An Environmental Performance Index for Products: How to take Damage Costs into Consideration

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ABSTRACT

Several studies have demonstrated how to use DEA based techniques to estimate environmental performance indices. None of these studies, however, are taking into account information on the environmental damage costs of the pressure types considered. This study is bridging a gap between environmental indices founded in physical pressures and damage costs founded in welfare economics. The aim of the paper is twofold: First, to demonstrate how to implement information on environmental damage costs within a DEA based environmental performance index, and second, to estimate these indices at product level by using Danish input-output and environmental data from 1997.

Keywords: Environmental performance index; Environmental damage costs; Life Cycle Assessment; Data Envelopment Analysis (DEA); Input-output modelling.

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1. Introduction

EU promotes the idea of establishing a common framework to account for national environmental pressures. The framework is named NAMEA: National Accounting Matrix Including Environmental Accounts (Eurostat, 2001). Today, several countries have initiated the development of environmental pressure accounts compatible with national input-output tables, implying that economic flows, physical flows and various types of emissions can be linked together. Using this integrated accounting framework, it is possible by using input-output modelling to estimate environmental profiles for various goods, countries, or households, including several types of environmental pressures. The disadvantage of environmental profiles, however, is that the large amounts of information included in such profiles might be difficult to interpret, making it difficult to assess whether improved environmental performance in general occurs, or not. Consequently, there is a need for weighting together different types of environmental pressures in a general environmental performance index, aggregated across environmental pressure types.

When weighting together different environmental pressure types, it is necessary to assign proper weights. According to neoclassical theory, such weights should equal market prices. However, due to market imperfections or lack of property rights no such market prices normally exist for environmental pressures[1]. In economic literature this kind of market imperfection is described as “external costs” meaning that environmental damage costs caused by the producer are passed on to society. In several studies the damage costs of different environmental pressure types have been estimated with a great

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[1] Markets for emission permits have evolved due to national targets for the reduction of e.g. CO_2 and SO_2. Reduction targets, however, are not necessarily founded in a strict trade-off between marginal damage costs and marginal abatement costs as is requested in economic theory.

deal of uncertainty making it difficult to sort out valid estimates. Facing the problem of estimating proper weights founded in the concept of external damage cost, DEA (Data Envelopment Analysis) can manage to determine these weights endogenously within intervals of damage costs specified a priori by the analyst.

On this background:

First aim of the paper is to demonstrate how to implement information on environmental damage costs within a life-cycle context combining input-output and DEA analysis in order to develop an environmental index for the environmental pressure of consumption.

Second aim of the paper is to estimate an environmental indices based on Danish input-output data and NAMEA data for year 1997 and based on these indices to rank consumer goods on the scale of good environmental performance.

The paper is organised as follows: Section 2 gives a description of the methodologies used in this study. The design of the analysis is described in Section 3. Section 4 presents the data used for the analysis. Results are presented in Section 5 and Section 6 concludes the paper.

2. Methodology

The methodology used in this study combines input-output modelling with DEA in order to estimate an environmental performance index on product basis. When applying DEA we take into consideration a priori given information on damage costs for the environmental pressure types included in the index in order to put restrictions on the weights endogenously determined by DEA. Input-output analysis is used to estimate on product basis the total embodiments of different types of environmental pressures from producing the product. On top of this analysis DEA is used to estimate an overall environmental index for the performance of each product considered.

Below we give a brief description of the two methodologies: Input-output analysis and DEA, whereas Section 3 goes into the design of analysis used in this study.

2.1 Input-output environmental analysis

Input-output analysis is a top-down economic technique, which uses sectoral monetary transactions data to account for the complex interdependencies of industries in modern economies as well as the flows from industries to final demand categories. Within the scope of life cycle analysis environmental input-output analysis can calculate factor multipliers, i.e. embodiments of production factors (such as water, labour, energy, resources and pollutants) per unit of final consumption of products produced by industry sectors.[2]

In this study we use a static input-output model, encompassing direct and indirect emissions embodied in products consumed by households. The direct and indirect emissions of different types from household consumption are estimated using an extended model incorporating emission matrices (cf. Wier et al., 2004; Statistics Denmark, 2004).

2.2 DEA – a general introduction

DEA is a non-parametric method and uses piecewise linear programming to calculate the efficient or best-practice frontier of a sample of units, e.g. producers, countries or

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[2] An introduction to the input-output method and the application to environmental problems can be found in papers by Leontief and Ford (1970) and Proops (1977). The mathematical formalism is described in detail in Lenzen (2001).

products (cf. Charnes et al., 1978). The purpose of DEA is to measure the relative efficiency of each unit considered. The frontier enveloped by efficient units represents the reference technology. Efficiency is normally assessed as the amount of inputs used per unit of output (input productivity) or the amount of output per unit of input (output productivity). The efficiency of the individual unit relative to this reference technology is calculated in terms of scores on a scale from zero to unity, with frontier units receiving a score of unity. Hence, scores less than unity reflect how much performance should be changed for a unit to become efficient. For efficient units the score will be one, so that such units cannot be further distinguished with respect to their performance. However, in order to obtain a ranking of the units according to scores which also comprise the efficient units one can use the so-called super-efficiency score, which indicates by how much the performance of an efficient unit could be reduced while still being efficient compared to other units (Andersen and Petersen, 1993).

DEA is a useful method when a well-defined theoretical description of the performance of the producers is missing. The efficiency scores are calculated relative to an empirically based reference technology. DEA is designed so as to optimise the performance of each individual unit by choosing the best combination of weights for the inputs or outputs related to each unit included in the analysis. The efficiency scores are calculated by comparing productivity ratios (output divided by input), in which the different inputs and outputs are weighed together using weights selected so as to make the relative performance of each unit as favourable as possible. The point is that when the unit comes out inefficient even with the most favourable choice of weights, then it does indicate bad performance. In some situations this approach taken literally will allow choices of weights which are unrealistic, since there may be prior knowledge about the relative importance of different inputs or outputs. Adding such information in the form of bounds on the choice of weights will give better results, often revealing lower scores since the units are no longer allowed to hide behind favourable but unrealistic weights on particular outputs or inputs where they happen to behave well.

In the present study, we have introduced restrictions on the choice of weights which are taken from the nature of the problem, where some of the environmental effects considered are clearly more important than others, a fact which should be respected by the calculation of the scores.

2.3 DEA used for environmental analysis

DEA can be used to compare units with different environmental pressure profiles so as to obtain a general measure for the environmental performance of each unit. Environmental performance may be understood as the lowest possible environmental pressure per unit produced or consumed. The units may be different firms, plants, sectors, goods, countries or households.

When designing a DEA analysis environmental effects can be treated in various ways: As ordinary outputs, after taking their reciprocal, as undesirable outputs, or as inputs.[3] In this study, we treat environmental pressures as inputs, and consumption (utility) as output. In doing so, the DEA analysis measures input productivity for each group of consumption.

As inputs are environmental pressures we define this kind of productivity eco-efficiency. Various assumptions about returns to scale might be used when applying DEA. We assume constant returns to scale meaning that the environmental effect from an extra value unit consumed is independent of the consumption level. This assumption is corresponding with the inherent assumption about constant returns to scale in the input-output model approach used in this study.

Previous empirical DEA analyses on environmental performance have mainly focussed on comparing three types of units: Environmental performance of various *countries*[4], of various *sectors, firms, farms or plants*[5], and finally of *environmental management systems*[6].

Most studies concern one environmental pressure type, most often nitrogen[7], energy-related emissions such as CO_2, SO_2 and NO_X [8] or waste[9]. Other studies, however, apply DEA analysis across several pressure (emission) types: Bevilacqua and Braglia (2002) analyse performance of Italian oil refineries regarding six types of emissions to air, Hailu and Veeman (2001) consider performance of Canadian pulp and paper industries on the topic of waste water loading, and Jung et al. (2001) examine emissions, noise and health effects of various types of multinational firms. Lovell et al. (1995) analyse carbon and nitrogen emissions of 19 OECD countries, Reinhard et al. (2000) investigate environmental performance of Dutch dairy farms with respect to energy requirements, plus nitrogen and phosphate surplus. Finally, Sarkis and Cordeiro (2001**)** consider environmental efficiency (total releases to air and waste) of US industry.

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[3] For a discussion on strength and drawbacks of these approaches, see for instance Dyckhoff and Allen (2001).

[4] See Färe et al. (2004), Taskin and Zaim (2001), Zofio and Prieto (2001) and Lovell et al. (1995).

[5] See Ball et al. (1994), Bevilacqua and Braglia (2002), Färe et al. (1996), Golany et al. (1994), Hadri and Whittaker (1999), Hailu and Veeman (2001), Jung et al. (2001), Piot-Lepetit et al. (1997), Piot-Lepetit and Vermersch (1998), Reinhard et al. (1999, 2000), Sarkis and Cordeiro (2001) and Tyteca (1997).

[6] See Courcelle et al. (1998), Sarkis (1999) and Sarkis and Weinrach (2001).

[7] See Ball et al., 1994; Piot-Lepetit et al., 1997; Piot-Lepetit and Vermersch, 1998; Reinhard et al., 1999.

[8] See Färe et al., 1996; Golany et al., 1994; Taskin and Zaim, 2001; Tyteca, 1997; Zofio and Prieto, 2001.

[9] See Courcelle et al., 1998; Sarkis, 1999; Sarkis and Weinrach, 2001.

Like the studies described above the present study applies DEA across several emission types. However, all the previous studies consider environmental performance of production units, whereas our study focuses on household consumption as the environmental performance of products is assessed. In our study DEA is used to optimise the environmental performance of products consumed by households by weighting together various environmental pressure types into an aggregated environmental performance index (or score). We use information on the damage cost of the pressure types considered. As damage costs are estimated with a wide range of uncertainty we implement this uncertainty as restrictions on the weights to be determined endogenously by DEA. This is in contrast to previous studies in the field, but in line with the paradigm that activities (environmental effects) should be founded in either market values or uniform cost estimates (Agrell and Bogetoft, 2005).

Using totally flexible weights is not always very informative, because the DEA optimisation procedure allows each unit (product) to assign all weight to one environmental pressure type only. Consequently, a very polluting product, performing bad in relation to all pressure types except one, may turn out to perform very well according to the overall DEA score, because all weight is assigned to the single pressure type, where this product performs very well. In order to include information of the harmfulness of different environmental pressures the damage costs to society are highly relevant. To illustrate: One tonne of dioxin causes much more damage to society than one tonne of CO_2.

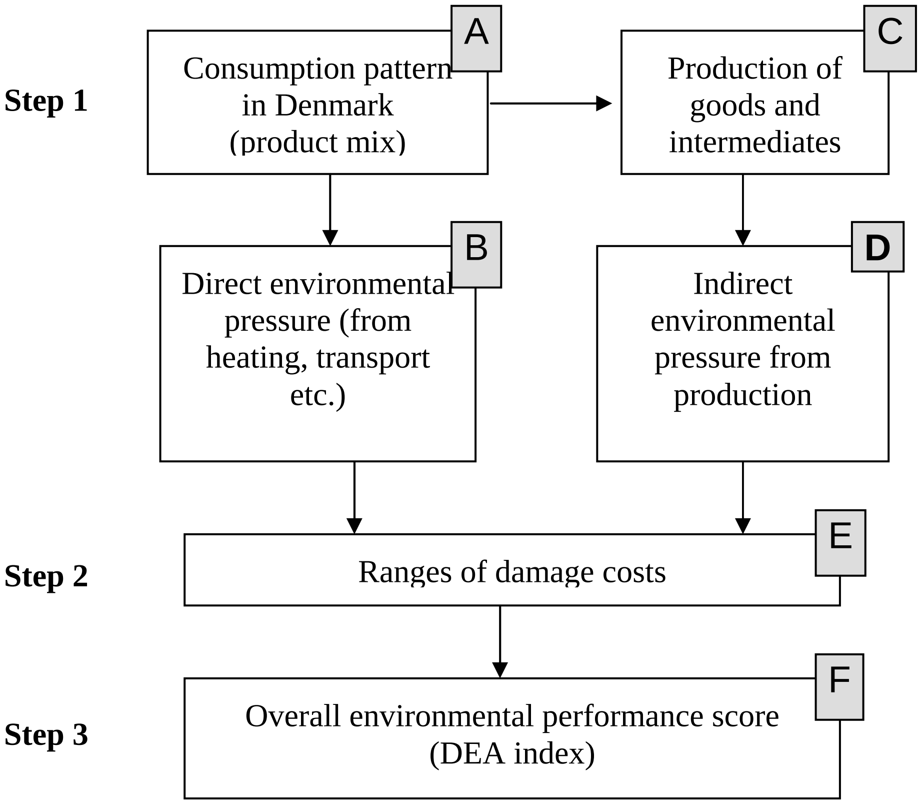
3. Design of the Analysis

The analysis carried out in this study includes the following steps:

1. To estimate environmental profiles for different products (i.e. embodiments of environmental pressures calculated in kilogram of emission per Euro of consumption) based on input-output modelling (see Wier et al., 2004). Output from this step is environmental multipliers at product level (products x pressure types)
2. To implement damage costs as a priori restrictions on the weights to be determined in DEA subsequently
3. To use DEA for the estimation of an index for the general environmental performance of products to be used for the ranking of products. Input to DEA is the environmental multipliers estimated at product level as well as the damage costs.

Figure 1 gives an overview of the design of analysis and serves as a reference in the more detailed description below.

Figure 1: Design of analysis



Source: Inspiration from Wier et al. (2004).

Step 1: To estimate environmental profiles

We consider consumption of different products in Denmark (Box A). For some of these products, environmental pressures arise *directly* from activities taking place within the households – for example, heating by using fuels in the house and driving a private car by using petrol. The pollutants emitted by households are called *direct environmental pressure* (Box B). In addition to these direct pressures, we consider environmental pressures arising *indirectly* through private household consumption of products (commodities and services) – that is, the corresponding environmental pressures needed to satisfy consumer demand (Box D). These indirect requirements occur in the numerous industries in the countries producing the products used by the consumers – and further, in the numerous industries providing raw materials and intermediates. These flows of products are modelled by traditional input-output analysis (Box C). The whole process of industrial interdependence is an infinite chain of deliveries, and encompasses domestic as well as imported goods. However, they are ultimately being consumed by households in Denmark. For more on the modelling approach see for instance Wier et al. (2001).

Step 2: To implement damage costs in DEA

By introducing restrictions on the weights determined endogenously by DEA, we take the harmfulness of different pressure types into account (Box E). As damage cost estimates are given with a great deal of uncertainty we implement ranges of damage costs including a minimum value $p_i^{\min}$ and a maximum value $p_i^{\max}$ for each pressure type i. The damage costs are implemented as restrictions on the weights set endogenously by DEA. We apply the assurance region approach, introduced by Thompson et al. (1986). Following this method, we impose constraints on the numerical magnitude of the weights for the various environmental effect types, using the damage cost estimates (i.e. estimates in Euro per tonne) as weights. Since the DEA computations take the form of a linear programming routine, the restrictions are most conveniently inserted in the form of linear inequalities. In the present case they take the form of a lower and an upper bound for each environmental effect type, thus limiting the weights to a restricted area.

The weights are calculated in pairs within minimum and maximum bounds as shown in (1).

$$\frac{p_i^{\max}}{p_j^{\min}} > \frac{\lambda_i}{\lambda_j} > \frac{p_i^{\min}}{p_j^{\max}} \qquad (1)$$

where λ_i is the weight assigned to environmental effect i, and where i, j = CO_2, CO, CH_4, SO_2, NO_x, N_2O.

Within the upper and lower bounds given in (1) the weights are optimised using DEA-based eco-efficiency analysis (cf. Wier et al., 2004).

Restricting the weights by using damage costs obviously will force DEA to take into account more environment pressures when establishing the environmental performance index as compared to the scenario in which DEA has the opportunity to make an index based solely on one single environmental pressure type in which the product is performing best. Consequently, one might expect the restrictions to lead to increased variation in performance scores between products and to reduced performance scores as well.

Step 3: To estimate indices for environmental performance

In order to assess the effects from implementing the information on damage costs we first make a DEA analysis without a priori given restrictions on the weights to be determined for the various environmental pressures considered, i.e. DEA is allowed to set individual weights freely so as to maximise the environmental performance of each product. This analysis is used as a reference scenario for the scenario including damage cost restrictions.

4. Data

To estimate the environmental multipliers at product level we used Danish national account data from 1997. The following kind of data has been used: Input-output tables, energy flow tables and environmental account data (NAMEA), all supplied by Statistics Denmark. Moreover, damage cost estimates have been collected by literature survey.

4.1 Danish national account data

In the national account data published by Statistics Denmark the energy flow tables and environmental account data are linked consistently with the national accounts and input-output tables through common classifications and definitions. Together, the environmental accounts and the input-output tables form a so-called hybrid flow account of the NAMEA type (National Accounting Matrices including Environmental Accounts), cf. United Nations (2003). More specifically the following data are included:

Danish *input-output tables*. These tables comprise 130 industries and 35 categories of final demand (e.g. private consumption, public consumption, gross fixed capital formation, exports, etc.) (Statistics Denmark, 2004). At the most detailed level private consumption is further sub-divided into 72 product categories, of which five are direct energy consumption by households (cf. Appendix B for product classifications). The unit of measure used is 1,000 DKK.

Accounts for energy flows. The accounts show balances for production (make) and use of 40 types of energy. Energy use is allocated across 130 industries as well as households and is accounted for in monetary, physical and calorific terms (TJ). The latter is used in this study.

Accounts for emissions. The following types of emissions to the air are accounted for: CO_2 (carbon dioxide), SO_2 (sulphur dioxide), NO_X (nitrogen oxides), CO (carbon monoxide), N_2O (denitrogen oxide) and CH_4 (methane). For each type of emission the accounts show the emissions in tonnes by 130 industries and households.

4.2 Damage costs

By literature survey we have identified damage costs estimates for the six types of emissions mentioned above. Several studies exist in the field of estimating the damage cost of greenhouse gases[10]. The ExternE study performed by the EU Commission includes damage cost estimates for CH_4 and N_2O, cf. ExternE (1998, 1997). Also some studies exist on the damage costs of NO_x and SO_2. Most recent and prominent is a study done by NetCen including an update of the SO_2 and NO_x figures included in ExternE (cf. Netcen, 2002). The EU Commission supports the results from this study. We found a single study on CO (cf. Cowi, 2002).

The cost estimates found in the literature survey cover uncertainties (discounting and valuation of human life) as well as variations in location and source of emission.

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[10] See IPCC (2001, 1995); ExternE (1998, 1997); Fankhauser (1994) and Cline (1992).

Moreover, variations in cost estimates are due to: Location of emissions (rural versus urban emissions) and emission source (transport versus others). As the DEA analysis is based on total embodied emissions arising from many different sources, locations and contributions it is not possible to implement these variations in the cost estimates. Consequently, the range in cost estimates applied in our analysis covers both aspects (uncertainty and variation). The data sources applied are corresponding to the diffusion of the emissions. Global cost estimates have been applied for the greenhouse gases (CO_2, CH_4 and N_2O), whereas Danish cost estimates have been applied for the emissions (SO_2, NO_x and CO) mostly having local impact.

The survey on damage cost of emissions is concluded in Table 1. The data source applied for each emission type is included. To reflect the uncertainty involved in the damage costs the table includes minimum and maximum values for each emission type considered. In order of consistency with regard to the prices used in the DEA analysis damage costs have been transformed to the common unit of “Euro in 1997-prices”.

Table 1: Damage cost estimates in Euro per tonne, 1997 prices

Emission type	**Data source**	**Cost estimates in Euro/ton**	
		Minimum value	**Maximum value**
CO_2	IPCC 2001	5	117
CH_4	ExternE 1997, 1998	386	741
N_2O	ExternE 1997, 1998	7,097	24,006
SO_2	Netcen 2002	3,072	27,930
NO_x	Netcen 2002/DEA 2001	3,072	25,016
CO	Cowi 2002	1	2

Note: The cost estimates have been converted into Euro. Cost estimates from IPCC have been converted from US $ into Euro (exchange rate: 122.58) and cost estimates from Cowi and the Danish Environmental Agency (DEA) have been converted from DKK into Euro (exchange rate: 744.33). Exchange rates are from December 2003. By using a price index values have been inflated and deflated into1997 price level.

Appendix A includes more detailed information on the findings of the survey.

In Table 2 the damage cost estimates from Table 1 have been transformed into bounds on the DEA weights by using (1). To exemplify: First and second row in Table 2 shows the bounds for CO_2 and CH_4. These bounds are calculated as follows:

$$\frac{741}{5} > \frac{\lambda CH_4}{\lambda CO_2} > \frac{386}{117} \quad , \qquad (2)$$

where 386 and 741 is $CH_4^{\min}$ and $CH_4^{\max}$, respectively, and 5 and 117 is $CO_2^{\min}$ and $CO_2^{\max}$, respectively.

Table 2: Bounds based on estimated damage costs

Restriction no.	Emission type					
	CO_2	CO	SO_2	NO_x	CH_4	N_2O
1	-386				117	
2	741				-5	
3	-7,097					117
4	24,006					-5
5	-3,072		117			
6	27,930		-5			
7	-3,072			117		
8	25,016			-5		
9	-1	117				
10	2	-5				
11					-7,097	741
12					24,006	-386
13			741		-3,072	
14			-386		27,930	
15				741	-3,072	
16				-386	25,016	
17		741			-1	
18		-386			2	
19			24,006			-3,072
20			-7,097			27,930
21				24,006		-3,072
22				-7,097		25,016
23		24,006				-1
24		-7,097				2
25			-3,072	27,930		
26			25,016	-3,072		
27		27,930	-1			
28		-3,072	2			
29		25,016		-1		
30		-3,072		2		

5. Results

Table 3 shows results from the two DEA analyses: *One*, without a priori restrictions on the weights, *two*, including restrictions based on damage costs. The table includes environmental performance scores for the top ten products performing best and worst, respectively.

Table 3: Environmental performance scores: Top and bottom 10

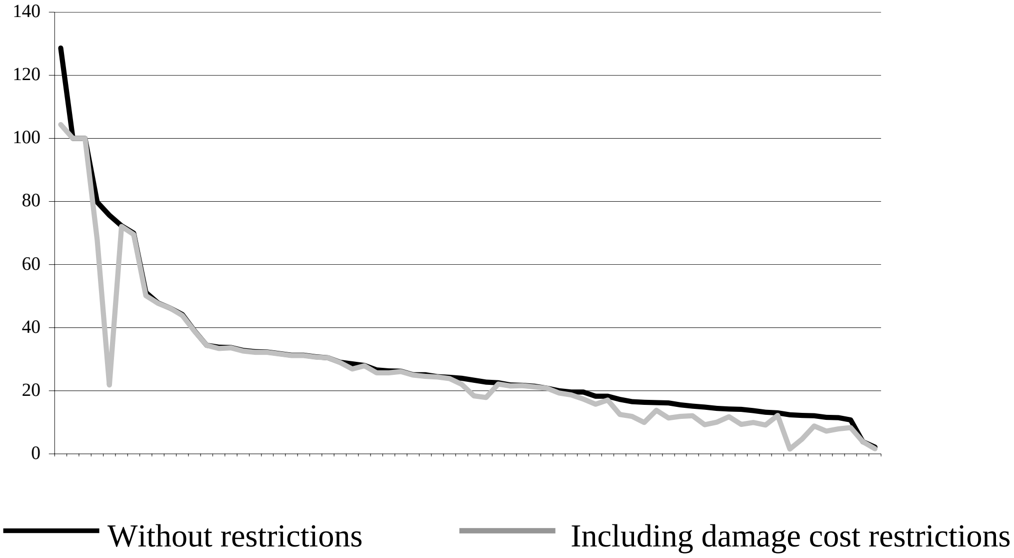
	Without restrictions		With restrictions	
Top 10		**Environmental performance score**		**Environmental performance score**
1	Domestic and home care services	129	Domestic and home care services	104
2	Imputed rentals for housing	100	Imputed rentals for housing	100
3	Actual rentals for housing	100	Actual rentals for housing	100
4	Tobacco	80	Financial services n.e.c.	72
5	Gas	76	Insurance	70
6	Financial services n.e.c.	72	Tobacco	68
7	Insurance	70	Kindergartens, crèches etc.	50
8	Kindergartens, crèches etc.	51	Out-patient services	48
9	Out-patient services	48	Communications	46
10	Communications	46	Other services n.e.c.	44
Bottom 10		**Environmental performance score**		**Environmental performance score**
59	Meat	13	Fish	9
60	Package holidays	13	Meat	9
61	Liquid fuels	12	Transport services	9
62	Fuels and lubricants	12	Fruit and vegetables except potatoes	8
63	Transport services	12	Milk, cream, yoghurt etc.	8
64	Butter, oils and fats	12	Butter, oils and fats	7
65	Milk, cream, yoghurt etc.	12	Fuels and lubricants	5
66	Fruit and vegetables except potatoes	11	Hot water, steam etc.	4
67	Hot water, steam etc.	4	Electricity	2
68	Electricity	2	Liquid fuels	2

Without taking into account the damage cost of emissions, “Domestic and home care services” is performing best (129%), whereas “electricity” is doing worst (2%) among the 68 product groups considered, cf. Table 3. The performance score of 129% means, that even if emissions are increased by 29% “Domestic and home care services” will still perform efficient, whereas a performance score of 2% means that “Electricity” has to reduce emissions by 98% to perform efficient**.** The top 10 list of commodities performing best is dominated by different kind of services characterised by very low energy intensity as is seen in Table 3. Only “gas” and “tobacco” are breaking this general rule. “Gas” performs very well because all weight is assigned to one pressure type, SO_2, for which gas has very low emission. “Tobacco” is characterised by relatively low emissions of CO and SO_2, and therefore performs best when DEA assigns all weights to these pressure types. Contrary to the top 10 list, the bottom 10 list is characterised by foods and converted energy and fuels, which are very energy-intensive commodities.

Except from a general reduction in the level of performance scores, the implementation of damage cost restrictions in DEA is not having a major influence on the ranking of products. As was also seen in the reference scenario without restrictions fuels and foods are still in the lower end, whereas services are in the top of environmental performance.

Figure 2 presents an overview of the results from the two analyses. The reference scenario is shown by the black curve representing 68 commodities in decreasing order of performance scores. The scenario including the damage cost restrictions is represented by the grey curve. This curve shows the performance scores based on the same ranking of commodities as in the reference scenario. By doing this it is possible to see how many commodities are affected and to what extent. As seen in both scenarios, about one third of the commodities has performance scores in the range above 35%, whereas about two thirds of the commodities have performance scores below that level.

Figure 2: Distribution of environmental performance scores



In Appendix B a list including the performance scores of 68 commodities is shown. Besides including the performance scores of the two analyses also the intensities of the specific emissions considered are included.

As damage costs have been implemented as restrictions on the weights endogenously determined by DEA, it is not surprising that no commodities in the damage cost scenario perform better when compared to the scenario without restrictions. Table 4 shows the effect on the weights actually determined in the two scenarios for the commodities having the largest change in estimated performance and for selected commodities with unaffected performance.

Table 4: Weights set by DEA for selected product groups

	Without restrictions							With restrictions						
	CO_2	CO	SO_2	NO_x	CH_4	N_2O	Ranking	CO_2	CO	SO_2	NO_x	CH_4	N_2O	Ranking
Fish	0	1,0	0	0	0	0	*(54)*	0	0	0,6	0,4	0	0,01	*(59)*
Milk, cream, yoghurt etc.	0	0,3	0,8	0	0	0	*(65)*	0	0	0,6	0,2	0,1	0,2	*(63)*
Fruit and vegetables except potatoes	0	1,0	0	0	0	0	*(66)*	0	0	0,1	0,9	0,01	0,02	*(62)*
Sugar	0	1,0	0	0	0	0	*(49)*	0	0	0,1	0,8	0,02	0,1	*(57)*
Tobacco	0	0,3	0,7	0	0	0	*(4)*	0	0	0,6	0,2	0,04	0,1	*(6)*
Actual rentals for housing	0,1	0,1	0,1	0,4	0,2	0,1	*(3)*	0	0	0,4	0,6	0,01	0,1	*(3)*
Imputed rentals for housing	0,1	0,2	0,2	0,3	0,1	0,2	*(2)*	0	0	0,4	0,6	0,01	0,1	*(2)*
Electricity	0	1,0	0	0	0	0	*(68)*	0	0	0,1	0,9	0,0	0,01	*(67)*
Gas	0	0	1,0	0	0	0	*(5)*	0	0	0,2	0,8	0,02	0,03	*(35)*
Liquid fuels	0	1,0	0	0	0	0	*(61)*	0	0	0,7	0,3	0	0,02	*(68)*
Hot water, steam etc.	0	0	0,7	0,3	0	0	*(67)*	0	0	0,7	0,3	0,01	0,01	*(66)*
Domestic services and home care services	0	0	1,0	0	0	0	*(1)*	0	0	0,7	0,3	0	0,01	*(1)*
Fuels and lubricants	0	0	1,0	0	0	0	*(62)*	0	0	0,3	0,7	0,01	0,04	*(65)*

As is seen from Table 4 “gas” performs best when all weight is put on the emission of SO_2. The introduction of damage cost restrictions implies that DEA has to use a portfolio of weights below one in order to optimise the performance of “gas”. The portfolio includes SO_2 (20%), NO_x (80%), CH_4 (2%), and N_2O (3%). “Gas” is exposed to the largest change in performance of 54.

By introducing damage cost restrictions in DEA, the possibility to determine extreme weights of “100%” is eliminated. This is exemplified by a variety of commodities in Table 4, e.g. fish, sugar, electricity, gas and domestic services. It also appears from the table that CO and SO_2 are the most environmental friendly pressure types as both have lost weight after the introduction of damage cost in the analysis. Contrary to this, taken damage cost estimations into consideration have increased the weights of SO_2 and NO_x significantly.

6. Conclusions

Within the context of Life Cycle Analysis attention is given to the development of environmental index methodologies in order to facilitate environmental decision making. Some recent studies suggest the application of environmental indices based on the DEA methodology. When based only on physical units DEA, however, is not able to make proper trade offs between the damage costs of the environmental pressures considered. On the contrary, DEA is aiming to choose individual weights for each product so as to optimise the environmental performance of each product. Consequently, different weights might be given to equal amounts of identical pressure types which are not consistent to general welfare economic recommending that environmental indices should consider how harmful different kinds of environmental pressures are to society. According to this line of thinking weighting together pressure types accounted for in physical units like tonnes will end up with an indicator of little relevance to the welfare of society.

Founded in welfare economics we propose to take into consideration information on the damage cost of each pressure type included in the index. In this study we demonstrate that information on damage costs given within ranges of uncertainty can easily be implemented in DEA as a priori restrictions on the weights endogenously set by DEA. Based on a literature survey we found damage cost estimates for six types of emissions: CO_2, CO, SO_2, NO_x, CH_4 and N_2O. By taking into account a priori information on ranges of damage costs will increase the relevance of the environmental index to society.

In order to investigate the influence from taking damage costs into account, two empirical analyses have been carried out: (One) an analysis without a priori restrictions on the DEA weights and (two) a scenario considering uncertainty ranges of damage costs for different environmental pressures. We found that taking damage costs into consideration increases the variations in environmental performance between product groups. Commodities having the lowest performance scores were most affected by the introduction of damage cost restrictions whereas commodities performing well were not affected very much. Our analysis shows that low performing commodities more frequently are including only one environmental pressure type in the index, whereas well performing commodities more frequently are including more than just one type of environmental pressure in the index. Consequently, low performing product groups are more exposed to a priori restrictions on the DEA weights than well performing commodities. Moreover, results show that introducing ranges of damage costs increases the weights given to SO_2 and NO_x in the performance index whereas the weights given to CO_2 and CO are reduced to zero.

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Appendix A: Survey on Damage Costs of Emissions

This appendix gives a brief presentation of the findings from the literature survey on damage cost estimates. The presentation is split up on each of the six emission types considered in the analyses.

CO_2: Carbon dioxide

Considering CO_2 emissions the damage cost estimates as reported by IPCC (Intergovernmental Panel on Climate Change) are most prominent. These estimates are referred to in ExternE (1997:295) and Andersen and Strange (2003:52).

The report published in 1995 (IPCC, 1995) includes a section on the social cost of climate change. This section includes an estimate on the marginal social cost of CO_2 emissions:

"IPCC does not endorse any particular range of values for the marginal damage of CO_2 emissions, but published estimates range between $5 and $125 (1990 U.S.) per tonne carbon emitted now. This range of estimates does not represent the full range of uncertainty." (IPCC, 1995:61).

In IPCC (2001) this range in cost estimates still remains. However, now a comment on the distribution of estimates is added: "Most estimates are in the lower part of that range" (IPCC, 2001:943).

CH_4 and N_2O: Methane and denitrogen oxide

The ExternE study financed by the EU includes damage cost estimates for CH_4 and N_2O (cf. ExternE, 1998, 1997). Due to the long-time perspective, estimates of damage costs are very sensitive to the discount rate used for estimating the present value of future damage costs. As no clear recommendation exists on the proper rate of discount to use, two discount rates have been used in ExternE (1998, 1997): 1% and 3%. The lowest discount rate is of course ending up with the highest damage costs. Besides, cost estimates have been based on climate damage models at two participating institutions – FUND at the Institute for Environmental Studies in Amsterdam, and the Open Framework at the Environmental Change Unit, Oxford. Considering the whole range in estimates across discount rates is ending up with damage costs for CH_4 ranging from 370 up to 710 Euro per tonne and damage costs for N_2O in the range from 6,800 up to 23,000 Euro per tonne.

SO_2: Sulphur dioxide

Two estimates of marginal costs of SO_2 emissions in Denmark are reported in Netcen (2002). One estimate of 3,300 Euro per tonne is related to rural areas and another estimate to urban areas depending on the size of population; Cities of 100,000 inhabitants: 6,000 Euro per tonne; cities of 500,000 inhabitants: 30,000 Euro per tonne and cities of 1,000,000 inhabitants: 45,000 Euro per tonne.

Considering the size of cities in Denmark an estimate of 30,000 Euro per tonne seems to be representative for urban Danish areas. Consequently, we have used a range from 3,300 up to 30,000 Euro per tonne as an estimate for the damage costs of SO_2 in Denmark.

NO_x: Nitrogen oxides

Cost estimates for NO_x are included in studies done by Netcen (2002), Danish Energy Agency (2001) and Cowi (2002). It is interesting that damage costs for transport are considerably higher compared to other purposes; see Danish Energy Agency (2001:50). Including the rural versus urban dimension the study done by Cowi is focusing on damage costs from transport only, whereas Danish Energy Agency (2001) is reporting cost estimates for energy use in general as well as for transport. Netcen (2002) is only reporting a cost estimate for rural areas without applying the distinction between transport and others. According to Netcen (2002) marginal external costs of NO_x in Denmark are 3,300 Euro per tonne. This figure is used as the minimum cost estimate. The maximum cost estimate is based on the figure supplied by Danish Energy Agency (2001) (200 DKK per kg).

CO: Carbon monoxide

Damage cost estimates for CO are based on Cowi (2002). The maximum value is an estimate of the damage costs in urban areas (0.02 DKK per kg), whereas the minimum value is of relevance for rural areas (0.01 DKK per kg). Estimates are related to transport.

In Table A.1 the damage costs found in the survey are summarised.

Table A.1: Damage costs for some emissions included in NAMEA

Emission type	**Data source**	**Price level**	**Damage cost estimates**			
			Minimum value		**Maximum value**	
CO_2	IPCC 2001	1990	5	USD/tonne	125	US$/tonne
CH_4	ExternE 1997, 1998	1995	370	Euro/tonne	710	Euro/tonne
N_2O	ExternE 1997, 1998	1995	6,800	Euro/tonne	23,000	Euro/tonne
SO_2	Netcen 2002	2000	3,300	Euro/tonne	30,000	Euro/tonne
NO_x	Netcen 2002/DEA 2001	2000	3,300	Euro/tonne	200	DKK/kg
CO	Cowi 2002	2002	0.01	DKK/kg	0.02	DKK/kg

The costs of CO_2 *provided by IPCC have been converted from US$ into Euro and inflated to 1997 price level. The cost figures of* CH_4 *and* N_2O *from ExternE have been inflated from 1995 prices into 1997-prices. The damage cost figures of* SO_2 *as supplied by Netcen have been deflated from 2000 prices into 1997 prices. The damage cost figures of* NO_x *have been transformed from 2000 prices into 1997 prices. Damage cost figures of CO are published in 2002 prices and have subsequently been deflated to 1997 price level.*

Appendix B: Performance Scores at Detailed Product Level

Table B.1:

	CO_2	CO	SO_2	NO_x	CH_4	N_2O	Consumption	**Environmental performance score**	**Ranking**	**Environmental performance score with restrictions**	**Ranking**
	kg/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	Mio. DKK	%		%	
Bread and cereals	65	182	137	233	375	43	10.499	17	*(48)*	12	*(52)*
Meat	67	236	130	332	1362	154	16.458	13	*(59)*	9	*(60)*
Fish	77	203	146	583	74	10	2.872	15	*(54)*	9	*(59)*
Eggs	62	253	115	348	1554	176	1.018	14	*(57)*	9	*(58)*
Milk, cream, yoghurt etc.	81	268	149	388	1591	180	5.176	12	*(65)*	8	*(63)*
Cheese	69	234	123	317	1125	127	3.300	14	*(58)*	10	*(56)*
Butter, oils and fats	86	261	184	388	1449	164	2.059	12	*(64)*	7	*(64)*
Fruit and vegetables except potatoes	120	281	278	322	224	26	8.473	11	*(66)*	8	*(62)*
Potatoes etc.	60	199	118	241	621	70	1.604	15	*(53)*	12	*(50)*
Sugar	79	185	300	250	456	52	451	16	*(49)*	10	*(57)*
Ice cream, chocolate and confectionery	65	187	127	259	595	68	9.507	16	*(51)*	11	*(54)*
Food products n.e.c.	73	209	150	287	572	65	2.689	14	*(55)*	10	*(55)*
Coffee, tea and cocoa	59	195	114	253	723	82	3.342	16	*(52)*	12	*(51)*
Mineral waters, soft drinks and juices	64	175	135	218	311	36	6.499	17	*(47)*	13	*(48)*
Wine and spirits	45	129	91	152	180	21	6.850	23	*(35)*	18	*(42)*
Beer	48	133	103	152	163	19	6.836	23	*(36)*	18	*(43)*
Tobacco	12	44	20	48	103	12	12.993	80	*(4)*	68	*(6)*
Garments and clothing materials etc.	39	145	67	127	56	7	22.695	25	*(31)*	25	*(30)*
Laundering, dry cleaning etc.	30	124	51	100	20	3	437	33	*(16)*	33	*(15)*
Footwear	37	142	63	121	78	9	5.244	27	*(27)*	26	*(27)*
Actual rentals for housing	8	30	17	28	3	0	35.243	100	*(3)*	100	*(3)*
Imputed rentals for housing	8	30	17	28	3	0	64.268	100	*(2)*	100	*(2)*
Regular maintenance and repair of the dwelling	58	186	129	206	24	3	7.310	16	*(50)*	14	*(47)*
Refuse collection, other services n.e.c.	36	129	56	160	16	2	3.679	29	*(25)*	27	*(25)*

	CO_2	CO	SO_2	NO_x	CH_4	N_2O	Con-sumption	**Environ-mental perfor-mance score**	**Ranking**	**Environ-mental perfor-mance score with restric-tions**	**Ranking**
	kg/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	Mio. DKK	%		%	
Water supply and sewerage services	55	168	100	151	17	2	6.934	20	*(43)*	19	*(41)*
Electricity	720	1390	1680	1670	226	26	12.188	2	*(68)*	2	*(67)*
Gas	518	282	18	626	107	9	3.514	76	*(5)*	22	*(35)*
Liquid fuels	737	244	981	2895	74	20	5.484	12	*(61)*	2	*(68)*
Hot water, steam etc.	550	10812	412	976	413	23	11.021	4	*(67)*	4	*(66)*
Furniture, furnishings, carpets etc.	47	156	78	144	29	4	12.331	22	*(39)*	22	*(36)*
Household textiles	45	154	78	140	48	6	2.909	22	*(38)*	21	*(37)*
Major household appliances	45	141	81	137	21	3	4.326	21	*(40)*	21	*(38)*
Repair of major household appliances	31	167	48	111	12	2	496	34	*(15)*	34	*(13)*
Glass, tableware and household utensils	47	155	82	143	21	3	3.588	21	*(41)*	21	*(39)*
Tools and equipment for house and garden	38	153	64	124	17	2	2.403	26	*(29)*	26	*(26)*
Non-durable household goods	46	151	89	147	54	6	3.724	20	*(42)*	19	*(40)*
Domestic services and home care services	9	51	13	55	5	1	2.035	129	*(1)*	104	*(1)*
Medical and pharmaceutical products	39	126	78	127	71	8	4.293	24	*(34)*	22	*(34)*
Therapeutic appliances and equipment	32	142	51	112	14	2	2.289	32	*(19)*	32	*(18)*
Out-patient services	21	98	37	59	10	1	5.414	48	*(9)*	48	*(8)*
Purchase of vehicles	32	130	55	96	13	2	33.526	31	*(21)*	31	*(20)*
Maintenance and repairs of motor vehicles	42	180	68	139	19	2	13.646	24	*(32)*	24	*(31)*
Fuels and lubricants	428	16887	111	2669	184	62	15.273	12	*(62)*	5	*(65)*
Other services in respect of personal transport equipment	38	149	67	146	51	6	4.863	24	*(33)*	24	*(32)*
Transport services	112	381	128	866	31	5	9.097	12	*(63)*	9	*(61)*
Communications	21	114	35	79	9	1	10.419	46	*(10)*	46	*(9)*
Radio and television sets etc.	33	123	54	109	16	2	4.743	31	*(22)*	31	*(21)*

	CO_2	CO	SO_2	NO_x	CH_4	N_2O	Consumption	**Environmental performance score**	**Ranking**	**Environmental performance score with restrictions**	**Ranking**
	kg/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	g/1000 DKK	Mio. DKK	%		%	
Photographic equipment etc.	32	138	53	108	15	2	870	31	*(20)*	31	*(19)*
Data processing equipment	33	140	53	117	16	2	4.635	31	*(23)*	30	*(22)*
Recording media for pictures and sound	35	148	58	128	21	3	2.138	28	*(26)*	28	*(24)*
Repair of a/v and data processing equipment	31	159	47	107	12	2	495	34	*(13)*	34	*(12)*
Other major durables for recreation and culture	45	169	75	142	59	7	2.122	23	*(37)*	22	*(33)*
Other recreational items and equipment	76	212	162	230	208	24	11.596	14	*(56)*	12	*(53)*
Recreational and cultural services	29	111	50	90	28	3	16.556	34	*(14)*	33	*(14)*
Books, newspapers and periodicals	31	129	52	103	15	2	8.829	32	*(18)*	32	*(17)*
Stationery and drawing materials etc.	40	155	66	132	23	3	1.236	25	*(30)*	25	*(29)*
Package holidays	91	251	130	313	30	4	5.836	13	*(60)*	12	*(49)*
Education	25	93	44	79	13	2	4.063	39	*(12)*	39	*(11)*
Catering	46	155	88	181	229	26	25.304	20	*(44)*	17	*(44)*
Accommodation services	53	165	105	180	188	22	3.116	18	*(45)*	16	*(46)*
Hairdressing salons etc.	30	127	52	102	20	3	4.430	32	*(17)*	32	*(16)*
Appliances, articles and products for personal care	53	165	101	164	65	8	7.521	18	*(46)*	17	*(45)*
Jewellery, clocks and watches	33	147	57	121	16	2	1.521	29	*(24)*	29	*(23)*
Other personal effects	38	148	63	131	61	7	2.204	26	*(28)*	26	*(28)*
Kindergartens, crèches etc.	18	64	33	62	26	3	6.642	51	*(8)*	50	*(7)*
Insurance	14	55	24	43	8	1	11.799	70	*(7)*	70	*(5)*
Financial services n.e.c.	13	55	24	41	7	1	8.698	72	*(6)*	72	*(4)*
Other services n.e.c.	23	111	36	85	14	2	4.469	44	*(11)*	44	*(10)*

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