\alpha_t^{LS}$ | Endogenous change in lumpsum transfers to offset changes in government income in period *t* |
| $\gamma_{h,t}^{LS}$ | Annual lumpsum transfer from (surplus) private households to the subsistence consumer, with $\sum_{h=1}^{H} \gamma_{h,t}^{LS} = 0 \ \forall t$ |
| $\Pi_{j,t}$ | Annual (net) profits in sector *j* in period *t* (equal to zero) |
| $A_{e,jh,t}$ | Annual demand for abatement of environmental theme *e* by sector *j* / consumer *h* in period *t* ($\sum_{e=1}^{E} A_{e,j,t} \equiv Y_{A,j,t}^{ID}$ and $\sum_{e=1}^{E} A_{e,h,t} \equiv C_{A,h,t}$) |
| $C_{j,h,t}$ | Annual consumption of good *j* by consumer *h* in period *t* |

[9] The variables for the good *'ncm'* are not given here but are analogue to the variables for domestically produced goods, as far as applicable.

| Symbol | Description |
|---|---|
| $E_{e,jh,t}$ | Annual total emissions of environmental theme *e* by sector *j* / consumer *h* in period *t* ( $E^A_{e,jh,t} + E^U_{e,jh,t} \equiv E_{e,jh,t}$ ) |
| $E^A_{e,jh,t}$ | Annual technically 'abatable' emissions of environmental theme *e* by sector *j* / consumer *h* in period *t* |
| $E^U_{e,jh,t}$ | Annual technically 'unabatable' emissions of environmental theme *e* by sector *j* / consumer *h* in period *t* |
| $EM_t$ | Level of greenhouse gas stock addition up to and including period *t* |
| $ES_{e,jh,t}$ | Annual emission services of environmental theme *e* by sector *j* / consumer *h* in period *t* |
| $I_{j,t}$ | Annual investment in sector *j* in period *t* |
| $\bar{K}_t$ | Annual capital supply in period *t* |
| $K_{j,t}$ | Annual capital demand by sector *j* in period *t* |
| $L_{j,t}$ | Annual labour demand by sector *j* in period *t* |
| $M_{j,t}$ | Annual imports of good *j* in period *t* |
| $p_{e,t}$ | Equilibrium market price of pollution permits for environmental theme *e* in period *t* |
| $p_{j,t}$ | Equilibrium market price of good *j* (including A) in period *t* |
| $p_{K,t}$ | Equilibrium market price of capital goods in period *t* |
| $p_{L,t}$ | Equilibrium market wage rate in period *t* |
| $p_{x,t}$ | Equilibrium exchange rate (price of foreign goods) in period *t* |
| $p^W_{h,t}$ | Equilibrium price of the 'instantaneous utility good' (price index of consumption bundle) |
| $r_{K,t}$ | Equilibrium market rental price of capital in period *t* |
| $S_t$ | Annual savings in period *t* |
| $TR_t$ | Endogenous annual tax revenues in period *t* |
| $U_h$ | Total utility of consumer *h* over all periods |
| $W_{h,t}$ | Annual, instantaneous utility level of consumer *h* in period *t* |
| $X_{j,t}$ | Annual exports of good *j* in period *t* |
| $Y_{A,t}$ | Annual production quantity of Abatement sector in period *t* (no international trade in Abatement goods) |
| $Y^{DD}_{j,t}$ | Annual domestic demand for good *j* in period *t* |
| $Y^{DS}_{j,t}$ | Annual production quantity (domestic supply) of sector *j* in period *t* |
| $Y^{ID}_{jj,j,t}$ | Annual demand for input *jj* by sector *j* in period *t* |
| $Y^{TS}_{j,t}$ | Annual total (Armington) supply of good *j* in period *t* |

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