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ECONOMIC GROWTH, STRUCTURAL CHANGE AND CARBON DIOXIDE EMISSION: THE CASE OF THE NETHERLANDS 1960-2008

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[1] The views expressed in this paper are those of the authors and do not necessarily reflect the policies of Statistics Netherlands. The data upon which our analysis is based is an experimental time series of Statistics Netherlands.

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Summary: During the second half of the twentieth century the Netherlands transformed from a low-energy economy into an economy that is known for its high level of energy use. The most important changes took place between 1960 and 1975, just after the newly found natural gas reserves started to be exploited. Of course, the increase in fossil fuel use also caused a large increase in the CO_2 emissions and the associated damages.

This paper answers two main questions. Firstly, the underlying driving forces of the transition to a high-energy economy are investigated. Secondly, the accumulated social cost of the CO_2 emissions between 1960 and 2008 are estimated.

To analyse the underlying forces of changes in energy use and accompanying CO_2 emissions we study the Dutch economy using Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA). Due to data restrictions we have focussed on the CO_2 emissions from the energetic use of energy.

Both analyses confirm previous decomposition studies which show that the influence of economic growth is by far the most important factor in increasing CO_2 emissions. However, the analysis also shows that the Dutch industry structure also changed markedly as a result of the newly found natural gas reserves. Energy intensive industries such as utilities, air and water transport, agriculture and the chemical industry grew extremely quickly in the period 1960-1975 because of Dutch policies to provide the natural gas at very low cost. The SDA results show that it was the growth in the exports of chemical products which was a particularly important driving force.

Finally, estimations of the accumulated Social Cost of Capital (SCC) by Dutch residents between 1960 and 2008 range from about 70 billion to 124 billion euros (2005 prices). This corresponds to approximately 1-8% of the physical capital stock and about 2-25% of GDP in 2008.

Keywords: Input-output analysis, Index decomposition analysis, Structural decomposition analysis, CO_2 emissions, Energy use, Time series, Social Cost of Carbon, Energy intensity.

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Introduction

During the second half of the twentieth century the Netherlands transformed from a low-energy into a highly energy-intensive economy. This transformation largely occurred in the 1960's and early 1970's and was partially driven by increasing use of oil but most importantly by the exploitation of natural gas which started in the late 1960's. This energy source leads to important shifts in the Dutch economy. Not only did this increase in energy intensity result in an acceleration of the depletion of energy resources, but it also led to high levels of CO_2 emissions.

This paper aims to understand what happened in the period 1960-2008 as well as the consequences of the emission of CO_2. The driving forces underlying the changes in the CO_2 emissions for the period 1960-2008 are analysed using both Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA). In addition to this, estimates of the accumulated social cost of the CO_2 emissions are discussed.

The structure of this paper is as follows. Section 1 focuses on the development of energy use and emissions of CO_2 in the Netherlands in the period 1960-2008. Section 2 will explore the determinants of CO_2 emissions, by means of decomposition analysis. Next, section 3 deals with the accumulated social cost of carbon (SCC) for the emissions that were generated between 1960 and 2008. Finally the main conclusions of the paper will be presented in section 4.

1. A long term perspective on energy use and CO_2 emissions in the Netherlands

The development of the energy intensity, in relation to other 5 important developed countries, is provided in Table 1. The energy intensity scores are compared to the 5 country average. It is clear that for the first half of the 20th century the Netherlands used relatively little energy per unit of GDP. However by 1987, the Netherlands had overtaken all countries except for the United States. Energy intensity in the Netherlands showed an annual increase of about 1.7% from 1950-1973, while energy intensity in other countries decreased annually by about 0.8% on average (Smits, 1999). Despite the fact that the Dutch energy intensities started to decrease after 1974, the Netherlands still exhibits high per capita emissions of greenhouse gasses (ninth highest in the EU27 (CBS, 2009a)).

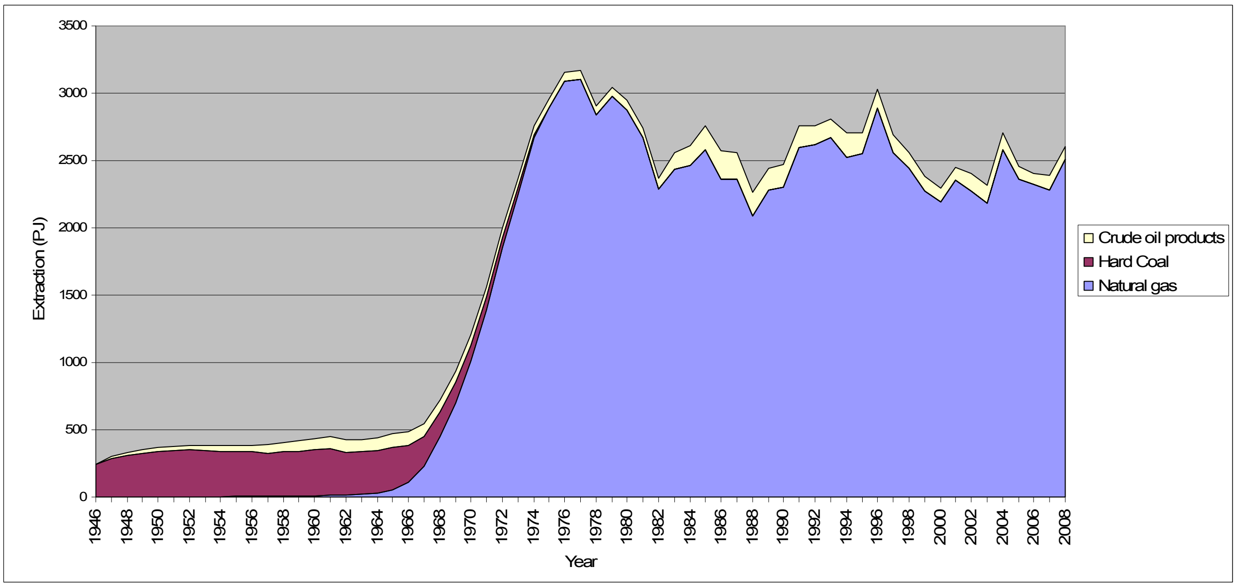
Table 1. Long run energy intensity development for 6 industrialized countries (Index, energy intensity[2], total=100)

	1913	1950	1973	1987
France	60,9	59,2	67,4	77,4
Germany	62,4	71,6	72,3	78,7
Japan	47,8	56,4	70,0	67,0
Netherlands	49,3	47,3	92,3	109,9
UK	110,7	92,0	83,9	84,3
USA	133,2	120,3	127,7	123,4
Total weighted average	100	100	100	100

Source: A. Maddison, *Dynamic forces in capitalist development. A long run view* (1991), www.ggdc.net/maddison/, (downloaded May 25).

Figure 1 shows the historical development of fossil fuel extraction in the Netherlands. Hard coal was the major fuel extracted in the Netherlands until the late 1960's, while the extraction of natural gas really took off in the second half of the 1960s. Large investments in both the distribution network and the extraction capacity went together with a very rapid growth of natural gas exploitation. Simultaneously the coal mining sector was phased out, with the last coal mine being closed in 1974. After the mid 1970's the extraction stabilized to levels between 2000 and 3000 PJ.

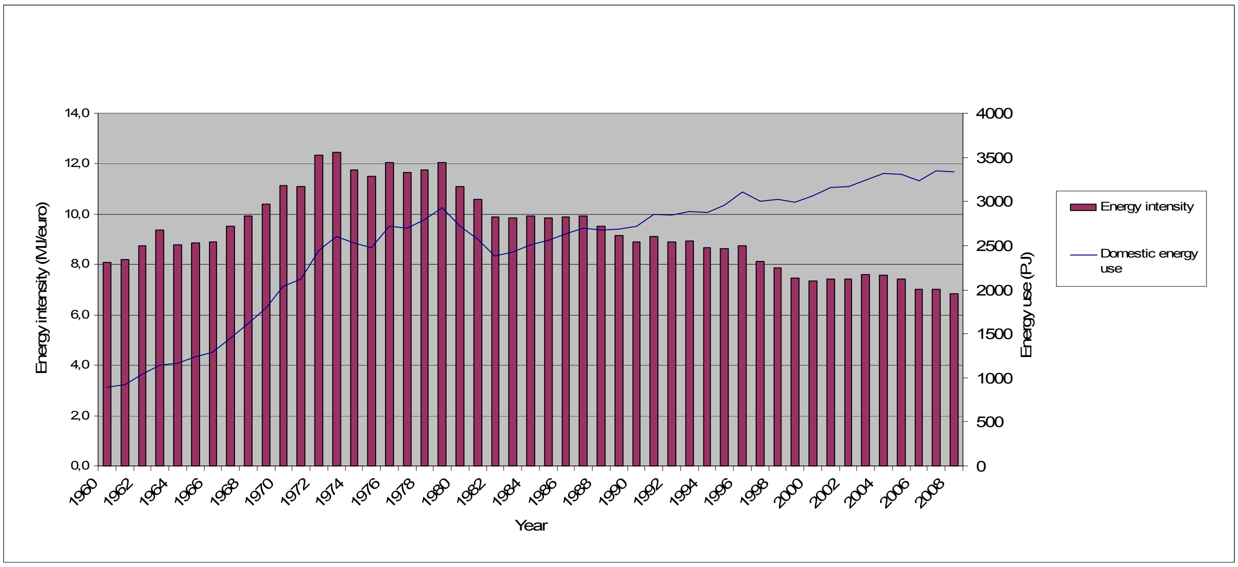
Figure 1. Extraction of fossil fuel in the Netherlands (PJ)



Source: Statistics Netherlands.

[2] Energy intensity is defined as: Energy consumption (tons of oil equivalents)/GDP (million Geary-Khamis 1990 dollars)

Figure 2. Total domestic energy use (PJ[3]) and energy intensity (MJ/euro GDP (prices 2005)) in the Netherlands.



Source: Statistics Netherlands, author's calculations.

Turning our attention to the energy use in figure 2 we see that energy use has increased fairly consistently for the 50 year period, with the largest growth rates exhibited for the 1960 and early 70s. This was also a period of rapidly increasing energy intensities. The first oil crisis (1973) and second oil (1979) crisis lead to short periods of reductions in energy use, but this has had a minor influence on the long term trend. On the other hand the second oil crisis did start the downward trend in the energy intensities which have reduced consistently since their highs in the mid 1970s. Similar results are found by Wilting (1996) and Wilting *et al.* (1998) for the dropping energy intensity of final demand between 1973 and 1982.

The figure reconfirms that the period before the oil crises was a defining period in the increasing Dutch energy use patterns. These shifts were stimulated by official government policies. The Dutch government of that time assumed that nuclear power would overtake fossil fuels for heating and electricity generation. As a result they started to sell the natural gas in large amounts at relatively low prices (Smits, 1999, p. 240). Most industries, in particular the chemical industry and agriculture (horticulture), were able to grow substantially using this cheap source of energy. As table 2 shows the growth rates of energy use exceeded 10% for these industries for the first period (1960-1975).

Table 2 shows the annual growth rates for both energetic[4] energy use and related CO_2 emissions for industries[5] and households. We have split the data into 3 time

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[3] PJ: Petajoules, 10^{15} joules and MJ: Megajoules, 10^{6} joules.

[4] Data limitations have forced use to limit ourselves to the energy use for energy purposes only, as we do not have the disposal of time series on *non*-energetic use at this time. The energetic energy use which is used for the analysis includes 1) final energetic energy use and 2) energy use for conversion into heat or electricity. More information on data sources and methodology are provided in annex A.

[5] A detailed breakdown of the industry and services classification is presented in Annex B.

periods.[6] Again the data confirm that the first 15 years of time series showed very large increases in energy use for a number of very energy intensive industries. However, growth rates of individual industries are very variable for each period. For example, two of the main drivers of the first period, agriculture and the chemical industry experience very modest growth or even a reduction in the subsequent two periods.

Table 2. Growth rates of energy use and CO_2 emissions for energy purposes in the Dutch economy[7] (Compound annual growth rates)

	1960-1974		1975-1989		1990-2008		Total			
	Energy use	CO_2 emissions	Energy use	CO_2 emissions	Energy use	CO_2 emissions	Energy use	CO_2 emissions	Energy use	CO_2 emissions
	%	%	%	%	%	%	%	%	PJ	Mton CO_2
Agriculture	14,7	13,5	2,7	2,7	-0,2	0,3	5,1	4,9	139,3	8,4
Mining	-0,7	-3,0	4,7	4,9	2,5	0,4	2,0	0,7	31,0	0,5
Food	4,2	1,4	1,1	0,7	0,5	-0,2	1,8	0,5	52,8	0,8
Textiles	-1,7	-4,5	-3,7	-4,7	-1,6	-1,9	-2,3	-3,6	-10,3	-1,0
Paper and publishing	2,0	-1,2	1,4	1,1	1,0	-0,8	1,0	-0,8	14,9	-0,7
Oil refineries	9,3	9,3	-1,1	-1,7	0,0	-0,5	2,4	2,4	100,9	7,3
Chemical industry	10,6	9,5	-0,6	0,4	-0,3	-1,8	3,3	2,2	245,9	8,5
Basic Metals	7,3	5,8	-2,5	-3,1	-0,5	0,6	0,8	0,4	17,0	0,8
Metal products, etc.	6,5	3,9	0,4	-1,1	0,1	-0,5	2,4	0,9	24,5	0,4
Other industry	7,3	4,5	-1,2	-2,0	0,2	-0,7	1,6	0,1	26,9	0,1
Utilities	8,0	5,4	0,8	2,5	0,6	1,2	2,5	2,7	249,3	34,9
Air and water transport	2,1	2,0	3,4	3,4	3,6	3,5	2,9	3,0	211,8	16,1
Road transport	6,9	7,8	4,5	5,1	2,8	2,9	4,8	5,7	118,0	8,3
Other branches	10,0	7,4	1,3	0,1	2,9	2,2	4,6	3,2	477,9	17,8
Total industry	**7,6**	**6,0**	**-0,6**	**-0,8**	**-0,1**	**-0,9**	**2,2**	**1,2**	**472,7**	**16,2**
Total producers	**7,6**	**5,8**	**0,8**	**1,1**	**1,2**	**1,0**	**3,0**	**2,4**	**1699,8**	**102,3**
Households	6,4	4,7	0,0	-0,2	0,4	0,3	2,0	1,3	417,3	16,6
Total Dutch economy	7,2	5,5	0,5	0,8	1,0	0,8	2,7	2,1	2117,1	118,9

Source: authors estimates based on official data from Statistics Netherlands and the International Energy Agency.

Table 3 shows the energy intensity of industries and services. High energy intensive industries are air and water transport, utilities, basic metals and chemical industry. Table 3 also confirms the decreasing levels of energy intensity from 1990 onward that was clear from figure 2. The major exception is the development in air and

[6] The breakdown of the time series used in this paper is based on trends observed in figure 2. Until 1974 total domestic energy use and the energy intensity increase sharply. Between 1975 and 1990 both variables are volatile. From 1990 onwards energy use increases rather steadily, while the opposite goes for the energy intensity.

[7] The energy use in the Dutch economy differs from the domestic use (CBS, 2009b). The Dutch economy includes the use of fuels by mobile Dutch actors (like consumption of gasoline by Dutch transporters) on foreign territory and excludes the fuel use of foreigner on the Dutch territory.

water transport. Energy intensities are about 25% higher in the last period compared to the second period.

Table 3. Energy intensity[8] of industries and services

	1960-1974	1975-1989	1990-2008	Total
	MJ/euro (2005 prices)			
Agriculture	5,0	9,1	7,6	7,3
Mining	4,6	1,1	2,5	2,7
Food	2,8	2,6	2,1	2,5
Textiles	2,5	2,2	1,8	2,1
Paper and publishing	3,4	2,4	2,3	2,7
Oil refineries	5,3	5,6	5,8	5,6
Chemical industry	14,6	13,5	7,5	11,5
Basic Metals	20,2	12,0	7,6	12,8
Metal products, etc.	0,8	1,3	0,7	0,9
Other industry	5,7	6,0	3,2	4,8
Utilities	20,2	18,6	14,2	17,4
Air and water transport	16,4	18,9	20,0	18,6
Road transport and transport services	2,9	3,3	3,9	3,4
Other branches	0,6	0,9	0,9	0,8
Total industry	**4,9**	**5,0**	**3,5**	**4,4**
Total industry and services	**2,9**	**3,2**	**2,6**	**2,9**

2. The driving forces of carbon dioxide emissions in the Netherlands (1960-2008)

To understand the underlying trends that have lead to the CO_2 changes described in the previous section, we have analysed the Dutch economy using decomposition techniques. To analyse the driving forces of CO_2 emissions from a supply side perspective (i.e. CO_2 emission by industries) of the economy we will perform an Index Decomposition Analysis (IDA). A Structural Decomposition Analysis (SDA) is used for analyse demand perspective of the changes in CO_2 emissions.

Our analysis is novel in two ways. Firstly, structural decomposition analyses of long time series have been done for a few countries (Denmark: Wier (1998); Wier and Hasler (1999); China: Guan *et al.* (2008); Cao *et al.* (2008); India: Mukhopadhyay and Forsell (2005); Australia (Wood, 2009), but span periods of 20-30 years. To our knowledge only one paper decomposes changes over a longer time span than the 48 years of this paper. (Sweden: Kander and Lindmark (2006) in which an 82 (!) year period is investigated starting in 1916. Secondly, to our knowledge, no paper has yet applied SDA and IDA simultaneously.[9] This is surprising because each of the two methods provides specific insights which feed well into the discussion on the "production versus consumption perspective" which is prevalent in the input-output

[8] The energy intensity is defined as: energetic energy use (Joules)/production value (euros)
[9] Hoekstra and van den Bergh (2003), Hoekstra (2005) and de Boer (2009) do discuss the methodological differences between IDA and SDA.

literature (Munksgaard and Pedersen, 2001; Gallego and Lenzen, 2005; Lenzen, 2007; Peters, 2008; and Wilting and Vringer, 2009).

2.1 Decomposition analyses

To analyse the driving forces that underlie the growth in CO_2 two decomposition methods are available. The first is index decomposition analysis (IDA) which decomposes changes using industry-level data. Ang and Zhang (2000) review over 100 articles which have adopted this technique to decompose changes in energy, CO_2 emission as well as other environmental emissions. The second method, structural decomposition analysis (SDA), uses input-output modelling techniques to attribute the changes in CO_2 emissions to changes in final demand categories, as well as technology. Hoekstra and van den Bergh (2002) and Hoekstra (2005) review over 30 environmental SDA studies. Rose and Casler (1996) and Rose (1999) summarize SDA techniques and environmental SDA applications respectively.

The main methodological difference is that IDA looks at the supply side of the economy while SDA has demand perspective. This also means that since SDA is based on input-output tables, it is far more data intensive than IDA.

Index decomposition analysis-top tier

We start our analysis by using the IDA formula provided in equation 1 which relates the annual emissions to 4 factors (intensity, fuel mix, industry structure and overall production effect).

$$\mathbf{m} = f \cdot \hat{n} \cdot s' \cdot \mathbf{q} \qquad (1)$$

where

$\boldsymbol{m}$	Total CO_2 emissions (scalar)
$\boldsymbol{q}$	Total output (scalar)
m	CO_2 emission per industry (1 by 15 industry vector)
e	Energy use per industry (1 by 15 industry vector)
q	Output per industry (1 by 15 industry vector)
f	CO_2 emission per unit of energy use per industry (1 by 15 industry vector) $(m \cdot \hat{e}^{-1})$
n	Energy use per unit output per industry (1 by 15 industry vector) $(e \cdot \hat{q}^{-1})$
s	Industry share (1 by 15 industry vector) $(\boldsymbol{q}^{-1} \cdot q)$

Equation 1 can be decomposed as shown in equation 2. The effects need to be weighed using an index approach. There are many alternatives which are adopted in the literature, although the choice of index varies significantly in the IDA and SDA literature. We have chosen to adopt a method which is common to both fields: in the IDA literature it is known as the Sun (1998) approach and in the SDA literature it is referred to as the Dietzenbacher and Los (1998) approach. Hoekstra and van den Bergh (2003) show that these two methods are equivalent.

$$\Delta \mathbf{m} = \Delta f \cdot \hat{n} \cdot s' \cdot \mathbf{q} + f \cdot \Delta \hat{n} \cdot s' \cdot \mathbf{q} + f \cdot \hat{n} \cdot \Delta s' \cdot \mathbf{q} + f \cdot \hat{n} \cdot s' \cdot \Delta \mathbf{q} \qquad (2)$$

where

$\Delta \boldsymbol{m}$	Total change in CO_2 emissions
$\Delta f \cdot \hat{n} \cdot s' \cdot \mathbf{q}$	Fuel mix effect
$f \cdot \Delta \hat{n} \cdot s' \cdot \mathbf{q}$	Energy intensity effect
$f \cdot \hat{n} \cdot \Delta s' \cdot \mathbf{q}$	Structure effect
$f \cdot \hat{n} \cdot s' \cdot \Delta \mathbf{q}$	Production effect

Index decomposition analysis- detailed

The results of the top tier decomposition can also be broken down into industry level results quite easily using equation 3. The decomposition, which is not shown, leads to 60 decomposition effects (15 industries by 4 effects).

$$m = f \cdot \hat{n} \cdot \hat{s}' \cdot \mathbf{q} \qquad (3)$$

Structural decomposition analysis-top tier

The model for the top-tier formula is provided in equation 4 while equation 5 depicts the decomposition formula which leads to 5 decomposition effects.

$$\boldsymbol{m} = \boldsymbol{f} \cdot \hat{\boldsymbol{n}} \cdot \boldsymbol{L} \cdot (\boldsymbol{y}_{house} + \boldsymbol{y}_{gov} + \boldsymbol{y}_{exp} + \boldsymbol{y}_{gcf}) \qquad (4)$$

Variables that have not been introduced previously are:

L	Leontief matrix (15 by 15 industry matrix)
y_{house}	Final demand for domestic products by households (15 by 1 vector)
y_{gov}	Final demand for domestic products by government (15 by 1 vector)
y_{exp}	Final demand for domestic products for exports (15 by 1 vector)

y_{gfc} Final demand for domestic products by gross capital formation (15 by 1 vector)

$$\Delta\mathbf{m} = \Delta f \cdot \hat{n} \cdot L \cdot y + f \cdot \Delta\hat{n} \cdot L \cdot y + f \cdot \hat{n} \cdot \Delta L \cdot y + f \cdot \hat{n} \cdot L \cdot \Delta y \qquad (5)$$

$\Delta f \cdot \hat{n} \cdot L \cdot y$	Fuel mix effect
$f \cdot \Delta\hat{n} \cdot L \cdot y$	Energy intensity effect
$f \cdot \hat{n} \cdot \Delta L \cdot y$	IO coefficients effect
$\boldsymbol{f} \cdot \hat{\boldsymbol{n}} \cdot \boldsymbol{L} \cdot \Delta\boldsymbol{y}$	Final demand effect

Structural decomposition analysis-detailed

The SDA results can also be broken down into the 15 different output categories per final demand category. Since the Netherlands has an industry-by-industry table this attributes the CO_2 emission to industry output rather than commodities. Decomposing this relationship leads to 105 decomposition effects.

$$m = f \cdot \hat{n} \cdot L \cdot (\hat{y}_{house} + \hat{y}_{gov} + \hat{y}_{\exp} + \hat{y}_{gcf}) \qquad (6)$$

2.2 IDA results

Figure 4 shows the top-tier results for Index decomposition analysis (IDA). The increase in production has a large positive[10] effect on the change in CO_2 emission for all periods. The fact that economic growth is the most important factor in increasing CO_2 emission is fairly unsurprising. This has been shown by countless of decomposition studies to date.

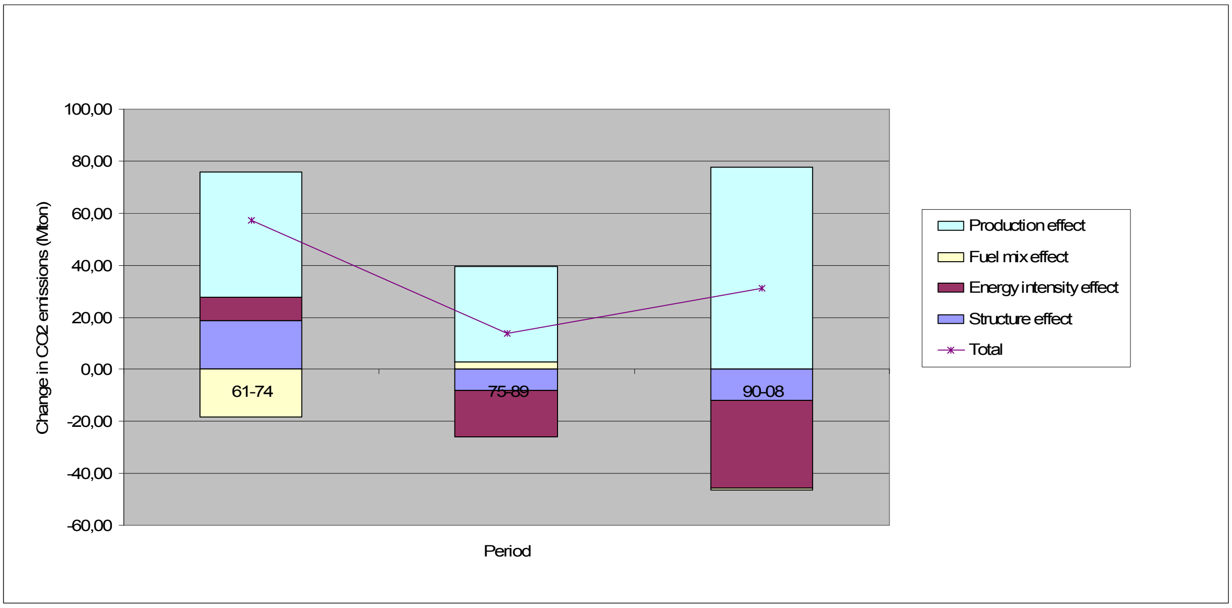
The changes in technology and industry structure are interesting since they are very different for each period. The energy intensity effect and the structure effect are positive in the first period, while they are negative for both other periods. This indicates that the economy has shifted towards energy-intensive industries and that the average energy intensity of these industries has also increased in the first period. The fuel mix effect shows that in the first period there is a transition to less CO_2 intensive energy carriers.

The results from the detailed IDA (see annex C) attributes the total change in CO_2 emissions for the 1960-2008 period. The main contributors were 1) utilities, 2) other

[10] Positive and negative refer to the sign of the effect on CO_2 emissions rather than to the consequence for the environment.

branches, 3) air and water transport, 4) agriculture and 5) chemical industry. Over one third of this change can be attributed to utilities. Perhaps counter intuitively, the contribution by the basic metal industry is very low. This can, beside the mentioned effects, be explained by the fact that only energetic use of fossil fuels is taken into account. A large part, about 40 percent in 1990, of total emissions by basic metals originates from non-energetic use of fossil fuels and other process related emissions.

Figure 4. Index Decomposition Analysis (Top-tier)



Detailed IDA shows that the structure effect depends highly on the changing economic importance of the energy intensive industries like utilities, chemical industry and basic metals.

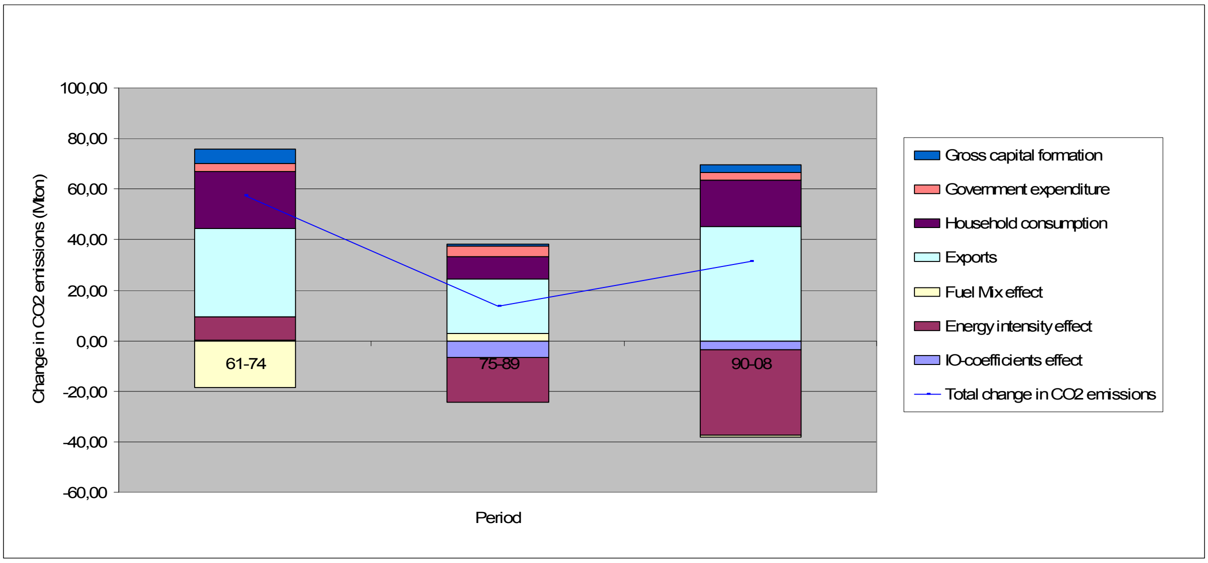
The energy intensity is influenced mainly by energy intensification of agriculture, decreasing production in oil refineries and substitution (planes for ships) in air and water transport between 1960 and 1974. The negative effect in the last two periods can be explained by the second oil crisis and relatively high production growth rates for most industries. Efficiency gains in energy generation and supply also play a role of some importance.

The substitution of hard coal fuels by natural gas in all industries, mainly in utilities, explains the fuel mix effect in the first period. The slight negative effect in the last period is caused by an increase in the relative weight of electricity use in total energy use. The substitution of other fuels by hard coal causes a positive effect of fuel mix between 1975 and 1990. This substitution can be partly explained by the diversification strategy introduced by the department of economic affairs as a reaction to the oil crises (Smits, 1999. p. 239).

2.3 SDA results

The large influence of economic growth which was shown by the IDA is confirmed by SDA through the large overall impact of the 4 final demand categories in figure 5. Particularly the large influence of the increase in exports is very consistent over the 3 time periods. Household consumption (excluding CO_2 emissions from direct energy use) is the second largest effect.[11]

Figure 5. Index Decomposition Analysis (top-tier)



Detailed SDA confirms the positive domination of the exports effect for all industries except utilities, which are mostly driven by household consumption (See Annex D). The influence of the exports effect on the CO_2 emissions of the chemical industry is very large and accounts on average for 25% of the total effect of exports. From a commodity perspective it strikes that around 91% of the exports effect on the chemical industry is attributed by exports of chemicals commodities.

Furthermore, a large influence by the exports effect is perceptible in utilities and air and water transport. From a commodity perspective air and water transport are influenced mainly by the exports of their own output, while utilities are dominated mainly by exports of other industries.

The influences of government expenditure, along with gross capital formation, are observable in utilities and remaining sectors mainly.

[11] Note that the energy intensity and fuel mix effect are the same as in the IDA.

3. The Social Cost of Carbon

In the previous sections we discussed the origins of CO_2 emissions from energetic energy use by the Dutch economy. In this section we will estimate the environmental "debt" which has accumulated as a result of these emissions. For this estimation we will use the social costs of carbon (SCC) which is the economic value of the marginal impact (damage) of the additional emission of one tonne CO_2 in any point of time (Yohe *et al.*, 2007). Tol (2005) summarizes a number of limitations of climate change impact studies like 1) incomplete understanding of climate change and its regional details, 2) knowledge gaps in impact analysis and 3) the hardness of capturing adaptation in impact assessments. Tol (2005) also argues that the marginal damage costs of carbon dioxide "are only useful to provide a benchmark for the costs of emission reduction policies". As a results of these limitations SCC estimates are highly uncertain (Klein *et al.*, 2007) and vary due different assumptions about discount rates and weighting of monetized figures over countries (Tol, 2005).

In an overview of 28 studies, including 103 estimates for the SCC, Tol (2005) states that the central estimate of the SCC of peer reviewed is \$43/tC (i.e. \$12 per tonne CO_2 emitted)[12] with a standard deviation of \$83/tC and a mode of \$5/tC. He also found that peer reviewed estimates generally show lower values and smaller uncertainties than other literature. Yohe *et al.* (2007) finds the same results for the marginal cost, standard deviation. Finally the IPCC (2007) identifies an average of \$12/tCO_2, but the estimates from 100 peer reviewed estimates range from \$-3/t CO_2 to \$95/tCO_2.

Pearce *et al.* (1996) shows that most SCC estimates are at the low end of the range of outcomes (\$5 - \$125/tC) in the Second Assessment Report by the IPCC. More recent studies concur with Pearce *et al.* (1996) that "estimates in excess of \$50/tC (i.e. \$14/tCO_2) require relatively unlikely scenario's of climate change, impact sensitivity and economic values" (Tol, 2005). Downing *et al.* (2005) state however that the use of a SCC level of \$50/tC or lower is only reasonable for global policies to reducing the threat of dangerous climate change. Finally Tol (2007), based on 47 studies including 211 estimates of the SCC, shows that there is only 1% probability that the SCC is greater than \$78/tC (i.e. \$21/tCO_2).

Despite the problems and uncertainties associated to the SCC, it is the most advanced way of giving insights in the environmental costs of economic growth. Based on the above literature review we chose a "range of SCC" of \$1.4/ tCO_2 (i.e. \$5/tC), \$12/tCO_2 and \$21/ tCO_2 to estimate the accumulated cost of CO_2 emissions by the Dutch economy from 1960 to 2008.

Table 6 shows the SCC obtained for the three price levels. The result area also related to both GDP and the physical capital stock. Note that CO_2 emissions resulting from household direct energy use are included in the estimations.

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[12] One tonne of carbon (tC) is equal to approximately 3.7 (44/12) tonnes of CO_2 (tCO_2). Conversion is based on molecular weights.

Estimations for the accumulated SCC of energetic energy use ranges from around 70 to 124 billion euros (2005 prices). It is striking that the growth of average annual SCC tends to decrease but in absolute figures the SCC increases periodically, meaning that the incurred "debt" increases more rapidly than in earlier periods. In addition to this, SCC is equal to a maximum of 8% of the physical capital stock available in 2008 and up to 25% of the 2008 GDP level.

Table 6. Accumulated SCC (millions of 2005 Euros) for three SCC-levels[13]

		$1,4/t$CO_2$	$12/t$CO_2$	$21/t$CO_2$
1960-1974	Total	1832	15706	27485
	Average annual	122	1047	1832
1975-1989	Total	2518	21579	37763
	Average annual	168	1439	2518
1990-2008	Total	3905	33471	58574
	Average annual	206	1762	3083
total (1960-2008)	Total	8255	70756	123822
% of Physical capital stock in 2008 (2005 prices)	Total	1%	5%	8%
% of GDP in 2008 (2005 prices)	Total	2%	15%	25%

Total greenhouse gas emissions (GHG) in 2008 are approximately 237 Mton CO2-equivalents (CBS, 2009b). CO_2 emissions (187 Mton) used for the estimations account for about 79% of total GHG emissions. Assuming that this ratio is representative for the course of the time series, the accumulated SCC as a percentage of GDP in 2008 would be about 7 percentage points higher.

4. Conclusions and further research

In this paper we showed that energy use and extraction of fossil fuels increased sharply in the Netherlands between 1960 and 1975. High growth of energy use, CO_2 emissions and energy intensity were driven by agriculture, chemical industry, oil refineries and other energy-intensive industries. The growth of the exports of these industries has a particularly large effect on the CO_2 emissions. These developments were stimulated by government policy that provided the newly discovered natural gas supplies at very low cost to the industry at the beginning of the 1970s. The decomposition results also show that the conversion from coal to natural gas contributed to lower CO_2 emissions.

After the oil crises energy use continued to grow but energy intensities started to drop. From 1990 relatively high growth of energy use is perceptible in transport services and other services.

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[13] The estimation of SCC is based on i) SCC scenarios $12/ t$CO_2$ to $21/ t$CO_2$, ii) CO_2 emissions from the previous sections for all years and iii) the 2005 annual exchange rate ($/€ = 1,2241) from the European Central Bank.

The decomposition results show the, unsurprising, large influence that economic growth has on growth of CO_2 emissions. The SDA shows the exports effect is particularly important and twice as large as the household consumption effect for example.

In this paper we have also estimated the social cost of carbon (SCC) for the 50 year period under investigation. Our estimates vary from about 70 billion to 124 billion euros (prices 2005). Compared to 2008 figures the upper limit of the SCC is equal to around 8% of the physical capital stock and approximately 25% of GDP. One should however take into account that only energetic energy use is included in the estimations, which is equal to about 79% of total GHG emissions in 2008.

Further research and improvements of data/time series

We plan to expand our analysis for the following environmental emissions:

1. Emission from non-energetic energy use (process emissions)
2. Non-energy use related CO_2 emissions
3. Other greenhouse gasses
4. Other air emission related to energy use (e.g. SO2 and NOx)

We are also not yet fully satisfied by the energy use series and input-output tables produced for this study. The input-output tables pre1969 were produced using backward calculation methods which could be improved (see annex A).

Finally we wish to do a second decomposition set so that the energy intensity is the variable which is explained. Also we want to include population effects in the analysis.

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Annex A. Data description

For this study time series for energetic energy use and input-output tables from 1960 to 2008 were compiled. In this annex we will discuss the various time series that were constructed. In some cases the official data of Statistics Netherlands were used, but for many years the time series were compiled using other sources. Below is an overview of the data used and the methods to compile the time series.

Input-output tables at basic prices (current prices and prices of previous year)

For the period from 1969-2008 onwards the official time series of input-output tables at basic prices from the National Accounts department of Statistics Netherlands were used. These tables are available at current prices and in prices of the previous year[14] and they are fully revised according to the 2001 revision.

During a small project experimental input-output tables at basic prices from 1950 to 1969 were compiled in both current prices and prices of the previous year. In the first step input-output tables at current prices (producer prices) from old publications were used to calculate the cells of 1969 input-output table (producer prices) backward annually to 1950 (CBS, 1960-1973). The input-output tables used for the backward calculation were corrected for the SNA 1968 revision first. In addition, the backward calculation was performed on a rather high aggregated level to minimize effects of NACE revisions. Differences that occur due extrapolation of value added and imports on one hand and exports, household consumption, government expenditure, gross capital formation and changes in stocks on the other hand are offset in value added. We are aware that this leads to changes in GDP, but for most years, except 1951 (2.2%) and 1953 (1.4%) the adjustment is less than 0.8% of total value added. After the extrapolation of all cells a Lagrangian method[15] adjusted the interior of the table to column and row totals.

To convert the input-output tables from step 1 to basic prices, provisional taxes *less* subsidies (TLS) matrices were compiled. For 1959, 1961-1969 TLS matrices were available (CBS, 1960-1973). For these years the percentages TLS per cell (*TLS rates*) were calculated. These matrices however include levies and subsidies on imports in the row for wholesale and retail trade. These levies and subsidies are excluded and replaced by the TLS rate for wholesale and retail trade in previous year (t+1) of the backward calculation.

The average of the TLS rates for 1959 and 1961 is used for TLS in 1960, while the TLS rates for 1959 are use for all preceding years. The calculated TLS rates are subsequently used to calculate the new TLS matrices for all years. The row totals are obtained from the TLS row by industry from the input-output tables estimated in step 1. The interior is adjusted to the row totals using absolute weights of the calculated TLS per cell. Finally the TLS is subtracted from the input-output table

[14] The input-output table of 1969 is only available in current prices

estimated in step 1, leaving an input-output table at basic prices. In some case the above mentioned adjustment leads to negative numbers in the input-output table at basic prices. This is corrected manually.

After the backward calculation of input-output tables at current prices we used price index figures from De Boer (1981) to deflate the input-output table estimated in step 1. The macro economic aggregates were deflated using deflators from Statistics Netherlands (Statline). Finally the calculated interior is adjusted to the row and column totals using the Lagrangian method again.

Assuming TLS is volume related, the volume indices that result from the input-output tables in current prices and previous years prices (both in producer prices) are used to estimate the TLS matrices in previous year's prices for all years. Again the row totals for TLS are obtained from the input-output table in previous year's prices and the interior is adjusted to these totals using their absolute weight. After subtracting the TLS matrices from the input-output tables at producer prices, the input-output table at basic prices results. If necessary, negative numbers are corrected manually in the input-output table at basic prices.

Energetic energy use of the Dutch economy

From 1990 to 2008 the energy use by industry is obtained from official Environmental Accounts (NAMEA) at Statistics Netherlands. The energy use is split into energy use by stationary sources (houses, commercial buildings, etc.) and mobile sources (cars, ships, etc.).

From 1975 to 1990 revised energy balances from the Energy Department (Statistics Netherlands) were used. Energy balances give a detailed overview of supply and use of a range of energy carriers (CBS, 2010) Energy use is available for different industries, the energy sector, transport and other final users.

For the years preceding 1975 energy balances from the International Energy Agency (IEA) were used as framework for the backward calculation (http://data.iea.org, downloaded January 2010). Specific information on energy use in the industry is obtained from old publications (CBS, 1961-1977).

No data on use of chemical waste gases was available before 1975. For backward calculation prior to 1975 we used the development of naphtha use in the chemical industry, since most chemical waste gases are obtained from cracking naphtha.

Since the use of transport and extraction from bunkers only refer to the fuels sold in the Netherlands instead of use by Dutch residents these figures need to be adjusted. The backward calculation of the use of fuels in Fishery (1990) is performed using data from the Agriculture Economic Institute (LEI) from 1974 onward. For the preceding years developments of engine power of the Dutch fishery fleet is used.

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[15] For the lagrangian method a program (WINADJUST) was developed by Statistics Netherlands (Van Dalen and Sluis, 2002)

For fuel use in (seagoing) shipping and internal navigation fleet specifications (number of active ships, gross tonnage, performance and developments in world trade) are used for extrapolation. Fuel use for road traffic is extrapolated using figures about the traffic performance by type of vehicle (1000 million kilometres), monetary data from supply and use tables, numbers of holidays by Dutch residents and a fixed portion of fuel sold in the Netherlands.

Further detail for commerce, agriculture and government is not available in the energy balances. Data from other publications are used for the division of other final users. Use of energy carriers in agriculture, mining and quarrying of non-energy products along with water supply is based on data from Statistics Netherlands back to 1979. Figures for agriculture in preceding years are calculated using data from the IEA (http://data.iea.org, downloaded January 2010), supply and use tables and the experimental input-output tables (before 1969). Energy use in mining and quarrying of non-energy products is backward calculated using monetary data from the supply and use tables and the earlier mentioned experimental input-output tables. Developments in the amounts of clean water supplied in the Netherlands are used for extrapolating energy use for water supply. Energy use in the remaining NACE industries like government, construction and other services than transport services is not robust enough to be published separately and are therefore bundled under “Other branches”.

Fixed emission coefficients are used to convert the energetic energy use to CO_2 emissions. These coefficients are obtained from the national list of emission coefficients.

Summary

Note that the above mentioned time series are still experimental and not yet official data of Statistics Netherlands. Since the compiled time series are experimental, detailed descriptions are available in internal (Dutch) memos of Statistics Netherlands only. (Van der Helm, 2010a-c)

We hope to finalize these time series somewhere over the summer of 2010. Nevertheless these data will probably remain an “experimental series” of Statistics Netherlands.

Annex B. Industry classification

An aggregated industry classification based on the SBI[16] 1993 is used to be close to the classifications used in the input-output tables before 1969 and from 1969 onward and the energy statistics.

Top-tier classification (names used in the paper)	Detailed classification	SBI 1993 classification
Agriculture	Agriculture, forestry and fishery	A, B
Mining	Mining and quarrying	C
Food	Food, beverages and tobacco	DA
Textiles	Textiles and leather	DB, DC
Paper and publishing	Paper and publishing	DE
Oil refineries	Oil refineries	DF
Chemical industry	Chemicals, rubber and synthetic fibres	DG, DH
Basic Metals	Basic Metals	DJ (27)
Metal products, etc.	Metal products, electronics and transport equipment	DJ (28), DK, DL, DM
Other industry	Wood and wood products, building materials and other industry	DD, DI, DN
Utilities	Energy and water supply	E
Air and water transport	Air and water transport	I (61, 62)
Road transport	Road transport and transport services	I (60, 63)
Other branches	Construction, government and other services	F, G, H, I (64), J - Q

[16] SBI (Standaard Bedrijfsindeling) is the industry classification used by Statistics Netherlands based on NACE rev.1.1 and ISIC rev. 3.1.

Annex C. Detailed IDA results

Detailed IDA results for industries in the Netherlands (Contribution to change in CO_2 emissions, Mton)

Industries	61-74					75-89					90-08					Complete time series				
	E_{STR}	E_{EI}	E_{FM}	E_{PROD}	Total effect	E_{STR}	E_{EI}	E_{FM}	E_{PROD}	Total effect	E_{STR}	E_{EI}	E_{FM}	E_{PROD}	Total effect	E_{STR}	E_{EI}	E_{FM}	E_{PROD}	Total effect
	(Mton CO_2)																			
Agriculture	0,4	3,2	-0,5	1,6	4,7	1,8	-0,7	-0,1	2,7	3,7	-3,0	-2,7	0,5	5,2	0,0	-0,9	-0,1	-0,1	9,5	8,4
Oil refineries	0,7	2,8	0,0	5,0	8,5	-4,8	-1,8	0,0	3,0	-3,6	-3,8	-0,1	0,0	6,4	2,5	-7,9	0,9	0,0	14,4	7,3
Chemicals	7,6	-0,9	-1,2	5,9	11,4	1,8	-6,1	-0,8	5,0	0,0	-0,6	-5,8	-4,3	7,7	-3,0	8,8	-12,8	-6,2	18,7	8,5
Basic metals	3,8	-1,8	-1,0	3,5	4,5	-1,2	-3,3	-1,3	1,6	-4,2	-1,3	-1,2	0,6	2,3	0,5	1,3	-6,3	-1,6	7,3	0,8
Utilities	9,9	-0,2	-8,9	14,3	15,1	-6,0	-3,2	8,5	11,5	10,7	-4,6	-18,9	6,9	25,6	9,1	-0,8	-22,3	6,5	51,4	34,9
Air and water transport	-3,4	1,4	-0,1	3,8	1,7	0,1	0,8	0,0	2,8	3,6	2,8	-2,0	0,4	9,6	10,8	-0,5	0,2	0,3	16,1	16,1
Road transport	0,2	0,0	0,1	0,8	1,2	0,4	0,5	0,6	1,1	2,7	0,3	0,1	0,2	3,9	4,5	0,9	0,6	0,9	5,9	8,3
Remaining sectors	-0,6	4,7	-7,0	13,2	10,3	-0,1	-4,1	-4,1	9,0	0,8	-1,5	-3,4	-5,2	17,0	6,9	-2,3	-2,8	-16,3	39,3	17,9
Total	18,5	9,2	-18,4	48,0	57,3	-8,1	-17,7	2,8	36,7	13,7	-11,8	-34,0	-0,8	77,8	31,3	-1,3	-42,5	-16,4	162,5	102,3

E_{STR}: Structure effect

E_{EI}: Energy intensity effect

E_{FM}: Fuel mix effect

E_{PROD}: Production effect

Annex D. Detailed SDA results

Detailed SDA results for industries in the Netherlands (Contribution to change in CO_2 emissions, Mton)

Industries	1961-1974								1975-1989								1990-2008								Total							
	E_{IOC}	E_{EI}	E_{FM}	E_{EXP}	E_{PHH}	E_{GOV}	E_{GFC}	**Total effect**	E_{IOC}	E_{EI}	E_{FM}	E_{EXP}	E_{PHH}	E_{GOV}	E_{GFC}	**Total effect**	E_{IOC}	E_{EI}	E_{FM}	E_{EXP}	E_{PHH}	E_{GOV}	E_{GFC}	**Total effect**	E_{IOC}	E_{EI}	E_{FM}	E_{EXP}	E_{PHH}	E_{GOV}	E_{GFC}	**Total effect**
	(Mton CO_2)																															
Agriculture	0,1	3,2	-0,5	1,2	0,5	0,0	0,1	**4,7**	-0,1	-0,7	-0,1	4,1	0,4	0,1	-0,1	**3,7**	-2,1	-2,7	0,5	3,5	0,5	0,1	0,1	**0,0**	-2,0	-0,1	-0,1	8,9	1,4	0,2	0,2	**8,4**
Oil refineries	-0,8	2,8	0,0	5,7	0,3	0,1	0,5	**8,5**	-0,6	-1,8	0,0	-1,4	0,1	0,1	-0,1	**-3,6**	-0,8	-0,1	0,0	3,3	0,4	0,1	-0,4	**2,5**	-2,2	0,9	0,0	7,6	0,8	0,2	0,0	**7,3**
Chemicals	0,0	-0,9	-1,2	11,6	1,0	0,6	0,3	**11,4**	-0,4	-6,1	-0,8	6,7	0,2	0,2	0,2	**0,0**	-0,4	-5,8	-4,3	6,8	0,7	0,1	-0,1	**-3,0**	-0,7	-12,8	-6,2	25,1	1,9	0,9	0,4	**8,5**
Basic metals	-0,4	-1,8	-1,0	6,8	0,4	0,1	0,4	**4,5**	-0,3	-3,3	-1,3	0,6	0,0	0,1	-0,1	**-4,2**	-0,9	-1,2	0,6	1,8	0,1	0,0	0,0	**0,5**	-1,6	-6,3	-1,6	9,1	0,5	0,2	0,4	**0,8**
Utilities	3,3	-0,2	-8,9	2,2	15,7	0,7	2,3	**15,1**	-5,3	-3,2	8,5	4,2	5,3	1,2	0,0	**10,7**	1,7	-18,9	6,9	9,3	7,8	0,9	1,2	**9,1**	-0,3	-22,3	6,5	15,8	28,8	2,7	3,6	**34,9**
Air and water transport	0,1	1,4	-0,1	-0,4	0,5	0,0	0,1	**1,7**	0,2	0,8	0,0	2,1	0,3	0,0	0,2	**3,6**	0,2	-2,0	0,4	10,2	1,7	0,1	0,2	**10,8**	0,5	0,2	0,3	12,0	2,4	0,2	0,6	**16,1**
Road transport	0,1	0,0	0,1	0,5	0,3	0,0	0,1	**1,2**	0,2	0,5	0,6	0,9	0,4	0,0	0,1	**2,7**	-0,7	0,1	0,2	2,6	1,6	0,4	0,3	**4,5**	-0,5	0,6	0,9	4,0	2,2	0,5	0,5	**8,3**
Remaining sectors	-2,3	4,7	-7,0	7,4	3,8	1,7	1,9	**10,3**	-0,4	-4,1	-4,1	4,2	2,3	2,3	0,5	**0,8**	-0,5	-3,4	-5,2	7,6	5,6	1,4	1,4	**6,9**	-3,2	-2,8	-16,3	19,3	11,7	5,4	3,8	**17,9**
Total	0,1	9,2	-18,5	35,1	22,4	3,2	5,7	**57,3**	-6,7	-17,7	2,8	21,4	9,0	4,0	0,8	**13,7**	-3,4	-34,0	-0,8	45,2	18,4	3,1	2,9	**31,3**	-10,0	-42,5	-16,5	101,7	49,8	10,3	9,4	**102,3**

E_{IOC}: input-output coefficients effect

E_{EI}: Energy intensity effect

E_{FM}: Fuel mix effect

E_{EXP}: Exports effect

E_{HH}: Household consumption effect

E_{GOV}: Government expenditure effect

E_{GFC}: Gross Capital Formation effect