DECOMPOSITION OF HISTORICAL CARBON EMISSIONS FROM ENERGY USE IN THE FIRST KYOTO PERIOD (1990-2012)

MASTER THESIS

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ABSTRACT

The first target of the Kyoto Protocol for the Netherlands was 6% reductions of average CO_2-equivalent emissions over 2008-2012 compared to 1990 levels. The vast majority of energy-related CO_2 emissions, had however increased with 9.4%. Only due to the large reductions of other greenhouse gas emissions and partly the acquirement of emission credits, the target was reached. This research aimed to uncover the driving factors and its relation with the energy and climate policies behind these energy-related emissions, to better reduce emissions and accordingly reach future emission targets. The logarithmic mean Divisia index (LMDI) method was executed to decompose these emissions into different kinds of volume, structure and intensity effects taking place at the demand sectors and indirectly at electricity and heat supply. Three main drivers were distinguished explaining 82.5% of the total observed change of +17.56 Mt by 2008-2012. At first the increased level of activity (in terms of economic output, travelled distance and number of households) caused an increase of +42.73 Mt. The second driver is related to this, namely the global crisis causing the large activity decrease at the economy sectors and transport since 2008, which may otherwise have reached as high as +56.74 Mt. by 2012. The third driver responsible for large reductions were the efficiency improvements, reflected in the energy intensity effects from final energy use at the main demand sectors (-16.74 Mt) and the energy efficiency effects considering primary inputs at electricity and heat supply (-11.51 Mt). Improving the efficiency was also the main decarbonization strategy in the Netherlands, in clear correlation with the observed effects over time. At the demand sectors this comprised different sector dependent conservation measures, at electricity and heat supply the CHP development clearly ruled the efficiency improvements. The savings effect from policies is however lower, as these effects still incorporate other structure effects and effects from autonomous improvement. The large upwards activity effect and associated influential weakening effect from the recession signify the importance to incorporate the impact of activity growth in energy and climate policies. Achieved efficiency effects show that efficiency policy remains a favorable strategy if there is more room for efficiency improvement. The encouragement of renewable energy and fuel substitution in decarbonization policy is also recommended, as these are indicated as potential drivers of future reductions. Taking into account these insights from historical developments helps to better curb future energy-related CO_2 emissions.

PREFACE

The past year I have been working on this thesis as a concluding work of my master Sustainable Development, track: Energy & Materials. I remember being intrigued by the decomposition subject since the first course when I started the programme in the end of 2014. The charm of this method is that it is able to so simply show the impact of different types of effects in such pretty, colourful and easy to comprehend figures. Nonetheless, decomposition analysis on the level of a whole country turned out to be anything but simple, but I enjoyed the challenge to crush all the data; especially when everything came together in one synthesized figure. I would like to thank my supervisor Robert Harmsen for his professional support during the research process; his expertise and enthusiasm are highly appreciated. The study adviser Pieter Louwman also deserves an acknowledgement for helping me combine this research with two courses and my recovery process. Writing this thesis has been a very educational and enjoyable experience for me, I hope the same applies to you as a reader.

Carmen van den Berg

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LIST OF ABBREVIATIONS

A	activity
bln	billion
cap	capita
CBS	Statistics Netherlands
CF	carbon factor
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CRF	common reporting format (of the UNFCC national inventory submission)
EA	economic activity
ECN	Energy research Centre of the Netherlands
EE	energy efficiency
EI	energy intensity
ES	economy structure
FE	fossil energy
FS	fuel substitution
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule
GVA	gross value added
HH	households
IDA	index decomposition analysis
IEA	International Energy Agency
IPAT	impact = population x affluence x technology
IPCC	Intergovernmental Panel on Climate Change
kt	kiloton
kWh	kilowatt-hour
LMDI	logarithmic mean Divisia index
MJ	megajoule
mln	million
Mt	megaton
NC	National Communications
NEa	Dutch Emission Authority
OE	other energy (non-CO_2)
PJ	petajoule
pkm	passenger-kilometre
POP	population
RE	renewable energy
S	structure
TD	travelled distance
TE	total energy
TJ	terajoule
tkm	tonne-kilometre
UNFCCC	United Nations Framework Convention on Climate Change

1. INTRODUCTION

In 1997 on December the 11th, the industrialized countries signed the Kyoto Protocol extending the 1992 United Nations Framework Convention on Climate Change. This international agreement contained binding greenhouse gas (GHG) emission reduction targets for each submitting country, depending on its responsibility, in order to collectively combat climate change (UNFCCC, 2015a). As of 2005 a 192 countries were committed to the Kyoto treaty (UNFCCC, 2015b). For the Netherlands the emission target of the first Kyoto period was set on a reduction of 6% of the average emissions during 2008-2012 compared to the Kyoto base year of 1990 (NC6, 2013). In order to reach this target a variety of policy measures was introduced, focusing for example on increasing the share of energy from renewable sources, improving energy efficiency or decreasing the energy demand. According to article 7 of the Kyoto protocol, committing countries were obliged to regularly report their greenhouse gas inventories following the Intergovernmental Panel on Climate Change (IPCC) guidelines and so-called National Communications to demonstrate how they were complying with the protocol (UNFCCC, 2015c).

During this first Kyoto period total carbon dioxide equivalent (CO_2e) emissions decreased from 219.5 megaton (Mt) in base year 1990 to 196.3 Mt in target year 2012 (CRF, 2015), as shown in Figure 1. The emissions are measured in CO_2e emissions, so that different types of GHG emissions can be compared. Other GHGs include methane, nitrous oxide and fluorinated gasses. As the figure shows, especially these non-carbon dioxide GHGs have significantly decreased during the Kyoto period, by 50.0%. Actual average CO_2 emissions over 2008-2012 on the other hand reached in fact up to 8.1% above base year value. With that CO_2 emissions increased its share in total CO_2 equivalents from 73.1 to 85.0% between 1990 and 2012 (CRF, 2015). As opposed to other GHGs, CO_2 emissions are mostly originating from the combustion of fossil fuels for energy purposes (Hekkenberg & Verdonk, 2014; RIVM, 2014), which is defined here as energy-related CO_2 emissions. Fugitive emissions, which are nevertheless related to energy production, are excluded from this category. Non-energy related CO_2 emissions originate for example from cement production and land-use change. A stable average of 94.5% of the CO_2 emissions has been energy-related (CRF, 2015). By the end of Kyoto these emissions had increased from 150.2 to 164.4 Mt (average over 2008-2012), an increase of 9.4%. Compared to the other GHG categories the energy-related CO_2 emissions have shown the largest increase (both relative and absolute) while also being responsible for the largest share: 81.4% over 2008-2012 compared to 68.5% in 1990 (CRF, 2015).

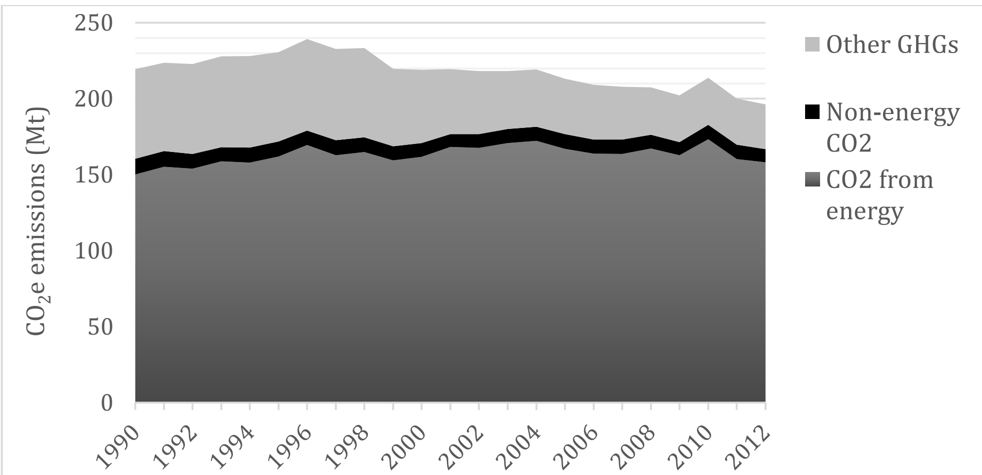

Figure 1 – Carbon dioxide equivalent emissions between 1990-2012 for three different categories of greenhouse gasses: CO_2 originating from energy use, non-energy related CO_2 and all other GHGs (CRF, 2015)

Despite the recent decreasing trend in total CO_2 equivalent emissions, the emission cap of 200.2 Mt on average for 2008-2012 was exceeded. The Dutch Emission Authority (NEa) reported that 45 Mt of foreign emission credits had to be acquired by the government in order to compensate for the excessive emissions (NEa, 2013), as shown in Figure 2. Though this mechanism for emission credits has been an effective tool to reach emission targets after the first Kyoto period, it should be the main priority to aim to reach targets by reducing domestic GHG emissions. It is therefore important to get a good understanding of the drivers of change behind these emissions during this period, so that future policies will be able to better curb GHG emissions and reach future (Kyoto) targets, to combat climate change. To evaluate the effect of implemented policies different evaluation reports have been published. According to a parliamentary examination in 2012 about 121 reports (of which 67% ex post) aimed to evaluate the Dutch energy and climate policy. The use of the so-called Index Decomposition Analysis (IDA) methodology is mentioned only twice (RVO, 2012), which is the method that will be used in this paper.

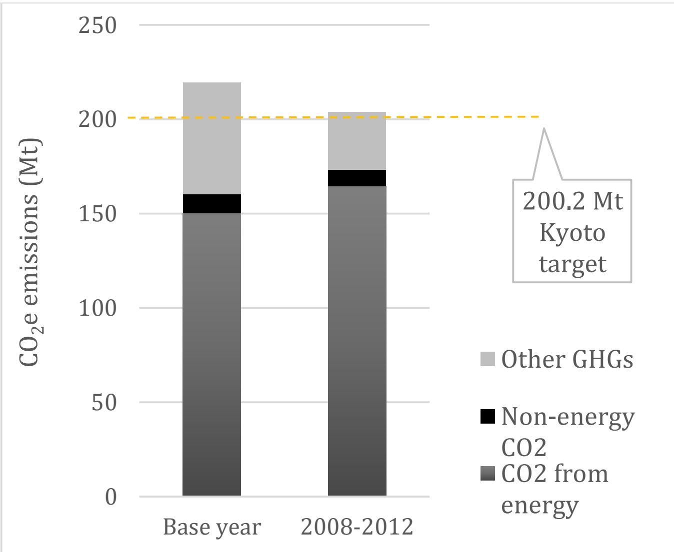

Figure 2 – Base year (1990) emissions compared to average yearly 2008-2012 emissions and the Kyoto target level (CRF, 2015; NEa, 2013)

The use of a decomposition analysis as opposed to other (for example bottom-up) methods is useful because it allows to decompose a certain trend to different driving factors. Three types of effects can be distinguished: volume, structure or intensity effects. A volume effect is for example a difference in carbon emissions due to a change in population size. A structure effect is about 'doing things differently'. An example is a changing economic structure, like an increasing importance of the service sector as opposed to the energy-intensive heavy steel sector. The intensity effect at carbon decompositions is usually further split out including the effects of energy intensity and the carbon emission coefficient. When policy measures for example focus on the increase of energy efficiencies its effect can be found in an energy intensity effect – as long as this exceeds autonomous improvements (Boonekamp et al., 2001). In fact, decomposition analysis allows to decompose to as many factors as pleased. The crux is to 1) obtain the statistical data in the appropriate units of measurement and 2) to pinpoint what the different effects mean – like which ones are caused by energy and climate policies (Boonekamp et al., 2001; Xu & Ang, 2013). In this study the currently preferred logarithmic mean Divisia index (LMDI) method is applied, because of its advantages in ease of use and result interpretation and the fact that it does not generate a residual term (Ang, 2004).

With an increasing interest in the driving factors behind energy use and related CO_2 emissions, the literature on decomposition analysis has been rising exponentially since first used in the 1980s (Ang, 2015). However, decomposition analysis covering the Netherlands is not abundant in academic literature. The focus has in general been on the trend of energy use itself (not the associated CO_2 emissions). Moreover, none of the evaluation reports covered the full Kyoto period from 1990 up to 2012. This report therefore fills a gap in literature by decomposing historical carbon dioxide emissions during this first Kyoto period. The research will be limited to energy-related CO_2 emissions because this has been the largest and seemingly most difficult segment of CO_2e emissions to get a grip on. The research question is now formulated as follows:

What were the driving factors of energy-related carbon emissions from combustion during the first Kyoto period (1990-2012) in the Netherlands and how can they be attributed to energy and climate policies?

First a thorough literature review follows in Chapter 2 covering the theory behind LMDI decomposition analysis. The specific method of the different analyses is discussed in Chapter 3. Chapter 4 to 10 cover the resulting decomposed emissions of the sectoral analyses: electricity and heat supply, industry, services, agriculture, transport and the residential sector. Besides the results of the decomposition analysis at the end of each chapter the link with energy and climate policies is discussed. In Chapter 11 the results are synthesized in order to be able to review the total achieved effects taking into account the found historical trajectory between 1990 and 2012. At last an answer to the research question is formulated in Chapter 12, followed by a discussion of the results in Chapter 13.

2. LMDI DECOMPOSITION THEORY

This chapter covers the theory of the decomposition method, which is used in this research to quantify the effects from different factors behind changing CO_2 emissions. Index Decomposition Analysis (IDA) has been applied to explore the drivers behind different kinds of trends since the 1980s. Especially trends in energy use and carbon emissions have gained increased interest due to the current environmental crisis. The use of different IDA methods was found in almost six hundred scientific papers by 2014 (Ang, 2015). At the moment the logarithmic mean Divisia index (LMDI) is the preferred IDA method, mostly because of the absence of a residual term and its ease of use and result interpretation (Ang, 2004). Also within the LMDI theory, different methods are applied. When the studied trend is a quantity like CO_2, Ang (2015) recommends the additive LMDI method as introduced by Ang et al. (1998), which was the basis here. The most well-known and easy to comprehend decomposition model is the IPAT or Kaya identity, which describes the human impact (I) on the environment as a product of population (P), affluence (A) and technology (T) (IPCC, 2000). It has been long-debated, with the main criticism on the factor of 'technology' which cannot solely explain the emissions per unit of economic output (Roca, 2002). IDA on carbon dioxide emissions can be considered an extended IPAT or Kaya identity since it aims to deal with more factors to explain the impact (in terms of CO_2) on the environment.

Theoretically, decomposing a certain quantity can be done for as many factors as pleased. The amount of studied factors in IDA depends on the availability of data and the effects that are aimed to be studied. Most common is to break down CO_2 emissions into five effects, the effects of the driving factors: activity, structure, energy intensity, fuel mix and emission factor change, as elaborated in the practical guide for LMDI decomposition by Ang (2015). In this research, deriving from among others O'Mahony et al. (2012), the factor of 'fuel mix' is split up to an effect of the substitution between fossil fuels only and a factor explaining the renewable energy penetration. The aggregates can be broken down to different subsectors (i) and different fuel types (j) (Xu & Ang, 2013). Total carbon dioxide emissions of a certain sector can now be expressed by the following Formula F1 (see Table 1 for terms). This formula will be referred to as the basic formula for the remaining analyses with different LMDI CO_2 decompositions:

F1: $$CO_2 = \sum_{ij} CO_{2_{ij}} = \sum_{ij} A \frac{A_i}{A} \frac{E_i}{A_i} \frac{FE_i}{E_i} \frac{FE_{ij}}{FE_i} \frac{CO_{2_{ij}}}{FE_{ij}} = \sum_{ij} A \cdot S_i \cdot EI_i \cdot RE_i \cdot FS_{ij} \cdot CF_{ij}$$

Table 1 – Clarification of terms and relations of formulas F1 and F4

Effect in Formula F4		Factor in Formula F1		
ΔCO_2	Total carbon dioxide effect	CO_{2ij}		*With:*
ΔA	Activity effect	A		*A = activity level in main sector*
ΔS	Structure effect	S_i =	A_i/A	*A_i = activity level in subsector i*
ΔEI	Energy intensity effect	EI_i =	E_i/A_i	*E_i = energy consumption in subsector i*
ΔRE	Renewable energy effect	RE_i =	FE_i/TE_i	*FE_i = fossil energy consumption in sector i*
ΔFS	Fuel substitution effect	FS_{ij} =	FE_{ij}/FE_i	*FE_{ij} = fossil E use in sector i from fuel j*
ΔCF	Carbon factor effect	CF_{ij} =	CO_{2ij}/FE_{ij}	*CO_{2ij} = CO_2 emissions in sector i from fuel j*

The part of Formula F1 behind the last equality sign gives the corresponding factors: activity (A), structure (S_i), energy intensity (EI_i), renewable energy (RE_i), fuel substitution (FS_{ij}) and carbon emission factor (CF_{ij}). For example, factor FS_{ij} now determines the effect in terms of delta carbon dioxide emissions, due to a changed share of a certain fossil fuel 'j' in the total fossil fuel consumption in sector 'i'. The activity factor has the most complex indicator and differs between sectors, as it is deemed to be a direct determinant of energy use which becomes most meaningful on the lowest levels of demand sectors (Boonekamp, 2001). The unit of measurement of activity therefore depends on the studied sector. Energy components are in general measured in the terajoule (TJ), carbon dioxide amounts in kiloton (kt). Note that the unit of measurement (TJ versus kWh or the used prefix) is irrelevant at decomposition analysis, as it is based on relative changes.

Each factor induces an effect in delta carbon dioxide emissions. To be able to calculate this amount for each factor the logarithmic mean (L) is used, hence the name of the method logarithmic mean Divisia indix. For the calculation of a logarithmic mean between two values a and b, the L can be calculated by Formula F2F1:

F2: $$L(a,b) = \frac{a-b}{(\ln a - \ln b)}$$

Using the logarithmic mean, each effect in delta CO_2 emissions between t and 0 in a certain subsector 'i' due to a certain fuel 'j' can be calculated. The sum of all these separate effects represents the total effect of a certain factor ($A=\Sigma A_{ij}$). The following Formula F3 enables to calculate the activity effect. To calculate the other effects, the A term should be replaced by the terms of their corresponding factors (Table 1):

F3: $$\Delta A = \sum_{ij} L(CO^t_{2_{ij}}, CO^0_{2_{ij}}) \ln\left(\frac{A^t}{A^0}\right) = \sum_{ij} \frac{CO^t_{2_{ij}} - CO^0_{2_{ij}}}{\ln(CO^t_{2_{ij}}) - \ln(CO^0_{2_{ij}})} \ln\left(\frac{A^t}{A^0}\right)$$

The total difference in CO_2 emissions between a certain interval (t and 0) is the sum of the six separate effects, for all subsectors and fuel types together. This is mathematically described with the following Formula F4:

F4: $$\Delta CO_2 = CO_2^t - CO_2^0 = \Delta A + \Delta S + \Delta EI + \Delta RE + \Delta FS + \Delta CF$$

When decomposition analyses cover large research periods, they are subdivided into shorter time intervals. According to Liu & Ang (2007) interesting information might get lost when a research period exceeds 15 years, because effects might be levelled out. Short periods on the other hand might display short-term fluctuations. Therefore, periods between 5 and 15 years are preferred. Sometimes studies follow political periods like the 5-year plans in China (Zhang et al., 2011). However, if the long period is not a multiple of for example five, one cannot compare the effects in the 'rest years' with the five-year periods. Therefore, Wu et al. (2005) converted the 5-year effects to yearly effects, so that comparison was facilitated. A stacked figure (from Formula F4) can eventually clearly show how the different effects compare in both amount (usually kilotons of CO_2) and direction ('+' or '-') to the total change of CO_2 emissions at the different researched intervals.

3. METHOD

This chapter comprises a detailed elaboration of the research method. At first (3.1) the overarching research method is given, covering the different research steps and aspects that were applicable for all the executed LMDI decompositions. The two sections that follow subsequently discuss the detailed operationalisations of the different types of decomposition analyses that were executed for: electricity & heat supply (3.2) and the main demand sectors (3.3). The latter comprises the method for the industry, services, agriculture, transport and the residential sector. In Section 3.4 the method to analyse the link between deployed energy & climate policies and the demonstrated effects is discussed. Section 3.5 covers how all sectoral results were synthesized. Lastly Section 3.6 sets out the quantitative and qualitative data collection required for all analyses.

3.1 OVERARCHING RESEARCH METHOD

The core of this research is the analysis of the five main demand sectors: the industry, services, agriculture, transport and the residential sector. As a result of their energy demand, CO_2 is emitted into the atmosphere. To be able to include indirect emissions taking place at electricity and heat production, first the electricity and heat supply of the Netherlands needed to be analysed. The carbon factors of electricity and heat use that came forward here, could be used at the analyses of the demand sectors, so that the developments in electricity and heat supply came back here as a carbon factor effect. After each sectoral analysis, including the analysis of the electricity and heat supply, a possible link between the observed effects and the deployed energy and climate policies was analysed. Besides this link, also other possible influences are shortly discussed at the end of each sectoral analysis, as these are very sector specific. Eventually all results are synthesised in order to be able to see what all found developments meant for the 2012 Kyoto target. The overarching research method is graphically shown in Figure 3.

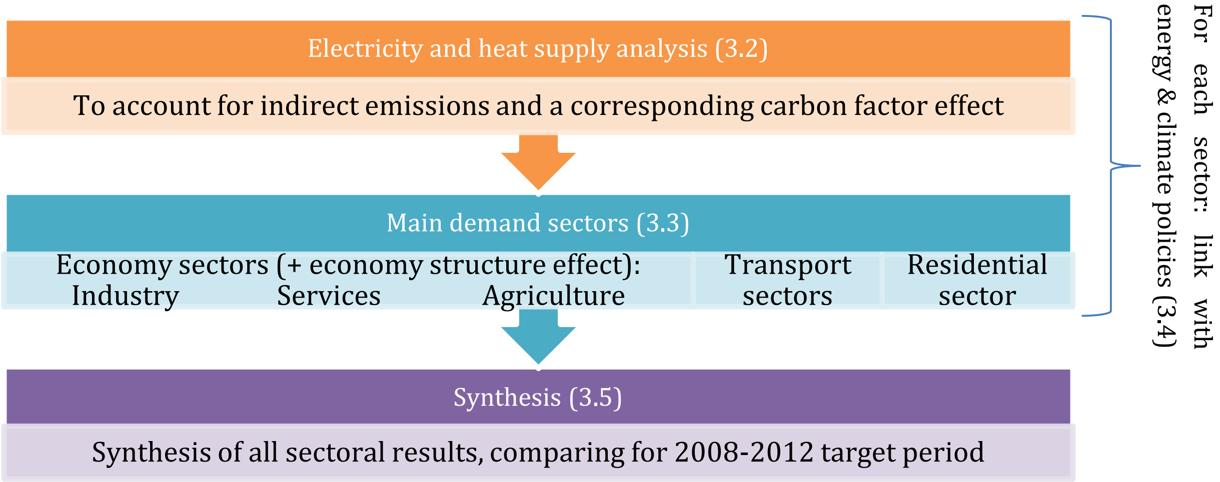

Figure 3 – Steps in research, the overarching research method

For each decomposition analysis, a slightly different decomposition formula was used to analyse CO_2 changes. Formula F1 is the basic starting formula, which including six factors (activity, structure, energy intensity, renewable energy, fuel substitution and carbon factor). Depending on the type of analysis factors were added or removed to be able to execute a meaningful decomposition, appropriate to the concerned sector. In the next section the detailed operationalization of these separate LMDI analyses are set out. First however the chosen time intervals, the included energy sources and the handling of zero values are set out, applicable for all the executed decomposition analyses.

TIME INTERVALS

The preferred length of time intervals for decomposition analysis is between 5 and 15 years (Liu & Ang, 2007). In this research the time periods were chosen looking at two criteria: political periods and economic output (see Appendix A). Since we are interested in the effects of different policy instruments the course of the cabinets in the Netherlands was largely followed, which generally consist of 4-year periods (Rijksoverheid, 2015). Secondly the dynamics of the economy in terms of GDP (gross domestic product) was considered to determine the different time periods. A simple investigation of different time intervals looking at the absolute differences between interpolated values between the intervals shows that 4-4-4-6-4 year intervals best fit the dynamics of the GDP from 1990 to 2012. These intervals also largely follow the political situation in the Netherlands. In Appendix A, the development of both the political and the economic situation of the Netherlands and how they follow the chosen time intervals are discussed in more detail. To be able to compare between intervals (as the fourth interval covers six years instead of four), the resulting effects from the analyses were converted to yearly effects. At all decomposed effects it was important to examine whether chosen intervals were able to represent the overall trends; without levelling out the effects, or on the other hand representing short-term fluctuations. On a country-wide level the effects due to GDP were compared with a yearly decomposition analysis, in order to examine whether the chosen time periods represented the trend, which served as an extra validation of the chosen time periods.

ENERGY SOURCES (J)

CO_2 emissions that are energy-related result from the combustion of fossil fuels. In this research four different main categories are distinguished: oil, coal, gas and waste. Oil fuels are both crude oil and petroleum products. The coal category comprises coal and coal products. The category 'gas' comprises only the fossil fuel natural gas. Other gaseous fuels are covered in the primary fuel category they are derived from (blast furnace gas from coal, refinery gas from oil, biogas from biomass). Lastly the category 'waste' is built up by municipal waste and industrial waste (IEA, 2016a; IPCC, 2006). The biomass fraction of waste is covered in the renewable energy source biomass. The subtypes and the carbon factors of the fossil fuel categories are also given in Table 2. As the gas category only consisted of natural gas, its carbon factor was constant. This is however not the case for the other fossil fuels categories, but only the changing carbon factor of waste is taken into account in this research. More on the carbon factors of fossil fuels is explained in Section 3.6, covering the (energy-related) data collection.

Energy demand is also fulfilled by other energy sources which typically have no associated CO_2 emissions as a result of its use. These other energy sources can be subdivided into three categories. The first is the category of renewable energy including hydro, geothermal, wind, solar and biomass energy which can all infinitely be harvested. The use of biomass does generate CO_2 emissions, but because this type of biomass is part of the short-term carbon cycle, these emissions do not contribute to the greenhouse gas effect - as opposed to CO_2 from fossil fuels which are part of the long-term cycle. Indirect emissions from land-use change are not included in this research. The second category is that of nuclear energy, which is used at power plants. Nuclear energy is not considered renewable energy because uranium is a finite resource. The final category of other energy sources involves electricity that is net imported (import minus export) from abroad. This form of energy needed to be included as it contributes in fulfilling the energy demand of the Netherlands. Potential associated emissions as a result of its production abroad are however not accounted for in the Dutch inventory submissions for Kyoto. This means that an increased net electricity import improves the domestic carbon intensity of energy use.

At the demand sectors electricity and heat were also both considered an energy source 'j'. As their supply in the Netherlands still requires the use of fossil fuels, these energy sources were therefore also assigned with carbon factors. These carbon factors took into account the fossil inputs causing the CO_2 emissions, but also the production from nuclear energy, renewables and the net electricity input contributing to the energy mix. The calculation method is explained in more detail in Section 3.2).

Table 2 – Energy source categories included in the decomposition analyses (with colour codes), the type of source(s) they consist of and their carbon factor (CRF, 2015; IEA, 2014; IPCC, 2006)

Energy source j	*(Sub)type(s)*	*Carbon factor (tCO_2/TJ)*	*Reference*
Oil	*Crude oil and petroleum products*	*73.3*	*IPCC, 2006*
Coal	*Coal and coal products*	*94.5*	*IPCC, 2006*
Gas	*Natural gas*	*56.1*	*IPCC, 2006*
Waste	*Municipal and industrial waste (non-biomass fraction)*	*60.9 - 82.2*	*CRF, 2015*
Renewables	*Hydro, geothermal, wind, solar & biomass energy*	-	-
Nuclear	*Uranium fission*	-	-
Electricity import	*Net electricity import (import minus export)*	-	-
*Electricity**	*Publicly available electricity*	*92.7 - 141.3*	*Section 3.2*
*Heat**	*Publicly available heat*	*92.5 - 175.5*	*Section 3.2*

** The carbon factors of electricity and heat take into account all required inputs (fossil, renewable, nuclear and electricity import)*

HANDLING OF ZERO VALUES

In LMDI decomposition analysis the presence of zero values in a dataset causes problems, because the underlying equations are not suitable for zero values. This originates from the fact that there are no values possible for ln (0), because ln (0) means that $e^x = 0$, which is impossible. The data variables can therefore also not be negative. The natural logarithm is present multiple times in the earlier discussed Formula F3 as 'ln':

F3: $$\Delta A = \sum_{ij} L(CO^t_{2_{ij}}, CO^0_{2_{ij}})\, ln\left(\frac{A^t}{A^0}\right) = \sum_{ij} \frac{CO^t_{2_{ij}} - CO^0_{2_{ij}}}{ln(CO^t_{2_{ij}}) - ln(CO^0_{2_{ij}})}\, ln\left(\frac{A^t}{A^0}\right)$$

Usually in decomposition analysis the zero values in the dataset are therefore replaced by a very small value δ. According to Ang & Liu (2007) a δ of 10^{-100} is sufficient and gives comparable results to using an analytical limit. This strategy of using a small value however only partly solves the problem, because it now leads to a very large contribution of the effect containing the zero value, as a change $(\frac{A^t}{A^0})$ can become infinite and thus dominates. This is however counterintuitive; other variables should also contribute. No solution is offered in LMDI literature to overcome this shortcoming yet (Muller, 2007).

In this research zero values occurred only at the energy data, considering the use of energy sources. The first type of zero value issue is when there is no use of for example coal at t, but a considerable amount at t+1 (or vice versa). A second situation that occurred was no use at all of for example heat at both points in time. A part of this issue was solved by replacing the zero values in the dataset by a very small value (here: $\delta=10^{-200}$). This led however to an overly large contribution of the fuel substitution effect in the first depicted zero value situation. The other effects therefore had to be derived separately, by making a decomposition with total values without considering the different fuels. The difference of the total effects with the rightly calculated effects of the other fuels as were calculated in the initial calculations, could now be assigned to the missing fuel. Because there was no distinction of fuels of the decomposition done with total values, the effects of fuel substitution and a changing carbon factor were merged. As the introduction of a fuel cannot induce a carbon factor effect – the carbon factor on the moment of zero consumption is irrelevant – the difference here could completely be assigned to be a fuel substitution effect of the missing fuel. If multiple fuels in the interval contained this first type of zero value issue, the ratio of energy use in the non-zero data point ‘t’ was used to determine how much of the missing effect needed to be assigned to each of the fuels.

3.2 ELECTRICITY AND HEAT SUPPLY

Emissions from the electricity and heat supply were analysed in order to examine the underlying changes taking place here – and subsequently how these changes eventually affected the changes in indirect emissions from the main demand sectors consuming most of the electricity and heat. At the analysis of the main demand sectors the electricity and heat use are therefore considered energy sources with their own carbon factors. The decomposition analyses of both the electricity and the heat supply give insight into the driving factors behind these changing carbon factors, which depend on the plant efficiency, energy mix and individual carbon factors of the fossil fuels. The energy sector itself is not considered a demand sector, because all its emissions are the indirect result of the energy demand of the actual demand sectors.

THE DEFINITION OF ELECTRICITY AND HEAT SUPPLY

The supply of electricity and heat is defined as the electricity or heat that is supplied with the purpose to be sold to the consumers by the energy sector. A part of the electricity supply is (net) imported from abroad to fulfil the electricity demand. Between 1990 and 2012 the net balance between import and export of electricity has always been positive, allowing net import to be viewed as a source in the mix. The majority of the electricity (and all off the heat) supply was produced domestically. Not all the produced energy that is sold by the energy sector is produced at the large facilities of the energy sector itself, a part also occurs decentral at so-called autoproducers, mainly producing heat or electricity for their own use. If a part of the produced energy is sold to third parties, a certain part of the fuel input at these decentral autoproducers contributes to the carbon factors of public electricity and heat. The part of the fuel inputs that results into own heat use is accounted for as primary use of these input fuels in their corresponding sector. The distinction is made between both types of production to give a better insight of the developments occurring at the supply market of electricity and heat. A possible shift towards more (or less) efficient type of producers was not further quantified into effects in this research.

SINGLE AND MULTIPLE OUTPUT (CHP) PLANTS

Besides the distinction between central and decentral facilities, a distinction was made between plants that operate specifically for power or heat production (single output plants) and combined heat and power production (CHP). This distinction is necessary, because when there are multiple outputs (with CHP) the inputs should be allocated to these right products of electricity (E) and heat (H). In the dataset that is used in this research, the own use of the above discussed decentral CHP autoproducers is already allocated on the basis of energy content. This method was therefore also adopted for the other CHP plants. It must however be noted that allocation on the basis of exergy content better reflects the quality and usefulness of the energy carriers (Blok, 2007). This implies that a relatively large part of the inputs was here allocated to the heat production, which would otherwise (with the exergy method) had been allocated to the electricity production. The allocation of fuel inputs for electricity and heat was done using Formula F5. The allocation of fuel inputs allowed to do separate decomposition analyses for electricity and heat, without double counting of emissions at CHP plants. Double counting is therefore also avoided at the analysis of the demand sectors, using allocated inputs for their carbon factors.

F5: $$Fuel\ allocated\ to\ E\ or\ H\ output = \frac{E\ or\ H\ output}{total\ energy\ output} \cdot total\ fuel\ input\ for\ CHP\ plant$$

The possible effect due to a shift towards more CHP production could not be further quantified into its own effect in emission changes, due to found inconsistency in the database. Up to 1998 electricity plants seem to have been wrongly classified as CHP plants, caused by the fact that before 1998 no different plant types were distinguished by CBS (2016a). This does not influence the decomposition results, because the inputs were allocated. However, the available data did therefore not allow to see which part before 1998 was CHP and which was not, so a certain CHP effect could not be quantified.

DECOMPOSITION METHOD OF ELECTRICITY AND HEAT SUPPLY

The emissions from electricity and heat supply were decomposed according to the formulas F6 and F7. The formulas are very similar, but a couple important differences were present.

F6: $$CO_{2_{electricity}} = \sum_j CO_{2_j} = \sum_j TE \frac{FE}{TE} \frac{FE_j}{FE} \frac{PE_j}{FE_j} \frac{CO_{2_j}}{PE_j} = \sum_j A \cdot OE \cdot FS_j \cdot EE_j \cdot CF_j$$

F7: $$CO_{2_{heat}} = \sum_j CO_{2_j} = \sum_j TE \frac{FE}{TE} \frac{FE_j}{FE} \frac{PE_j}{FE_j} \frac{CO_{2_j}}{PE_j} = \sum_j A \cdot RE \cdot FS_j \cdot EE_j \cdot CF_j$$

The activity indicator for both equations is the total energy supply (TE) of electricity or heat respectively. For electricity the supply is not just what is domestically produced, but also includes a net import. The factor that follows says something about the share of non-emitting energy sources in the total energy supply. For electricity these other energy sources do not just include renewable sources, but also nuclear energy and the net electricity import. To notify this difference, this factor is represented by the 'other energy' (OE) factor at electricity supply in Formula F6, instead of a renewable effect (RE factor) at heat in Formula F7. The resulting effect due to 'other energy sources' at the electricity supply could simply be split out into the individual effects from each of the non-emitting energy sources, to still be able to decompose a renewable energy effect. Both factors (OE and RE) are expressed by the share of fossil energy (FE: electricity or heat from fossil fuels) in total electricity consumption (TE). The factor of fuel substitution (FS_j) is expressed in electricity or heat production from a certain fossil fuel source (FE_j) source in total energy production emanating from fossil energy sources (FE). For the electricity and heat supply a factor on the efficiency of energy transformation could be added to the basic decomposition Formula F1. The factor EE_j describes the required primary energy input of a certain fuel (PE_j) to generate a certain output of electricity or heat. The resulting effect incorporates both plant efficiency changes and the increased deployment of CHP plants. The CF_j factor is equal to the basic formula, explaining the amount of emissions (CO_{2j}) as a result of the incineration of a certain amount of primary fuel input. At the analysis of electricity and heat supply this is only applicable for the fuel source 'waste'.

Emissions trends from electricity and heat supply are discussed separately, but as policies do not always differentiate between one of the types, their results needed to be considered next to each other. An important part of this explanation also lies in the CHP, when electricity and heat production are combined. Therefore the formulas F6 and F7 also do not contain 'i' terms, because electricity and heat ought not to be considered separate sectors, nor to have a consequent structure effect. After decomposing the emissions, the effects were aggregated to analyse the total effects at electricity and heat supply, allowing also to compare the two types of supply.

CARBON FACTORS OF ELECTRICITY AND HEAT

Additional to the analysis of the change in emissions and their different effects, we were interested in the carbon emissions emanating from each unit of energy use. By calculating the carbon factors of electricity and heat, the indirect emissions from its use by the demand sectors could be determined. Moreover, the changing carbon factors allowed to show how changes at electricity and heat supply changed the (indirect) CO_2 emissions of demand sectors. The carbon factor is basically the amount of CO_2 emissions that originates from the incineration of fossil fuels at the energy plants, required for a certain amount of electricity or heat demand: as expressed in Formula F8. By using allocated inputs (according to Formula F5), the carbon factors avoid double counting from production at CHP plants.

F8: $$CF_{electricity} = \frac{allocated\ CO_2\ from\ E\ supply}{(E\ production + E\ import) * (1 - 3.78\%)};\ CF_{heat} = \frac{allocated\ CO_2\ from\ H\ supply}{E\ production * (1 - 15.0\%)}$$

Formula F8 also includes energy losses occurring at the distribution, because the carbon factor is supposed to represent the amount of CO_2 for each unit of energy demand by the users. Thus, when there is energy loss between the supplier and the final user, more energy needs to be supplied for each unit of consumption. These energy losses imply that for each unit of energy that is demanded, a factor of (1/(1-loss)) need to be supplied. For both electricity and heat distribution, the energy loss was almost constant, about 3.8% for electricity and 15.0% for heat. A change in these energy losses (by improvement of distribution) was therefore not large enough to be able to induce its own effect on the carbon factors of electricity and heat.

OTHER ENERGY USE AT THE ENERGY SECTOR

The electricity and heat supply analysis was done to be able to account for emissions occurring at the energy sector due to fuel inputs for electricity and heat production, which could be assigned to the indirect energy use at the demand sectors. Besides these energy inputs required for electricity and heat production, the energy sector also consumes energy at transformation processes and for its own use. These are eventually also indirectly the result of the energy consumption of the demand sectors, but as the energy use could not be assigned as indirect use required to supply a certain fossil fuel (like gasoline), this 'other energy use' at the energy sector could not be taken into account in the main analysis. This energy use comprised about 15.7% of all energy-related emissions in the Netherland between 1990 and 2012, ranging between 22.1 Mt and 29.8 Mt (including indirect emissions from its own electricity and heat use). The largest part of these CO_2 emissions originates from the use of oil at the energy industry associated with oil refineries. The use of electricity and heat of the energy sector was included in the analysis of the electricity and heat supply, as this analysis looks at the total supply that was required to fulfil all publicly available electricity and heat demand in the Netherlands. In the synthesis the other effects besides the effects from changes of the carbon factors of electricity and heat occurring at the energy sector are added as a residual effect (see Section 3.5), to give some insight into the changes occurring at this large CO_2 item on the balance.

3.3 MAIN DEMAND SECTORS

Five main demand sectors are distinguished which determine the final energy consumption in the country: the industry, services, agriculture, transport and the residential sector. Indirect emissions occurring at the energy sector are now passed on to these main demand sectors by considering electricity and heat as fossil fuels, with their own carbon factors as calculated according to Formula F8. An overview of the different main demand sectors (and covered subsectors) is given in Table 3, following the classification definitions of the IEA (2016a). Detailed information on the definition boundaries of the sectors is provided in Appendix B. The provided table also gives the activity indicators of the main demand sectors. Only the so-called economy sectors (industry, services and agriculture) share the same activity indicator (GVA: gross value added), therefore also sharing the same decomposition method and allowing to reveal an economy structure effect. For the economy sectors, transport and the residential sector the specific decomposition methods are subsequently given in the remainder of this section, including the method to determine the economy structure effect. First the excluded subsectors part of the final energy demand are shortly discussed.

*Table 3 – Main demand sectors, included subsectors and their activity indicators (see Appendix B for more detailed boundaries)**

Main sector	Subsector	Activity indicator
Industry	(1) Basic metals	Gross value added (GVA_i) - in mln Euros at constant 2005 prices *Applicable for all economy sectors (industry sectors, services & agriculture)*
	(2) Chemical and petrochemical industry	
	(3) Non-metallic minerals	
	(4) Transport equipment	
	(5) Machinery	
	(6) Mining and quarrying	
	(7) Food and tobacco	
	(8) Paper, pulp and print	
	(9) Wood and wood products	
	(10) Construction	
	(11) Textile and leather	
	(12) Non-specified industry	
Services	Commercial and public services	
Agriculture	Agriculture and forestry	
Transport	Road and rail transport	Passenger-km + tonne-km (pkm+tkm)
Residential	Residential sector	Number of households

** The non-specified sector, fishery, domestic navigation and domestic aviation were excluded in the decomposition analyses*

For the separate decomposition analyses of the demand sectors some subsectors had to be excluded. The first sector that was excluded from the analysis is a residual sector (labelled 'non-specified sector' by the IEA), comprising practices that could not be specified in one of the main categories, like military fuel use. This fact causes that no activity indicator could be assigned to the sector, so it had to be excluded from the decomposition analysis of the demand sectors. Moreover, data points were only available until 1994. Secondly fishery was excluded from the analysis due to a lack of data availability for all years up to 2006 and for 2010. At last domestic navigation and aviation were excluded from the transport sector due to the absence of a suitable activity indicator. In total these other demand sectors accounted for 1.16 Mt CO_2 emissions in 2012, 0.7% of energy-related emissions. Their total change in CO_2 emissions was included in the synthesis, to be able to show how they contributed to the difference in total emissions over 2008-2012, under the heading of 'other demand sectors' (see Section 3.5).

ECONOMY SECTORS

The industry, services and agriculture sectors are the economy sectors, because their activity is measured here in economic output: gross value added (GVA) in millions of Euros. To adjust for the effect of inflation the GVA is expressed in constant (2005) prices. The separate GVAs of the economy sectors make up the GDP of the country, together with the economic output of the energy sector. The GVA is the common activity indicator in decomposition analyses for these economy sectors (Oh et al., 2010; O'Mahony et al., 2012). Sometimes physical activity indicators are used, like tons of product output for manufacturing sectors. Physical products are however not applicable for all the sectors, like the service sector which is rather measured in floor space. The economic output on the other hand is available for all economy sectors, with that allowing to meaningfully compare these sectors and additionally to determine an economy structure effect. Moreover, the use of GVA is preferred because the use of one single activity indicator for an analysis with multiple sectors facilitates uniformity in the method. There are also downsides to the use of GVA, as the economic activity may not always correspond with the sector's actual (physical) activity and accordingly reflect its energy use. Certain shortcomings are further exposed and discussed at the end of the chapter on each economy sector (Chapter 5-7). Since policies in general focus on one of the three economy sectors (industry, services or agriculture) these are treated in separate chapters to discuss the possible policy influences. For each sector 'i' Formula F9 was used to decompose CO_2 emissions of the different economy sectors. For the industry the decomposition was done separately for each of its twelve subsectors (see Table 3).

F9: $$CO_{2_{economy}} = \sum_{ij} CO_{2_{ij}} = \sum_{ij} GVA_i \frac{TE_i}{GVA_i} \frac{FE_i}{TE_i} \frac{FE_{ij}}{FE_i} \frac{CO_{2_{ij}}}{FE_{ij}} = \sum_{ij} A_i \cdot EI_i \cdot RE_i \cdot FS_{ij} \cdot CF_{ij}$$

The activity factor (A_i) describes the activity change indicated by GVA_i in the considered economy sector. The factor of energy intensity (EI_i) shows the effect due to a change in total energy consumption in the sector (TE_i) required for each unit of activity. The renewable energy factor (RE_i) gives the effect from a change in energy emanating from fossil fuels (FE) in the total energy consumption in the considered economy sector, including electricity and heat. The factor of fuel substitution (FS_j) explains the effect due a change of a certain fuel (FE_{ij}) in the total energy consumption of the sector emanating from fossil fuels. Finally, the factor explaining the changing carbon factor of the individual energy sources (CF_{ij}) is expressed by the amount of carbon dioxide of that fuel (CO_{2ij}) emitted for each unit of its consumption. At these economy sectors, both secondary energy carriers 'electricity and heat' which indirectly required fossil fuels had changing carbon factors. Changes and accordingly effects within the carbon factor could be assigned to the changes occurring at the supply of electricity and heat.

To be able to distinguish an economy structure effect, Formula F10 was used, similar to the above Formula F9. The former activity factor in Formula F9 representing the activity in one (sub)sector was now further split up into two factors. The first is the activity factor (A) indicated by the total economic activity: GVA – the sum of the GVA_is of all economy sectors. As not all sectors are included in this analysis (energy sector, non-specified sector and fishery), this total GVA does not add up to the country's GDP. Nevertheless, this does not obstruct this method. The second factor is therefore the economic structure (ES_i) concerning the share of certain sector's activity (GVA_i) within the whole economy.

F10: $$CO_{2_{economy}} = \sum_{ij} CO_{2_{ij}} = \sum_{ij} GVA \frac{GVA_i}{GVA} \frac{TE_i}{GVA_i} \frac{FE_i}{TE_i} \frac{FE_{ij}}{FE_i} \frac{CO_{2_{ij}}}{FE_{ij}} = \sum_{ij} A \cdot ES_i \cdot EI_i \cdot RE_i \cdot FS_{ij} \cdot CF_{ij}$$

TRANSPORT SECTOR

The transport sector in definition includes all transport over rail, road, water and through the air, of both people and freight. Domestic aviation and navigation were however excluded from the decomposition analysis due to the absence of a suitable activity indicator. Emissions from these subsectors of transport were very small, comprising only 1.9% of the emissions of the transport sector in 2012. Notice that international aviation and navigation are entirely excluded from the national emission inventories. The activity indicator that is used to indicate the activity level of both the road and rail transport subsectors (from here on: transport sector), is the sum of all passenger-kilometres (pkm) and tonne-kilometres (tkm) travelled by both passengers and freight. This method is mathematically incorrect, but it is common practice in LMDI analysis in case the consumption data does not differentiate between consumption for passenger transport or freight transport (O'Mahony et al., 2012). The addition of the two indicators is then justified if the ratio between them does not vary significantly (Diakoulaki, 2006). In the Netherlands the traveled distance in tonne-kilometers of freight transport historically made up for 13.4 to 17.5% of the total amount. Whether this is a significant variation or not is debatable; it may have biased the results. However, as mentioned above, this issue could not be avoided as the energy data was not available disaggregated. This also hindered the allocation of emissions from freight transport to their corresponding economy sectors, which would more fairly represent their total emissions. At last also the possible substitution between the fuels gasoline and diesel within the oil category could not be quantified due to the aggregation of data into the single energy category 'oil', which is expected to have specifically influenced emissions at transport (see also Section 3.6 and Figure 4). Emissions from the transport sector were decomposed using Formula F11.

F11: $$CO_{2_{transport}} = \sum_j CO_{2_j} = \sum_j TD \frac{TE}{TD}\frac{FE}{TE}\frac{FE_j}{FE}\frac{CO_{2_j}}{FE_j} = \sum_j A \cdot EI \cdot RE \cdot FS_j \cdot CF_j$$

No structure effect could be distinguished for the sector for different modes of transport, like freight or passenger, but also not own transportation modes versus public transport or motor vehicles versus bicycles, due to the aggregated level of the available energy data. Additional data should give further insight into a possible modal-split effect, but it could not be quantified as an effect coming forward at the decomposition analysis. Formula F11 therefore also does not contain an 'i' term. The activity factor (A) covers the activity in the transport sector in terms of travelled distance (TD), as the sum of all passenger-kilometres and tonne-kilometres. The factor of energy intensity (EI) describes the total energy consumption (TE) for each unit of activity. The renewable energy factor (RE) is able to explain de effect due to a changing share of energy sources requiring fossils (FE) in total energy consumption at transport. The factor for fuel substitution (FS_j) gives the effect as a result of a change of a certain fuel (FE_j) in the energy consumption emanating from fossils. The final factor considers the carbon factor (CF_j) of the individual fuels, expressed in amount of carbon dioxide emissions (CO_{2j}) emitted for each unit of consumption of a certain transport fuel. At transport only the carbon factor of electricity changed due to the developments occurring at its supply, causing carbon factor effects coming forward at the emissions of transport. Heat is not used as energy source at transport.

RESIDENTIAL SECTOR

The residential sector is defined by the non-commercial daily living of people in dwellings. This excludes energy use from people living in institutions, which are included at the corresponding service sector. The indicator that best measures the size of the residential sector is therefore the number of households in the Netherlands; the common activity indicator used in decomposition analysis. A change in household size does affect the energy use and could be distinguished as its own influencing factor, as done by Smit et al. (2014) to reveal effects from these societal changes. However, this structure effect is not quantified in this research, because of the complication arising from analysing different energy functions. To clarify, a decreasing trend in household size is an important structure effect considering warmth as heating will be shared less, but it is not as meaningful for the function of electricity. Formula F12 mathematically describes how emissions at the residential sector were decomposed.

F12: $$CO_{2_{residential}} = \sum_j CO_{2_j} = \sum_{ij} HH \frac{TE}{HH}\frac{FE}{TE}\frac{FE_j}{FE}\frac{CO_{2_j}}{FE_j} = \sum_j A \cdot EI \cdot RE \cdot FS_j \cdot CF_j$$

For the residential sector also no structure effect was distinguished to reveal a structural shift towards certain household types, as this data was not available. A shift towards for example detached houses is therefore not quantified into a separate effect, so the ‘i’ term remains absent. The activity factor (A) is the activity level of the residential sector in terms of numbers of households (HH). The factor of energy intensity (EI) covers the total energy consumption (TE) for each household. The renewable energy (RE) factor describes the effect due to changes in the share of energy sources derived from fossil fuels (FE) within total energy consumption at households. The factor fuel substitution (FS_j) explains the effect due to a changing share of a certain fuel (FE_j) in the total fuel mix. The fifth and final factor covers how a changing carbon factor (CF_j) of a certain fuel inducing carbon dioxide influences the emissions, expressed in carbon dioxide emissions (CO_{2j}) that is emitted for each unit of consumption. At the residential sector the carbon factor effect explains how changes at the supply of electricity and heat affected changes in the (indirect) emissions from its use at households.

3.4 Energy and climate policy analysis

After the LMDI decomposition analyses of the emissions of each sector – including the electricity and heat supply at the energy sector – the found effects were linked to the deployed decarbonisation instruments possibly influencing the considered sector. The goal of this part of the research was to analyse whether a correlation was present between the policy strategy in the sectors and the observed (or achieved) CO_2 reduction effects. The aim is not to give a perfect picture for the individual effects of all ever deployed policy instruments, but rather to give a general picture on the type of measures and instruments that may have driven the emission changes up to the end of Kyoto.

A literature review of important policy documents (see qualitative data collection in section 3.6) was done in order to map for each sector the instruments that were deployed to reduce CO_2 emissions between 1990 and 2012. These instruments are usually sector specific (obligatory efficiency standards for cars) but also cross-sectoral (a tax on electricity use). For each instrument the timing and duration was assessed, to be able to see when (during which interval) between 1990 and 2012 they may have induced effects. Next the type of factor that was possibly influenced at each sector was assigned to the instruments in order to see at which effects of the LMDI analysis each instruments may potentially have caused possible CO_2 reductions. These could for example focus on reducing the activity level (less travelled distance), reducing the energy demand for each unit of activity (less energy consumption per household), increasing the share of renewables or switch to cleaner fuels. At the energy and heat supply also the energy efficiency of the plants was one of the factors that could be influenced. Instruments were also able to potentially influence multiple factors in the decomposition equation. For example, some fiscal instruments encouraged the investment in both energy-efficient technologies and renewable energy options to reduce CO_2 emissions. If other factors were indirectly influenced, this was discussed separately, because it was not an intended goal to achieve that type of reductions. For each sector the most important policies were mapped into a timeline with corresponding colour codes for the factors it was primarily aimed at, to be able to compare these efforts with the observed LMDI effects.

3.5 Synthesis of all decomposition analyses

To synthesize the results from all the separate decomposition analyses, the effects of the demand sectors could simply be added up. This allowed to show a total activity effect, energy intensity effect, renewable energy effect, fuel substitution effect and carbon factor effect which were taking place in the different intervals coming forward at the demand sectors. To see how all these changes between

1990 and 2012 contributed to the results achieved in the Kyoto target period over 2008-2012, a separate decomposition was required for each sector – including electricity and heat supply – using the average values over the target period. For this total picture the effects from changing carbon factors of electricity and heat that came forward as a carbon factor effect at the demand sectors, here again includes the electricity and heat use of the energy sector. The change in electricity and heat use is therefore the result of effects occurring at the final energy demand sectors, which earlier resulted in the activity effect present at the decomposition of electricity and heat supply. Also the other energy-related emissions that could not be included in the decomposition analysis, but did contribute to the emission target were included in this synthesis by simply showing their change between 1990 and average 2008-2012 emissions as a separate effect (hence: non-carbon factor effect of other energy use at the energy sector, the non-specified sector, fishery, domestic navigation and domestic aviation). The results that came forward in the separate analyses of the sectors now gave insight into how we got to the emissions levels achieved over 2008-2012, especially in terms of which (type of) energy & climate policies contributed to eventually get to these target period emissions.

3.6 DATA COLLECTION

The data collection considers energy-related and activity (quantitative) data to be able to execute the decomposition analyses according to the above discussed formulas. This section also covers the qualitative data collection required to analyse the possible link with energy and climate policies.

ENERGY-RELATED DATA

The core data of this research was acquired through the energy database of the International Energy Agency (IEA, 2014), as this database was most comprehensive in terms of included types of energy sources, inputs into energy plants and the breakdown to demand sectors. The IEA data is originally retrieved from the Dutch StatLine database (CBS), but as the current CBS publications on energy balances only cover data starting at 1995, the IEA balance was the main source here. Moreover, using this international database (as opposed to the Dutch StatLine database by CBS) allows to do similar analyses for other countries in the IEA database. There were also some drawbacks to the used data, of which the ones of important influence at this research were already discussed above in the appropriate method sections it affected. The most important drawbacks are also listed in Appendix C.

In combination with the appropriate carbon factors, the carbon dioxide emissions from the fossil fuels (including the secondary energy carriers electricity and heat) were constructed. According to the UNFCCC (CRF, 2015) the carbon factors of the four different fuel categories (oil, coal, gas and waste) changed between 1990 and 2012 (Figure 4). This is the result of a changing submix within the categories, which substantially varied in time within the sector (CRF, 2015; IPCC, 2006). Carbon factors also significantly differ between sectors because certain sectors prefer certain fuel subtypes. These effects could however not be taken into account because the IEA and CRF datasets were not compatible: the differences in primary energy use of the energy source categories differ to such an extent that it was likely to assume that different category definitions were used. This obstructed the adoption of CRF carbon factors. Instead default values by IPCC (2006) were used for the fuels oil, coal and gas (Table 2). The change in carbon factor of waste was so large that it could not be neglected in this analysis, ranging from 72.2 to 183.0 tCO_2/TJ, similar to the 95% confidence interval range as published by IPCC (2006). As waste is solely used at electricity and heat production at the energy sector and the waste data by the

IEA largely corresponds with the CRF data, using the CRF carbon factors was justified. The constructed amounts of energy-related CO_2 emissions were on average 1.5% above the official Kyoto submissions.

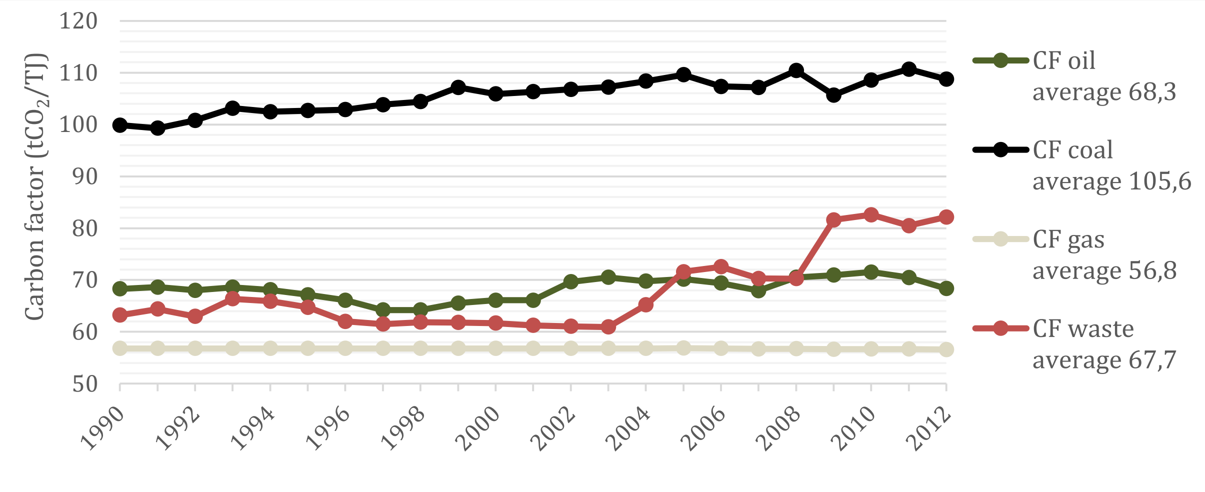

Figure 4 – The carbon factors (in tCO_2/TJ) of the fossil fuels according to the official emission inventories (CRF, 2015)

ACTIVITY DATA

The (non-energy) activity data points required for the decomposition calculations are derived from the StatLine databank of Statistics Netherlands (CBS). In order for the activity data of the sectors to match the energy data, the sector categorization as used by the IEA which provided the energy-related data was followed. For some economy sectors this meant that the GVA coming from CBS needed to be added up as the IEA categories were a combination of multiple subsectors. For example, the chemical and petrochemical industry are considered one subsector category at the IEA. Only for the basic metal industry this worked the other way around, as CBS only published the total economic activity of iron & steel and non-ferrous metals taken together. At transport the activity data had to come from multiple StatLine tables as the travelled distance was the sum of all road and train transport by both people and freight. The activity indicator for the residential sector was most straightforward, as it simply involved the number of households in the Netherlands which is annually published by the CBS. Lastly the activity indicator for the electricity and heat supply considered its total supply as was part of the IEA database.

QUALITATIVE DATA

The qualitative data required for this analysis considers the national energy and climate policies that were implemented during the first Kyoto period, to be able to relate the effects to the decarbonizing instruments that were in place. The main sources of data were the National Communication (NC) reports of the UNFCCC, through which the member states were obliged to explain how they were aiming to reach their Kyoto targets. There are six NCs that cover the developments during the first Kyoto period: NC1 (1994), NC2 (1997), NC3 (2001), NC4 (2005), NC5 (2009) and NC6 (2013). The IEA was the other important source for this qualitative data, as this agency also maintains three policy databases tracking country's policies and measures to reduce GHG emissions, improve energy efficiency and support renewable energy (IEA, 2016b). Where necessary the data from the NCs and IEA policy and measures databases were validated with information found in specific working programmes or evaluation reports from national research institutes. Only the most important policy instruments (those that came forward in multiple documents) were included in this research. A detailed description of the instruments remains absent in this analysis, as only the factors that they aimed to influence were important for this research. Short descriptions of all instruments covered in this research are given in Appendix D.

4. ELECTRICITY AND HEAT SUPPLY

4.1 TREND OF CO_2 EMISSIONS BETWEEN 1990 AND 2012 (ELECTRICITY AND HEAT SUPPLY)

The total electricity and heat supply in the Netherlands has almost doubled since the 1990 base year, from 307.2 to 563.0 PJ in 2012 (Figure 5). The bulk of the supply was produced domestically, by 2012 10.9% was net imported from abroad in the form of electricity. By then more than three quarters of this total supply was electricity supply. The distinction was made between plants that operate specifically for power production, heat production or combined heat and power (CHP) production. More than half of the produced electricity and heat came from CHP plants in 2012. The sharp bending in Figure 5 between electricity from conventional and from CHP plants is caused by a definition issue of the IEA dataset, as explained in the method description (Section 3.2). This does not further distort the results of the decomposition analysis itself, as the inputs are allocated.

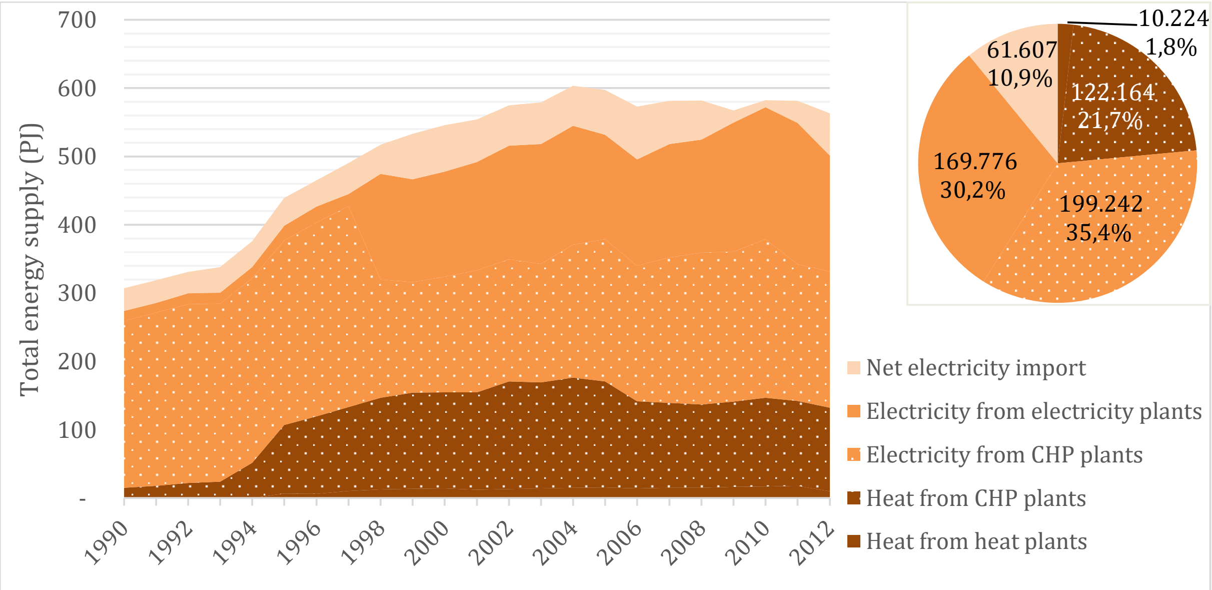

Figure 5 – Total publicly available supply of: heat production, electricity production (split out for single output and CHP plants) and net electricity import between 1990 and 2012, including pie chart with 2012 amounts and shares (IEA, 2014)

Of the generated output the largest part became final consumption for the demand sectors, but a part was also used by the energy sector itself (and in the case of heat also at transformation processes) and another part was lost at distribution (see Table 4). When allocating the losses to the consuming parties the energy sector would end up being responsible for 7.3 and 12.5% respectively of the electricity and heat supply (and associated emissions) and the main demand sectors for 92.7 and 87.5%.

Table 4 – Shares of electricity and heat supplied for three different balance items

	Electricity			Heat		
	1990	2012	Average	1990	2012	Average
Final consumption by demand sectors	90.6%	89.0%	**89.3%**	85.2%	60.6%	**74.4%**
Consumption by energy sector	5.6%	7.2%	**7.0%**	0.0%	23.5%	**10.6%**
Losses	3.9%	3.8%	**3.8%**	14.8%	15.9%	**15.0%**

Total associated carbon dioxide emissions from electricity and heat supply increased with a smaller rate than the supply itself, from 42.5 to 49.7 Mt in 2012 (Figure 6), which was also more stable after 2004.

Taking the emissions of 2008-2012, the average emissions were 24.9% above base year level (+10.6 Mt). In line with Figure 5 the largest share of emissions emanated from electricity supply, but declined (as the share of heat supply increased), from 94.7 to 79.0% between 1990 and 2012.

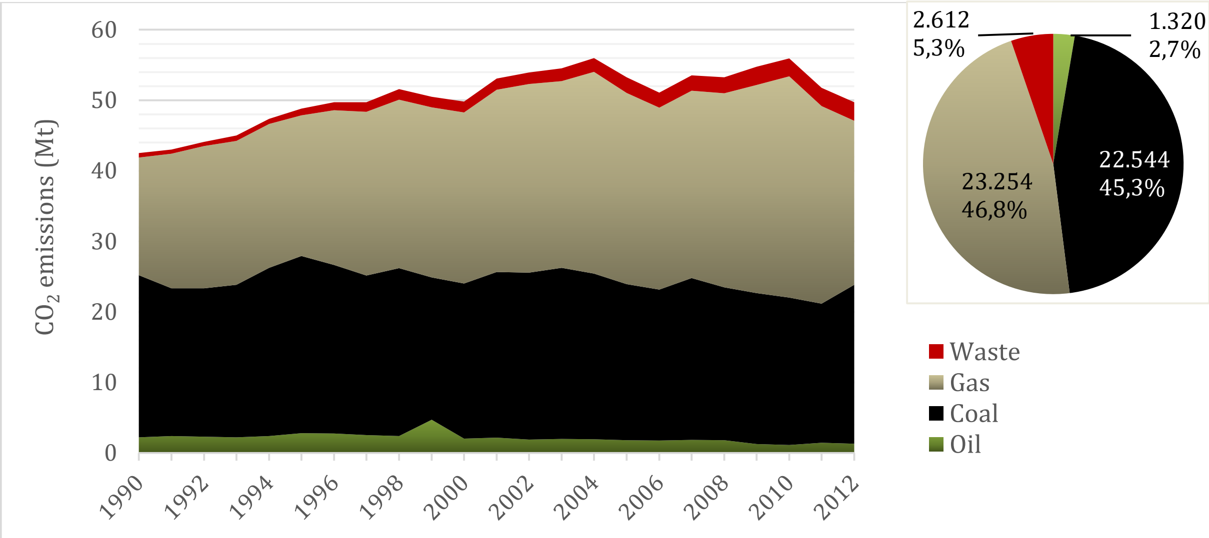

Figure 6 – Carbon dioxide emissions from electricity and heat supply in the Netherlands for four fossil fuel categories between 1990 and 2012, including pie chart with 2012 amounts and shares (IEA, 2014)

As the supply of electricity and heat increased much more than the associated emissions, the carbon intensity of this supply decreased from 138 to 88 tCO_2/TJ (second axis in Figure 7). Other factors besides the demand for electricity and heat supply must therefore explain the trend in historical emissions. The frozen technology scenario (Figure 7) shows how carbon dioxide emissions from electricity and heat supply would have developed in case all other 'technology' factors would have stayed constant (average emission factor of 138 tCO_2 per TJ energy supply) with the total electricity and heat supply as the only variable influencing the emissions. Over the 2008-2012 Kyoto period, the average CO_2 emissions would have been a considerable 26.5 Mt higher if no further development had taken place since 1990 (87.3% above base year instead). The following two decomposition analyses of both the electricity and the heat supply explain the gap between the frozen and the historical emissions looking into four other factors besides the level of activity.

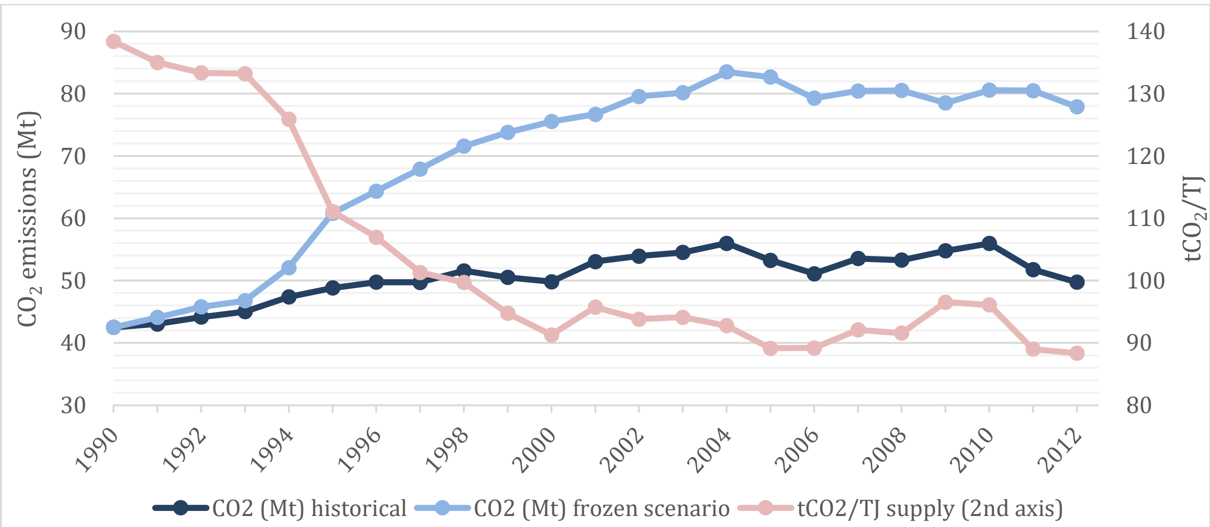

Figure 7 – Carbon dioxide emissions from electricity and heat supply (historical and for a frozen scenario) and on the second axis the historical carbon intensity of energy supply (IEA, 2014)

4.2 DECOMPOSITION ANALYSIS OF ELECTRICITY SUPPLY

By means of formula F6 emissions from electricity supply were decomposed into the five different effects, due to: the activity level in terms of electricity supply, the share of other energy sources that do not emit CO_2 (renewables, nuclear and net electricity import), fuel substitution between fossil fuels, the efficiency of electricity production and the changing carbon factors of the fuels (Figure 8). The results are transposed into yearly effects to make a fair comparison between the intervals using different time periods, as is done at all figures that follow. Below each effect is and its underlying trend is discussed.

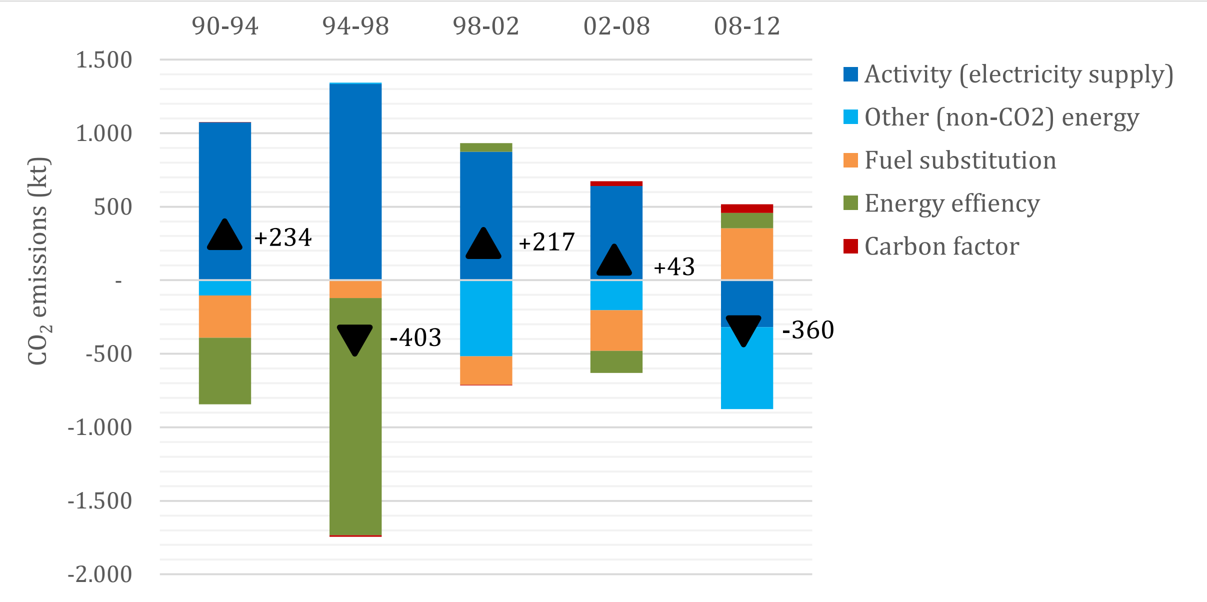

Figure 8 – Results of the decomposition of electricity supply, showing five yearly effects in the intervals between 1990 and 2012

ACTIVITY

The activity of electricity supply is indicated by the total amount of electricity supply, i.e. the demand for publicly available electricity. Figure 9 shows that by 2012 65.3% of the supply was produced centralized, 20.4% decentralized and 14.3% was net imported. The total electricity supply steadily increased until 2008, when it started to decrease again slightly. By 2012 the electricity supply was 119.6 TWh, still 47.4% above the base year level of 81.1 TWh.

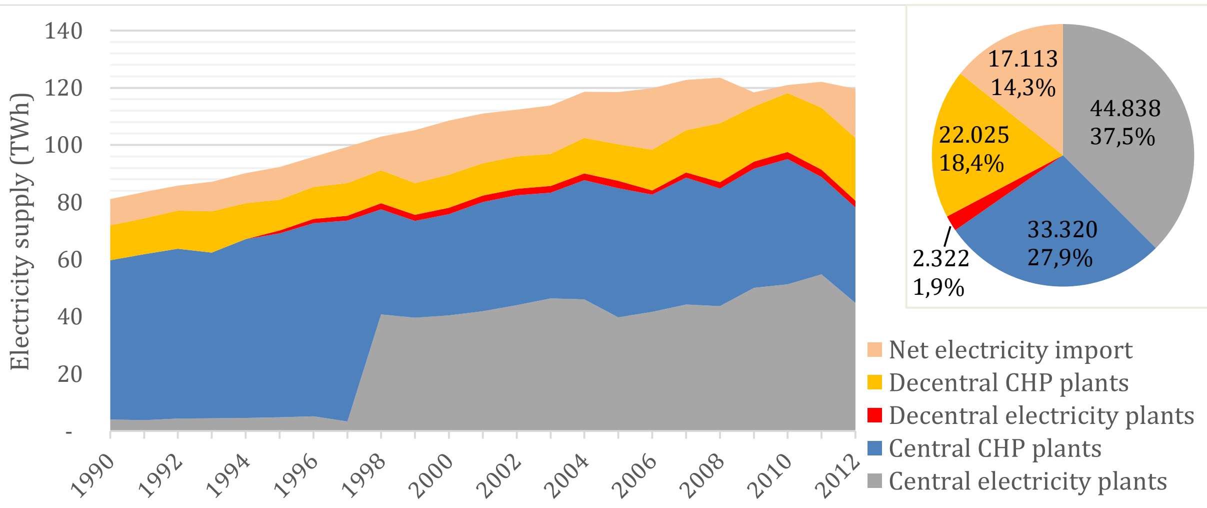

Figure 9 – Electricity supply from different producers (central and decentral) different plant types (single output and CHP plants) and electricity import between 1990 and 2012, including pie chart with 2012 amounts (in GWh) and shares (IEA, 2014)

Its resulting activity effect on CO_2 emissions up to 2008 was on average +942 kt yearly. The effect of activity clearly had the largest impact on the change in emissions; until 2008 it was almost solely responsible for the increase in emissions. In the last research interval, the decrease in total supply induced a downward activity effect of -318 kt yearly. According to the CBS (2015a) this supply has been growing with the economy since 1976. In this research the increased supply is further researched on the level of the demand sectors (92.7% of electricity supply), as the result of other underlying dynamics of activity, energy intensity and fuel mix.

OTHER (NON-CO_2) ENERGY SOURCES

The effect induced by 'other energy sources' (those that do not emit CO_2) mostly had a decreasing influence on CO_2 emissions, as its share in total electricity supply mostly increased (Figure 10). Its average effect on emissions was -268 kt yearly, while its share in total supply increased with about 0.32% points each year. The largest part of the other energy sources consisted however of non-renewable energy sources, namely net electricity import and nuclear energy. Renewable energy sources did on the other hand show the highest growth rates, as this category increased from 1.0 to 10.5% of the electricity supply (yearly 0.45% points) in the Netherlands between 1990 and 2012. Of the renewable sources that were used to generate electricity, a bit more than half has been biomass, a bit less than half was solar/wind and an almost negligible share came from hydro energy. Within the solar/wind category the wind source was dominant, covering 99 to 96% of production at this combined category (CBS, 2016b).

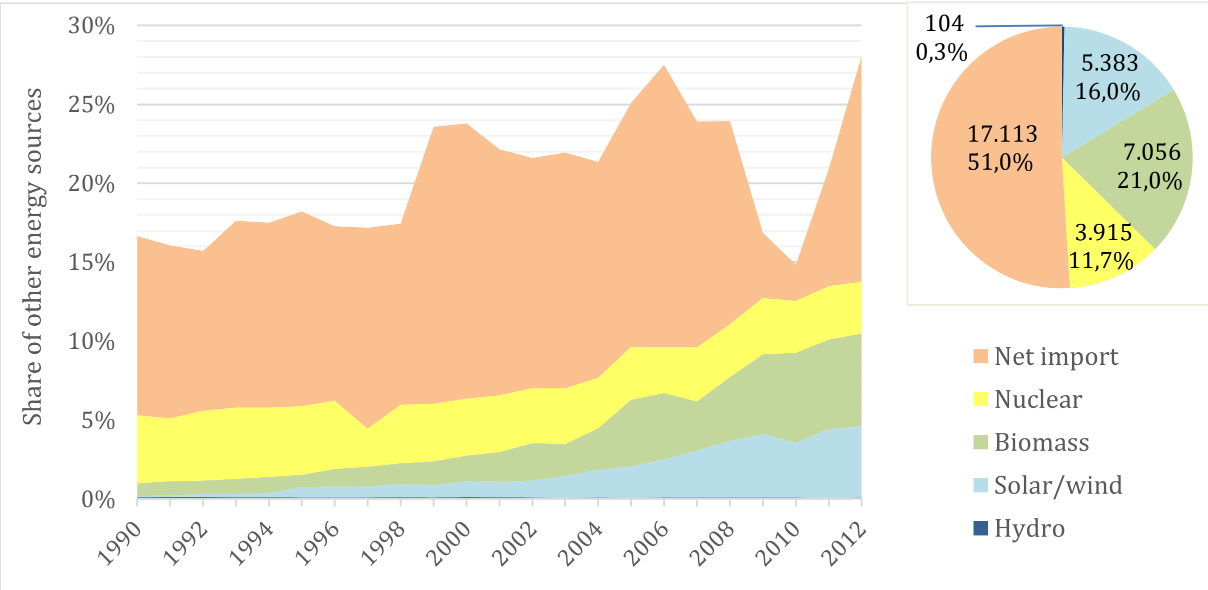

Figure 10 – The share of other (non-CO_2) energy sources in total electricity supply between 1990 and 2012, including pie chart with 2012 amounts (in GWh) and shares within the category of other energy sources (IEA, 2014)

The 'other energy' effect was further decomposed into subeffects of the specific other energy sources and are shown in Figure 11 and Table 5. The effect from renewables clearly increased over the years, with an average effect of -225 kt yearly on CO_2 emissions. The import of electricity was responsible for an average -67 kt yearly and the relative decreasing share of nuclear energy yearly increased emissions by +24 kt on average. As both biomass and wind/solar grew in a similar manner, only a little more than half of the effect from renewables could be assigned to the increase of electricity originating from biomass, as can also be seen in Figure 11 and Table 5.

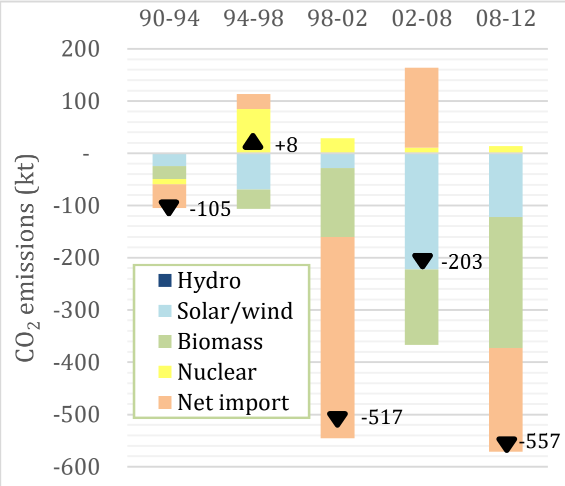

Table 5 – The individual effects (yearly) of the five other energy sources together causing the OE effect at electricity supply

Energy source	90-94	94-98	98-02	02-08	08-12
Hydro	-1	+0	+1	1	-1
Solar/wind	-24	-69	-28	-222	-121
Biomass	-25	-37	-131	-145	-251
Renewables	**-49**	**-106**	**-158**	**-365**	**-373**
Nuclear	-10	+85	+27	+10	+14
Net import	-45	+29	-386	+153	-198
Total effect	-105	+8	-517	-203	-557

← *Figure 11 – The other energy effect (yearly) of electricity supply decomposed for the five energy sources, values in Table 5*

FUEL SUBSTITUTION

The effect of fossil fuel substitution has been a bit smaller than the effect due to the increase of non-CO_2 sources at electricity supply. Until 2008 the effect was on average yearly reducing emissions with -226 kt. Between 2008 and 2012 however the fuel substitution effect caused emissions to increase with +353 kt yearly. The shares of the four fossil fuel categories, the total fossil fuel production and 2012 values are given in Figure 12. Taking a closer look at the underlying shares of the fuels, it shows that until 2008 the dynamics was an increased share of gas at the expense of coal, which is partly a result of increased CHP. After 2008 this trend reversed (gas was substituted by coal again) inducing the large CO_2 emissions increase by the end of that interval (+353 kt yearly). The constantly decreasing oil share and increasing share of waste also contributed to the fuel substitution effect, but only to a very small extent.

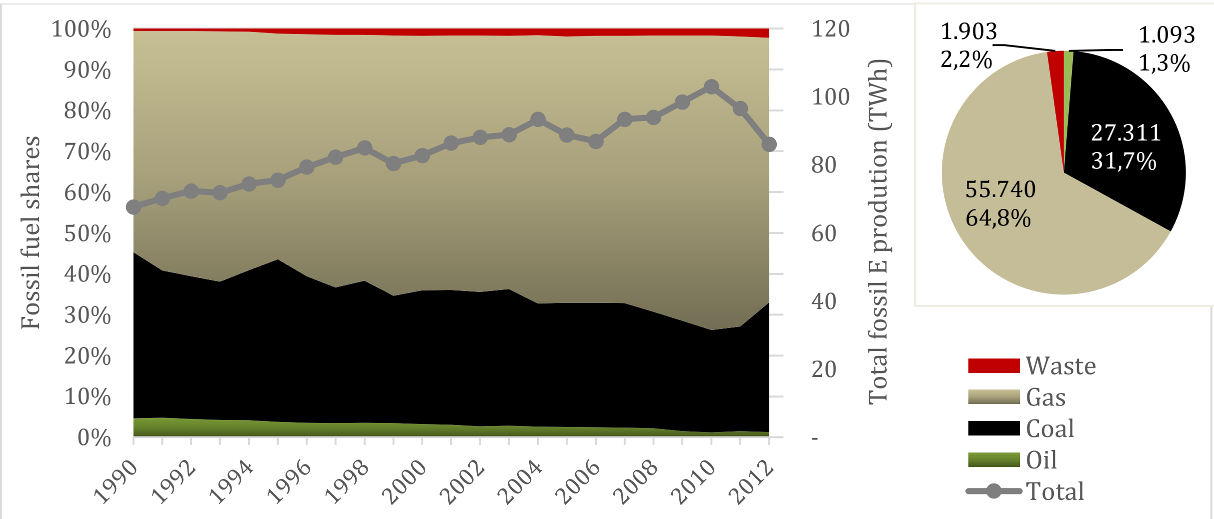

Figure 12 – Shares of the four fossil fuels in total electricity production from fossil fuels (second axis), including pie chart with 2012 amounts (in GWh) and shares within fossil fuel production (IEA, 2014)

ENERGY EFFICIENCY

The effect of energy efficiency has been on average reducing emissions with -386 kt yearly. The relatively high average effect is mostly caused by the large effect occurring between 1994 and 1998 (-1612 kt). The underlying trend is clearly reflected in Figure 13, which shows the individual fossil fuel efficiencies: between 1994 and 1998 especially the energy efficiency of gas for electricity increased substantially (with 12.2% points). All fossil fuels have overall increased their energy efficiencies of electricity production. Incremental increases can generally be accounted to individual plant efficiency improvements; large increases indicate the introduction of CHP plants. This is the result of the allocation of inputs to energy (according to formula F5) increasing the electric efficiencies of CHP plants, as high energy efficiencies are reached at CHP using allocated inputs. The actual electric efficiencies themselves are in the same range as the conventional single output plants (see detailed plant efficiencies in Appendix E). Especially until 2000 the overall efficiency of electricity production increased much, when CHP more than doubled its capacity in the Netherlands compared to 1990 (from 3000 to 7400 MWe). Most growth was caused by the introduction of large plants in the second half of that decade (Jeeninga et al., 2002). By 2012 the CHP capacity increased to 12700 MWe, which was mostly the result of the increased use of CHP in horticulture (CBS, 2015a).

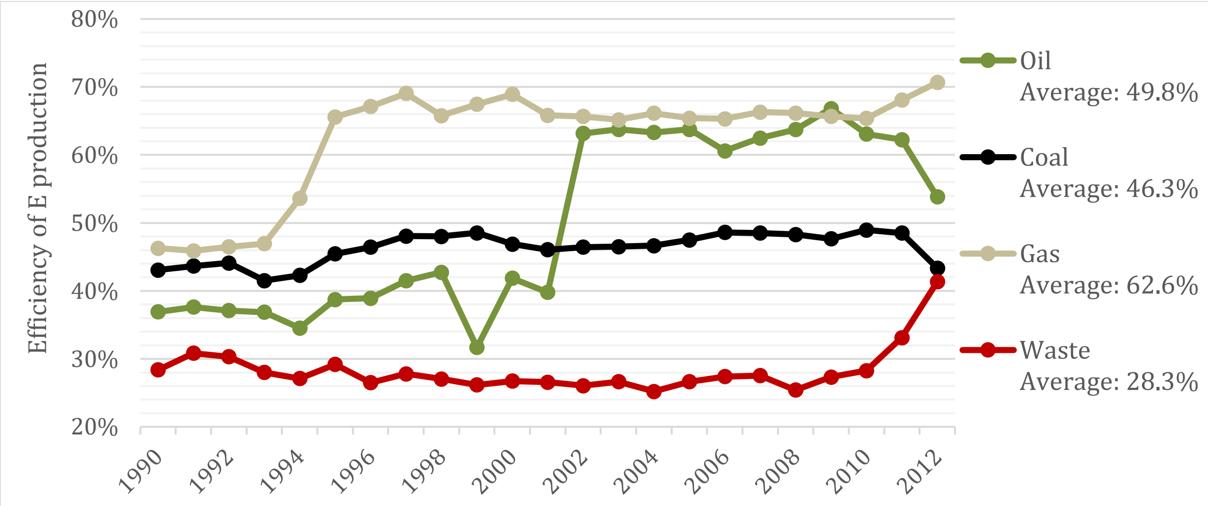

Figure 13 – Overall electric efficiency (with allocation of inputs) of the fossil fuel categories between 1990 and 2012 (IEA, 2014)

The actual electric efficiencies of the different types of plants have also improved – though not always as clearly pronounced – but contributed with a much smaller extent to the improvement of the overall electric efficiency (see Appendix E for more detailed efficiency figures). However, the efficiency of electricity from oil declined, as did the efficiency of electricity from gas at central CHP plants and decentral electricity plants. These developments are therefore assigned to be the cause of the small upwards energy efficiency effects that were shown after 2000. For the case of decentralized electricity generation this data is however less reliable, as these involve small numbers. For the larger plants the numbers are much more reliable, and the central electricity plants of both coal and gas clearly improved their electric efficiencies by 0.09 and 0.16% points yearly. Appendix E also shows that there can be large differences between efficiencies of central and decentral plants. The ratio between these plant types therefore also affects the overall energy efficiency, but this effect was not further quantified in this research.

CARBON FACTOR

The only variable causing the carbon factor effect at electricity supply has been a changing carbon factor of the fuel category of waste, as the other categories were assumed to have constant emission factors. Not unexpectedly – also because the emissions from waste have been small – the carbon factor effect was almost insignificant (+17 kt yearly on average). Only in the last two periods its effect has been notable, increasing emissions with respectively +33 and +58 kt yearly. The carbon factor shows such high fluctuations (as was already shown in Figure 4) because of the diverse mix of this non-biomass fraction of waste.

4.3 DECOMPOSITION ANALYSIS OF HEAT SUPPLY

Emissions from heat supply were decomposed using formula F7. The same five factors were studied as in the former section of the electricity supply, with the only difference that the effect from 'other energy sources' (without CO_2 emissions) is now a renewable energy effect, because the only other non- CO_2 energy source that produces heat is biomass. The five effects are thus caused by changes in: the activity level in terms of heat supply, the share of heat supply from renewable energy sources (i.e. biomass), fuel substitution at the fossil fuels, the efficiency of heat production and the changing carbon factors of the fuels. The decomposition results are shown in Figure 14.

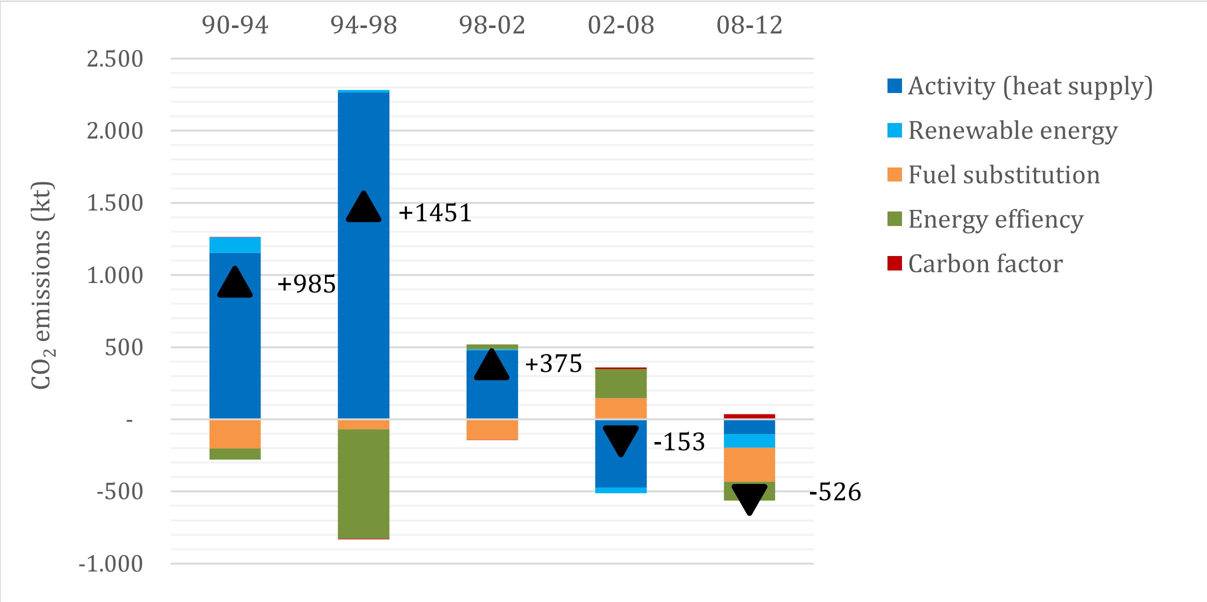

Figure 14 – Results of the decomposition of heat supply, showing five yearly effects in the intervals between 1990 and 2012

ACTIVITY

The indicator for the activity of heat supply was the total amount of heat supply in energy units. As opposed to electricity, heat is not imported and therefore the heat supply in the Netherlands is equal to its domestic production (Figure 15). CHP plants clearly dominate the production of publicly available heat. The figure also shows that heat is mostly produced centralized. However, as own use of decentralized heat production is allocated as consumption to the corresponding demand sector, this figure is somewhat distorted. The high increase in public heat production up to 1995 is caused by the increase of installed CHP capacity. If CHP heat substitutes former forms of heat production, this activity increase does not necessarily indicate increased heat demand, but rather causes a substitution effect towards public heat demand. The total heat supply increased from only 15.1 in 1990 to a maximum of 176.3 PJ in 2004. By 2012 the heat supply decreased again to a value of 132.4 PJ, almost nine times as high as during base year when it was only 15.1 PJ. The resulting activity effect was accordingly very high in the first two research intervals, increasing emissions with +1.154 kt and +2.264 kt yearly. Between 1998 and 2002 yearly emissions only increased by +480 kt, which was exactly reversed (-473 kt) between 2002 and 2008. During the last interval the effect reduced to only -105 kt, and for the first time the activity was not the largest influencing factor on CO_2 emission change of heat supply. The underlying dynamics of changes in heat supply needed to be further researched on the level of the demand sectors, which are directly responsible for at least about 87.5% of the heat supply in 2012.

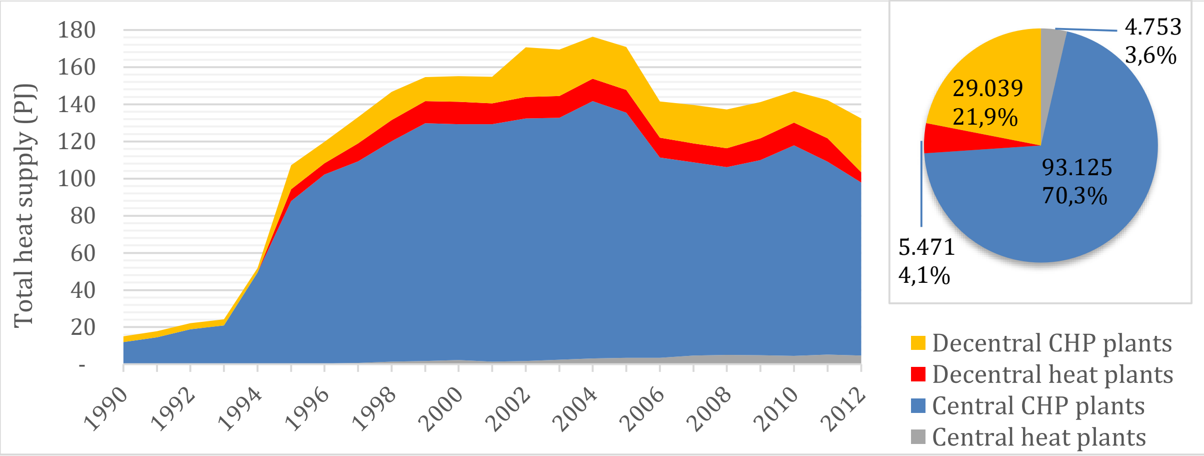

Figure 15 – Heat supply from different producers (central and decentral) and different plant types (single output and CHP plants, including pie chart with 2012 amounts (in TJ) and shares (IEA, 2014)

RENEWABLE ENERGY

The effect due to the use of biomass as opposed to fossil fuels is the renewable energy effect taking place at the heat supply. This effect has on average increased the emissions, but with the years it gradually improved, from a value of +106 kt yearly to +69 and then only +6 in the third interval (1998-2002). In the last two intervals the effect was in the negative direction: -41 and -95 kt yearly. After the effect due to the changing carbon factor of waste, the renewable energy effect was the least influential on emissions from heat supply. Figure 16 shows that the share of renewable energy in the total heat supply indeed dropped rigorously especially in the first interval (from 13.7 to 3.3%). The production of heat from biomass in absolute numbers however only decreased a little (to 91.8% or 1.7 PJ from 2.1 PJ in 1990). After the first interval the renewable heat supply started to grow again, but only after 2002 these growth rates were able to outweigh the growth of heat supply from fossil fuels, allowing it to obtain substantial CO_2 reductions. Especially the growth of gas use due to the installation of CHP plants in the first two intervals hindered the renewable energy effect in these periods.

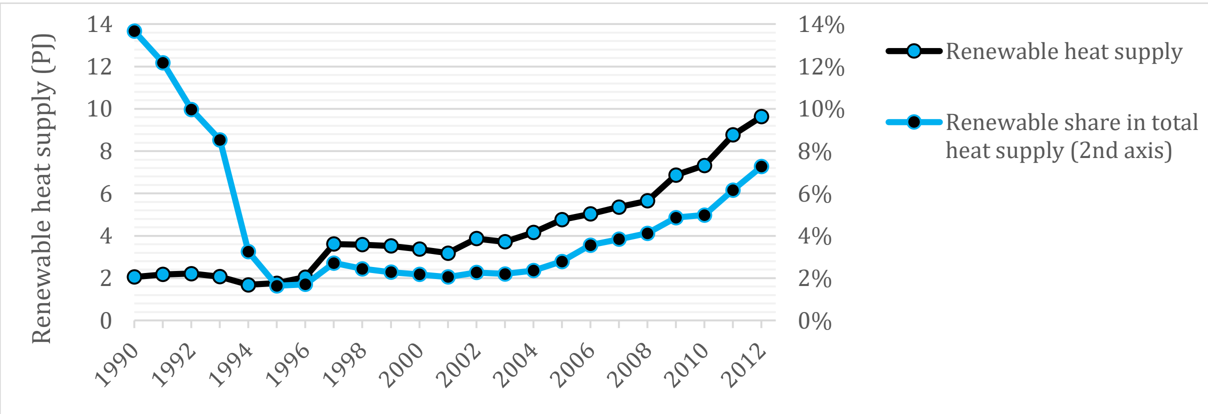

Figure 16 – Renewable heat supply and its share of share in total heat supply (second axis) between 1990 and 2012 (IEA, 2014)

FUEL SUBSTITUTION

The effect that is the result of fuel substitution at the heat supply has been predominantly in the negative direction. On average the fuel substitution effect was -78 kt yearly. Figure 17 shows that the main trend was an increase of heat production from gas, with that increasing its share at the expense of all other fuels until 2002. This dynamic can be assigned to the increased CHP. After 2002 the exact opposite trend set in, where the share of gas declined while all other fossil fuels increased in shares, causing emissions to increase by +146 kt yearly. This trend seemed to be pushing through, had it not that the production of heat from coal decreased so drastically in 2012 – when it was once more replaced by gas – causing the largest fuel substitution effect present in the first Kyoto period of -236 kt yearly.

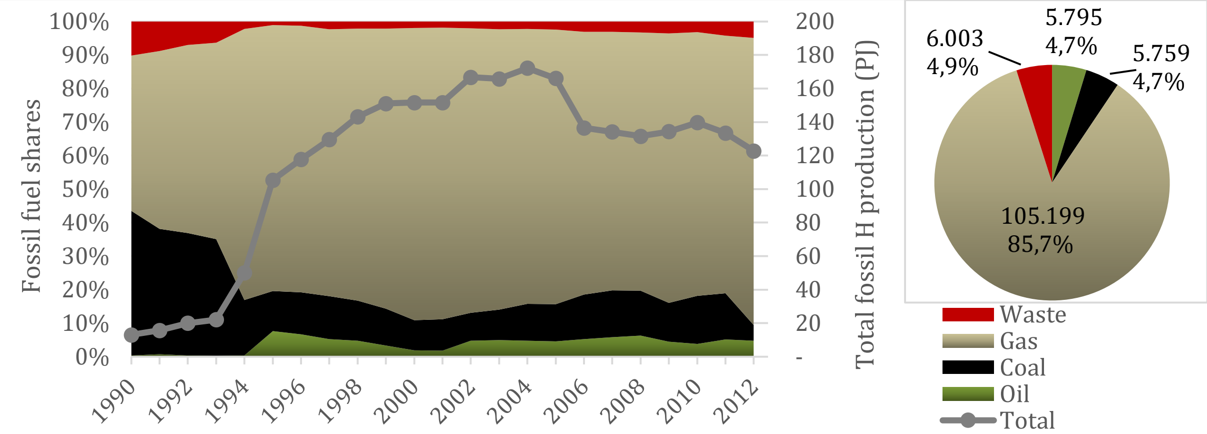

Figure 17 – Shares of four fossil fuel sources in total heat production from fossil fuels (second axis), including pie chart with 2012 amounts (in TJ) and shares within fossil fuels (IEA, 2014)

ENERGY EFFICIENCY

The energy efficiency effect for heat supply was on average -114 kt yearly, but between 1998 and 2008 the effect was in the positive direction. Figure 18 shows us that efficiency improvement was indeed most present until 1998, for all fuels, with the introduction of CHP plants having a large influence on the overall energy efficiencies because a smaller part of the inputs got allocated to heat production. The large variations in oil efficiency are caused by relatively small data amounts. On average all fuels had increased their efficiencies with 29.7% points by 1998 compared to the base year. In 1994-1998 the energy efficiency effect was accordingly very large: -758 kt yearly. After 1998 however the trends of efficiencies were more stabilized: the efficiency of oil and coal slightly increased in trend (+0.55 and +0.36% points), while gas and waste overall decreased their efficiency of heat production (-0.56 and -0.58 % points). The latter therefore must explain the upwards effects between 1998 and 2008.

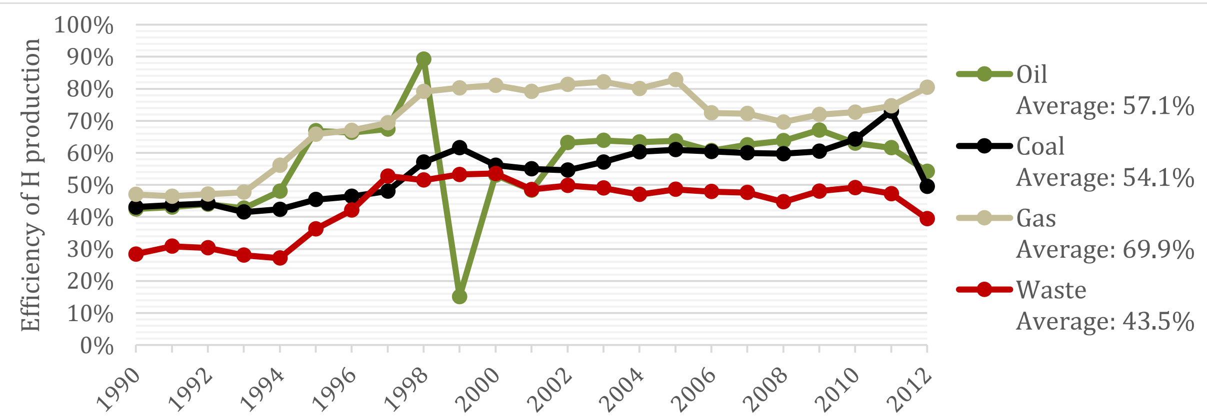

Figure 18 – Overall thermal efficiency (with allocation of inputs) of the fossil fuel categories between 1990 and 2012 (IEA, 2014)

Appendix E also shows this trend of decreasing efficiencies for all plant categories, except for the central CHP coal plant (+0.35% points thermal efficiency increase, without allocation). This implies that the plant improvements have been the dominant factor after 1998, while prior to 1998 the introduction of CHP has mostly ruled the energy efficiency effect. The differences between efficiencies of the different types of production were notable, but will not be further looked into here.

CARBON FACTOR

Similar to the analysis of the electricity supply, the carbon factor of waste was the only variable causing the carbon factor effect on emissions from heat supply, due to a worsening composition of non-biomass waste (Figure 4 in the method section). Its effect has been even smaller here (+9 kt yearly on average), with only notable effects in the last two intervals: +12 and +38 kt yearly.

4.4 AGGREGATION ELECTRICITY AND HEAT SUPPLY

Adding up all the calculated effects of electricity supply and heat supply gives the totals of effects present in these branches of the energy sector. Figure 19 shows that the effects have been mostly in parallel, which makes sense as these subsectors are closely linked, especially through CHP plants. Despite the fact that the largest share of the emissions emanated from electricity production (94.7% in 1990, 69.0% by 2012), the total effects of changes at heat production in CO_2 emissions were comparable to the effects occurring at the electricity supply. This is partly the result of the relatively high carbon factor of heat due to input allocation using energy content. The total activity effect from increased supply clearly had the largest impact on total carbon dioxide emissions from electricity and heat supply. The effect from an increased use of energy sources that do not emit carbon dioxide (the 'other energy' effect at electricity, the genuine renewable energy effect for heat) was dominated by the effects occurring at the electricity supply. The effects from fuel substitution had a significant impact reducing emissions until 2002, but after 2002 the developments at both electricity and heat (mostly substitutions between gas and coal) cancelled each other out. The total effect from energy efficiency improvement was very important until 1998, when the CHP plants entered the field. After 1998 the energy efficiencies have in fact slightly worsened, with the worsening of electric and thermal efficiencies itself (mainly oil and gas), inducing increasing CO_2 effects. The effect from the changing carbon factor of waste was almost negligible compared to the other effects in the field. Note that the largest part of the effects can be assigned to the demand sectors; the remaining occurs as own consumption of the energy sector, which is nevertheless also indirectly caused by the energy demand of the demand sectors.

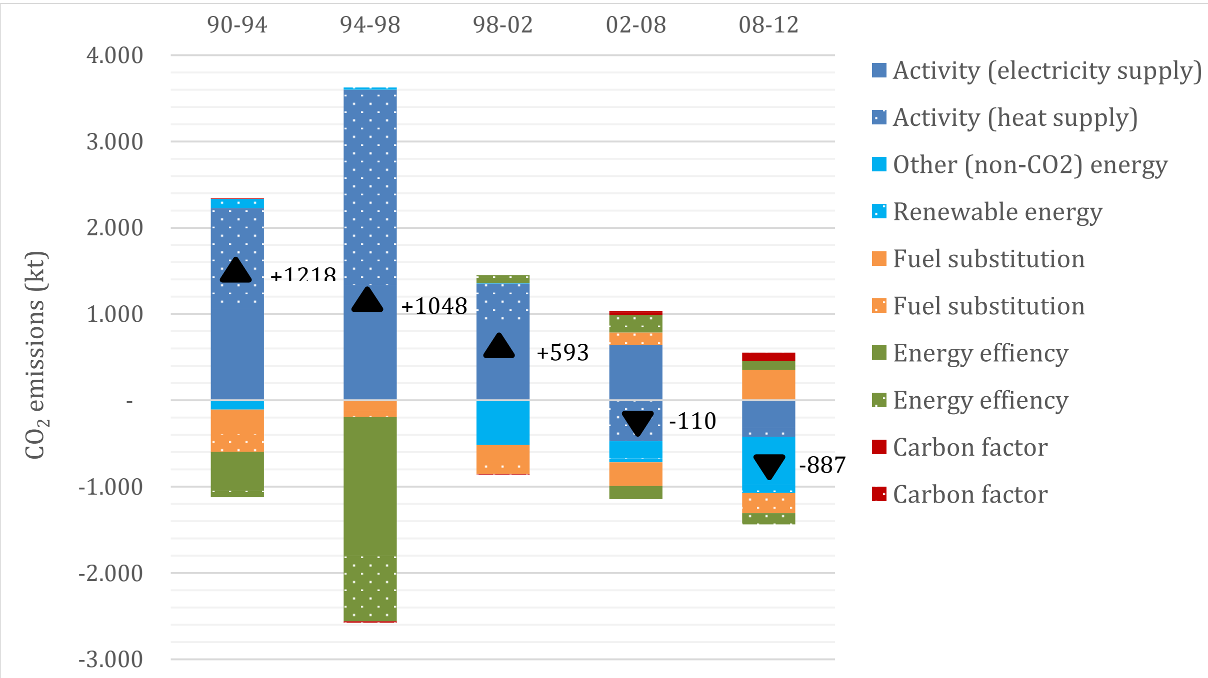

Figure 19 – Aggregation of decomposition results of the total electricity and heat supply. Five different effects are distinguished for both electricity (solid) and heat (patterned), representing yearly delta CO_2 emission effects in the intervals

As a result of the decarbonizing effects – increased use of sources that do not emit carbon dioxide as opposed to fossil fuels ('other energy' and renewable effect), the substitution towards cleaner fossil fuels and the overall improvement of energy conversion (energy efficiency) – the carbon factors of both electricity and heat supply have improved substantially since 1990 (Figure 20), as calculated using Formula F8. However, the improving carbon factors have not always been able to cancel out the large effect from increased activity (energy supply). In fact, it was not until the activity effect started showing negative effects when the total CO_2 emissions of electricity and heat supply were decreasing. The overall carbon factors have even improved less and less, the decreased supply was therefore the main reason for the total reductions. In the next chapter electricity and heat are treated as fuels to further explore the trends behind their demanded amounts of in public supply. The effects that caused the improvements of the carbon factors of electricity and heat (decarbonisation due to non-CO_2 sources, fuel substitution and energy efficiency) therefore come forward as subeffects within the carbon factor effects at the demand sectors.

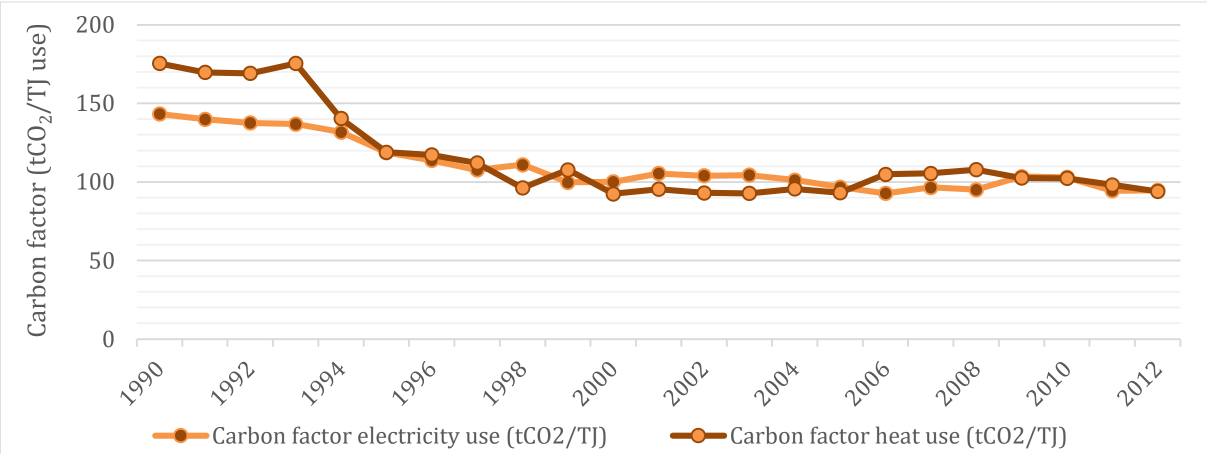

Figure 20 – Carbon factors of electricity and heat use in the Netherlands, taking into account energy losses as were shown in Table 4 (using Formula F8), in tonnes of CO_2 per TJ energy supply (IEA, 2014)

4.5 LINK WITH ENERGY AND CLIMATE POLICIES AT ELECTRICITY AND HEAT SUPPLY

Policies deployed in the energy sector that aimed to target carbon dioxide emissions in general focused on three main measures: encouraging renewable energy, improving energy efficiencies and promoting CHP production. These measures typically caused effects of renewable energy and energy efficiency. At the electricity supply the renewable energy effect was hidden inside the 'other energy' effect. The most important instruments targeting the electricity and heat supply are schematically shown on a timeline in Figure 21, a short explanation can be found in Appendix D. Instruments were specifically targeted to encourage CHP (Special gas price CHP, MAP, BSET/NEWS) or solely renewable energy (Green investment funds), but goals could also overlap as certain instruments for example offered financial support to multiple kinds of green initiatives (VAMIL, Energy tax, EIA, MEP/SDE/SDE+). Especially these economic incentives, but also voluntary agreements (the benchmark and coal covenants) have played an important role at the electricity and heat supply. At last Green certificates trading and EU ETS were regulatory instruments.

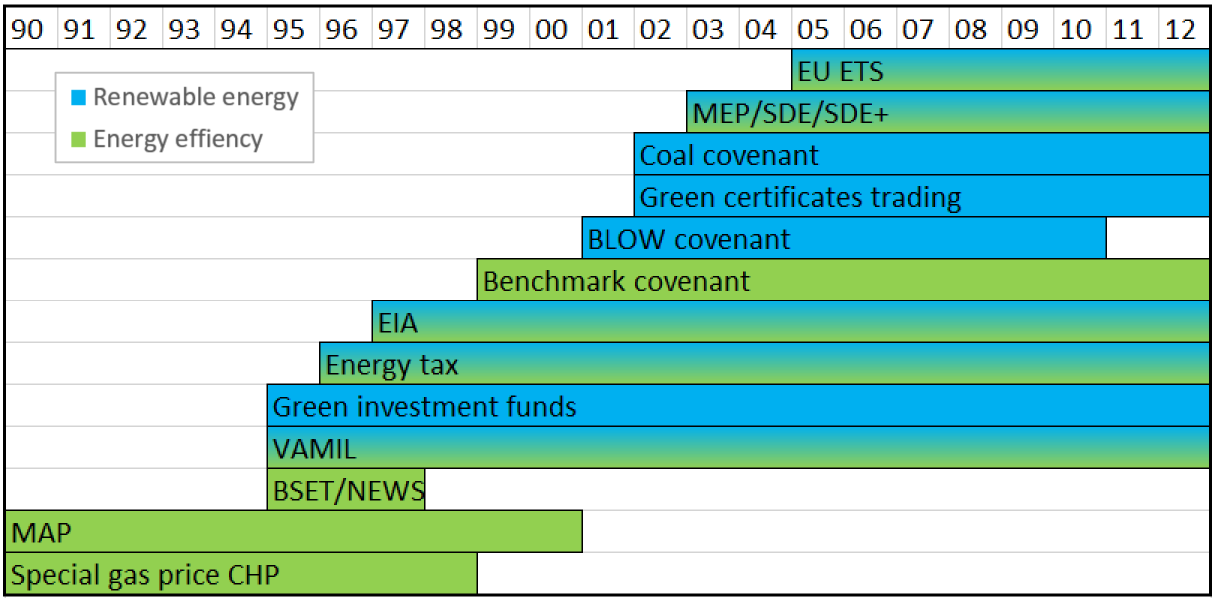

Figure 21 – Instruments targeted at renewable energy and energy efficiency of electricity and heat supply

Figure 21 shows that about half of the most important instruments that were to influence the electricity and heat supply aimed to induce a renewable energy effect, the other half was to cause an energy efficiency effect. Most of the instruments in the latter category focused on efficiency improvement through the encouragement of CHP, which was especially the focus in the nineties. This is also reflected in the decomposition analysis, as largest efficiency effects were found in the first two researched intervals: in total (electricity and heat taken together) -528 and -2369 kt yearly respectively. More incremental efficiency effects were aimed to be achieved through for example the benchmark covenant. These efforts were however not as effective, as the former analysis showed that some fuels considering both electric and thermal efficiencies have shown slightly declining rates taking over after the efficiency improvements from increased CHP production. In total the energy efficiency effects have caused the total emissions to decrease with -11.01 Mt between 1990 and 2012.

Instruments promoting the penetration of renewable energy were increasingly present. Here also a correlation can be found with the renewable energy effect increasingly growing with each interval. Especially after the turn of the century these effects were large, when also the largest intensity of renewable energy instruments was present. Most results were accomplished at the electricity supply sector which was also the main focus of the instruments. Especially the promotion of wind power was prominent here, but also the coincineration of biomass was an important strategy at the electricity sector. This also clearly comes back in the results, where about -2.65 Mt was the result of biomass at electricity supply and -2.30 Mt could be assigned to solar wind (of which 96-99% was wind). Reductions due to the reduced use of hydro power was negligible (+0.01 Mt by 2012) and a hydro strategy was absent in the Dutch policy documents. At heat supply the small increase of biomass use caused reductions of only -0.11 Mt by 2012.

No energy and climate policies targeted at the energy sector were found that aimed to specifically induce effects of activity, fuel substitution or a carbon factor effect. Possible activity effects are however indirectly the result of energy and climate policies that are targeted at the demand sectors to reduce their demand by promoting for example more efficient appliances. These are therefore analysed in the following chapters. Its total increase was already shown here to be very large, as the amount of electricity and heat supply has caused an increase of +28.04 Mt of CO_2 emissions by the end of Kyoto.

Fuel substitution was rather indirectly influenced by the EU ETS emission trading scheme, as it promotes the reduction of CO_2 which could be chosen to be achieved by fuel substitution to have sufficient emission rights. However, ambitions to achieve fuel substitution effects by EU ETS were not clearly pronounced. Moreover, even if the EU ETS was responsible for the shift to cleaner fuels, the shift to coal has overruled its effect. The coal to gas developments before 2002 were mostly responsible for the total fuel substitution effect of -4.38 Mt achieved by 2012, which was also recognized as a possible indirect result of the increase of CHP. To achieve a fuel substitution effect by promoting more CHP has not been expressed as part of the CHP strategy (the argument focuses on the efficiency of energy production), but it is an indirect 'extra' effect, because CHP mostly utilizes the relatively cleaner gas. Finally, gaining a carbon factor effect (by preferring cleaner types of waste) was also not mentioned in Dutch energy and climate policy strategies. The worsening carbon factor of waste may be an indirect effect of better waste recycling, which influences the waste mix. Its changing emission factor has caused the emission level to increase with +0.59 Mt by 2012.

OTHER POSSIBLE INFLUENCES

The analysis clearly shows that there is a correlation between the intensity of energy and climate policy instruments and decarbonizing effects due to the penetration of renewable energy and the improved energy efficiency. However, also other factors may have played a role in CO_2 emission reductions. The decomposition analysis of the electricity supply already showed that the use of other energy (nuclear and net electricity import) also substantially affected emissions. Especially the effect of the latter was surprising, reducing emissions with -67 kt yearly on average (-1.52 Mt in total). Nuclear energy on average had a yearly increasing effect of +24 kt yearly (+0.48 Mt in total). Increasing the relative share of net electricity import was however not a strategy of Dutch energy and climate policy. These import/export dynamics are driven by electricity prices: when the price of electricity from abroad is lower than domestic production costs, it is favorable to import electricity to meet the demand. Electricity prices are mainly the result of the prices of the input fuels. These prices of the input fuels themselves are also expected to be an important driver of fuel substitution. For example, the low coal prices in 2012 have had a large influence on the relatively increase of coal use at electricity production (CBS, 2013a). Also other exogenous factors like the liberalization of the electricity market has profoundly influenced the electricity and heat supply, which especially affected the development of CHP (Wees et al., 2000) and therefore indirectly the activity and efficiency effect. Lastly, a part of the efficiency improvements and renewable energy use would also have occurred autonomously, without the incentives from policy measures or other exogenous factors, but solely from the cost-effective perspective of companies and the technological development with time.

4.6 CONCLUSIONS ELECTRICITY AND HEAT SUPPLY

The decomposition analysis of the electricity and heat supply shows that the effect due to activity growth (more supply) has been the largest driving factor (+28.04 Mt), especially until the global economic crisis. This supply is the indirect result of the energy demand of the demand sectors, policies aiming to influence their demand are therefore discussed in the following chapters. A part of the increase also needs to be assigned to increased CHP heat, which may substitute earlier types heat production at the demand sectors. The effect of renewable energy (-5.05 Mt in total by 2012) mostly originates from the electricity supply. About 50/50 of this effect was caused by the increase of electricity from wind and biomass. At heat supply the use of biomass also increased, but it had difficulties to outweigh the increased gas use with the large growth of CHP capacity. The renewable energy effect was in correlation with the growing number of instruments aiming to increase the share of renewable energy between 1990 and 2012. The analysis also showed that the increased net electricity import substantially decreased CO_2 emissions by 2012 (-1.48 Mt), but this was not part of energy and climate policy. The same goes for nuclear energy, of which the decreased share caused CO_2 levels to slightly rise with +0.48 Mt. The effect of fuel substitution was much larger: -4.38 Mt in total, even though no specific policy instruments (only indirectly EU ETS) aimed to promote the substitution of fossil fuels here. The main trend was a coal to gas dynamic, which is indirectly also the result of the increased use of CHP gas. Shifts back to coal at both electricity and heat counteracted the possible fuel substitution efforts after 2002, assigned to the low coal price. The effects due to improvements in energy efficiency incurred the largest reductions, in total -11.01 Mt by 2012. Especially the large energy efficiency effect between 1994 and 1998 has been influential, when the energy supply from CHP increased immensely. This was also the focus of energy and climate policy before the turn of the century. Some policies have also aimed to improve the individual electric and thermal efficiencies, but these have actually somewhat worsened and even induced small increases in emissions after 2002. The total effect due to the worsening carbon factor was limited (+0.59 Mt); also no policy was found that aimed to improve this carbon factor of waste. Besides the discussed instruments of energy and climate policy, also exogenous factors and autonomous improvements have played a role in the decarbonizing effects that came forward at the decomposition analysis.

5. INDUSTRY

5.1 TREND OF CO_2 EMISSIONS BETWEEN 1990 AND 2012 (INDUSTRY)

The total amount of energy-related carbon dioxide emissions from the industry has slightly decreased during the first Kyoto period, from 39.2 Mt to 38.7 Mt. Average emissions over 2008-2012 were however still 3.8% above 1990 base year level (40.7 Mt). The emissions emanating from five different energy sources are shown in Figure 22, including indirect emissions from electricity and heat use (41.3% of emissions in 2012). Figure 23 shows that the energy consumption of the industry increased from 473.3 PJ in 1990 to 524.8 PJ by 2012, 10.9% above base year level (Figure 23). In 2007 a maximum consumption of 593.6 Mt was reached. The contribution of the chemical & petrochemical sector (2) was largest, followed by food & tobacco (7), with basic metals (1) in the third position. These three top energy users alone covered three quarters of the total final energy consumption of the industry in 2012.

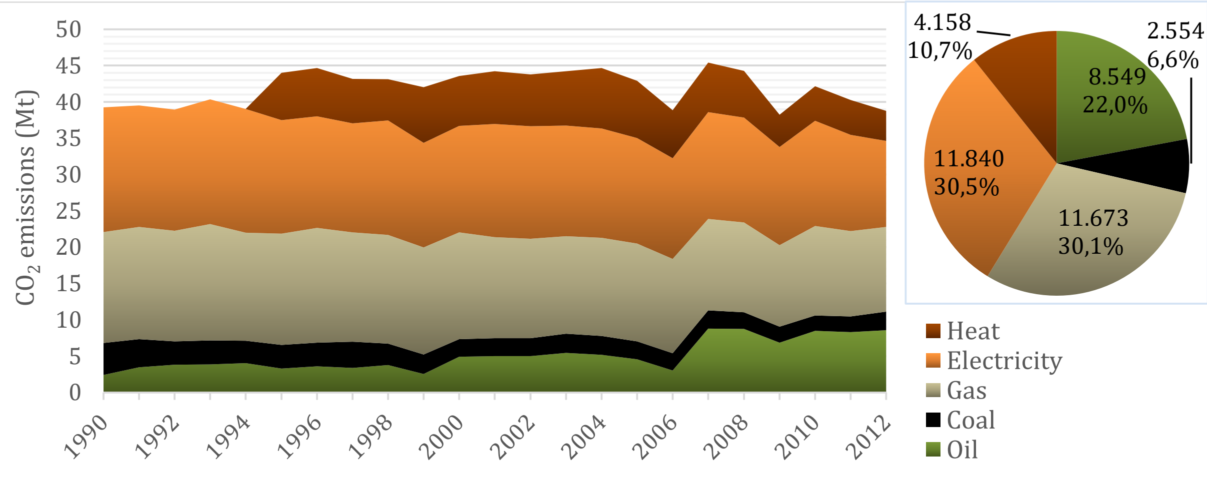

Figure 22 – Carbon dioxide emissions of the industry sector from five different fuel types between 1990 and 2012, including pie chart with 2012 amounts (in kt) and shares (IEA, 2014; IPCC, 2006)

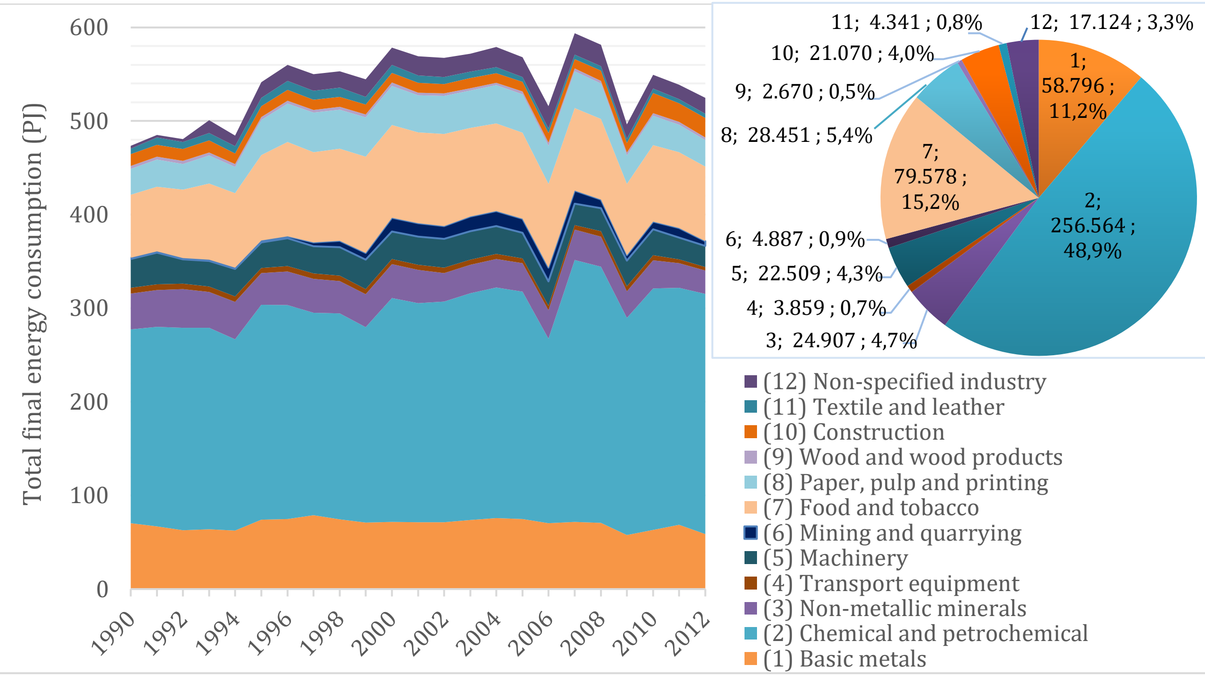

Figure 23 – Total final energy consumption of the twelve industry sectors between 1990 and 2012, including pie chart with 2012 amounts (in TJ) and shares (IEA, 2014)

Energy consumption is amongst others dependent on the activity of a certain sector: if it produces more, it requires more energy input. In case this ratio (the energy intensity) in a sector does not change, nor do any of the other factors which potentially change the carbon intensity of the total industry, we get a frozen technology scenario. Figure 24 shows how CO_2 emissions would have developed if the carbon intensity of the industry's GVA was kept on 1990 level, with CO_2 emissions only being dependent on the industry's activity. In this case emissions would have been even 8.9 Mt higher over 2008-2012 (24.5 % above base year level). The second axis shows that the carbon intensity of the industry actually decreased during the first Kyoto period, from 591 to 470 tCO_2/mln €. The decomposition analyses of the twelve industry sectors give insight into the drivers behind the changing industry's carbon intensity.

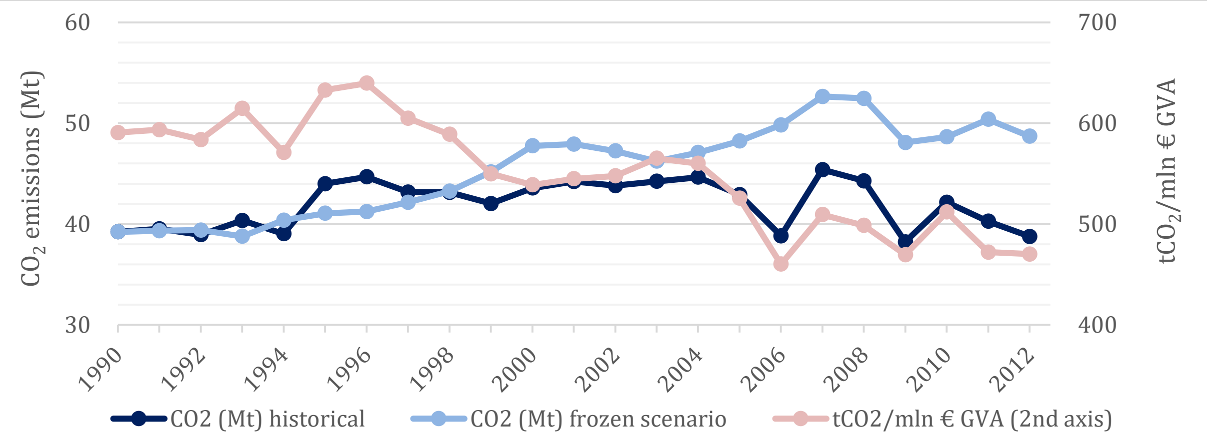

Figure 24 – Carbon dioxide emissions from the industry (historical and for a frozen scenario) and on the second axis the historical carbon intensity of GVA in 2005 constant prices (IEA, 2014; CBS, 2016c)

5.2 Decomposition analysis industry

Carbon dioxide emissions of the twelve industry sectors were decomposed by formula F9, the results are given in Figure 25. Five effects could be distinguished, due to changes in: activity of the sectors (indicated by their GVA), energy intensity in terms of final consumption for each unit of GVA, the share of renewable energy, substitution of fuels emitting CO_2 and finally the changing carbon factors of electricity and heat. Below the effects and their underlying trends are discussed.

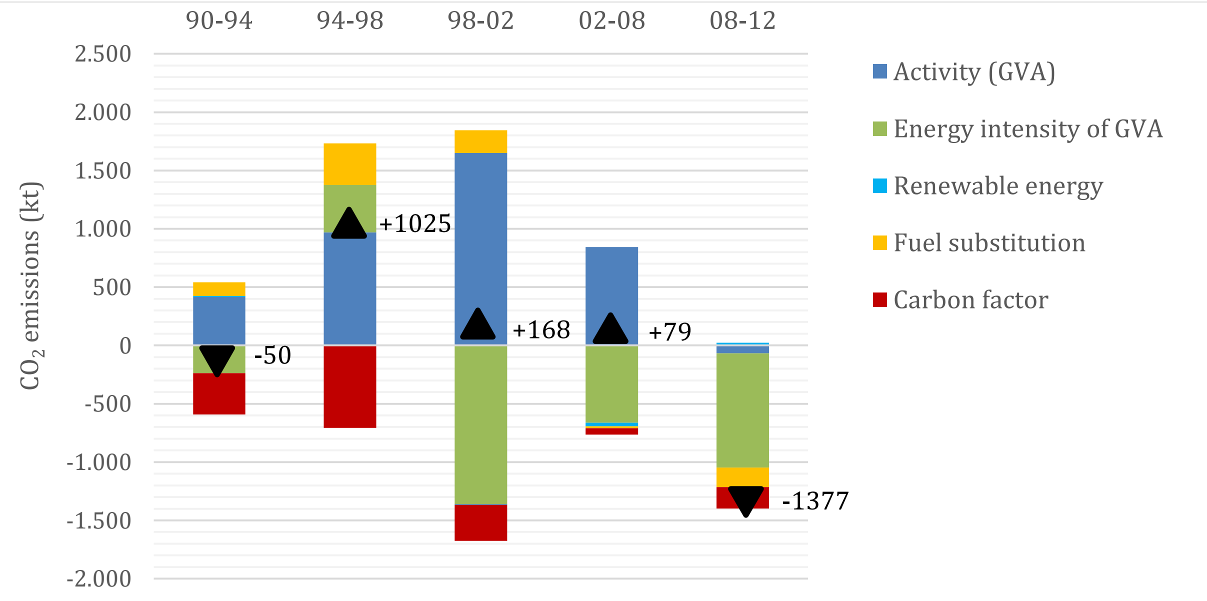

Figure 25 – Results of the decomposition of the industry, showing five yearly effects in the intervals between 1990 and 2012

ACTIVITY

Figure 34 shows the separate activity effects that were present at the twelve different industry sectors. The activity of the industry is indicated by gross value added (GVA), the level of economic activity of a sector. Between 1990 and 2012 the GVAs of the industry sectors in general increased (Figure 27), from 66.4 to 82.5 billion Euros, each sector growing by 26.9% on average. The chemical & petrochemical sector (2) almost doubled its economic activity (+90.6%), the textile and leather industry (11) showed most relative decrease (-19.2%). The resulting total activity effect on CO_2 emissions until 2008 was on average +969 kt yearly, the largest effect to influence emissions at the industry (see Figure 26). In the final interval, as the 2007/2008 global financial crisis set in, the activity was slightly negative: -73 kt yearly. Figure 26 shows that the activity effect was dominated by the three top sectors: chemical & petrochemical sector (11), followed by food & tobacco (7) and the basic metals sector (1).

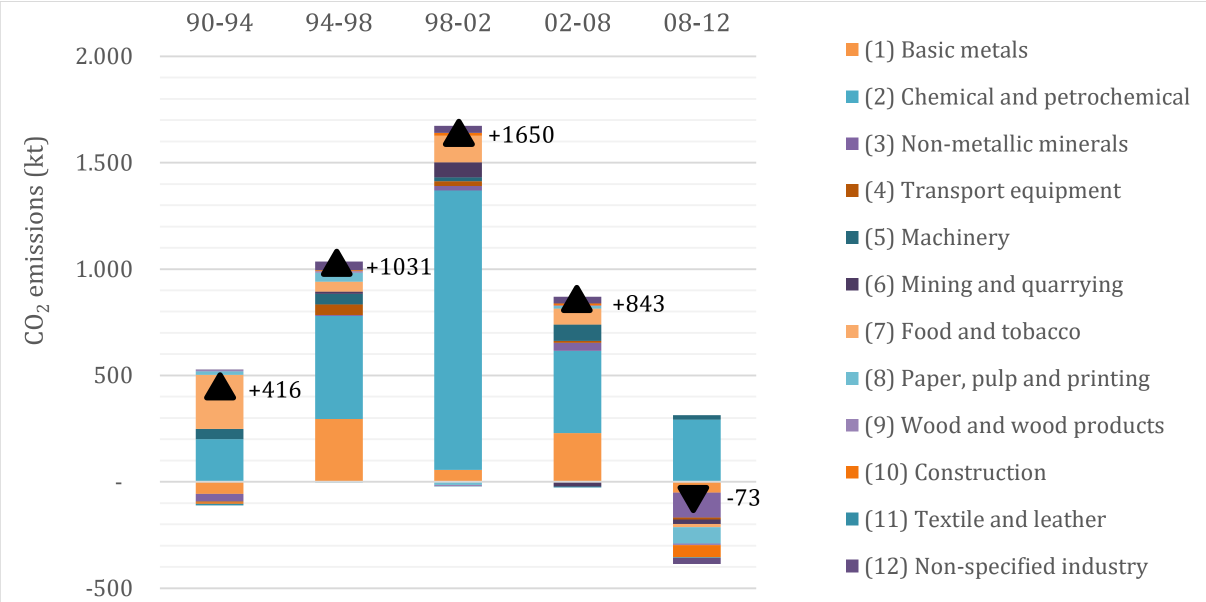

Figure 26 – The activity effect split out for the twelve industry sectors (yearly)

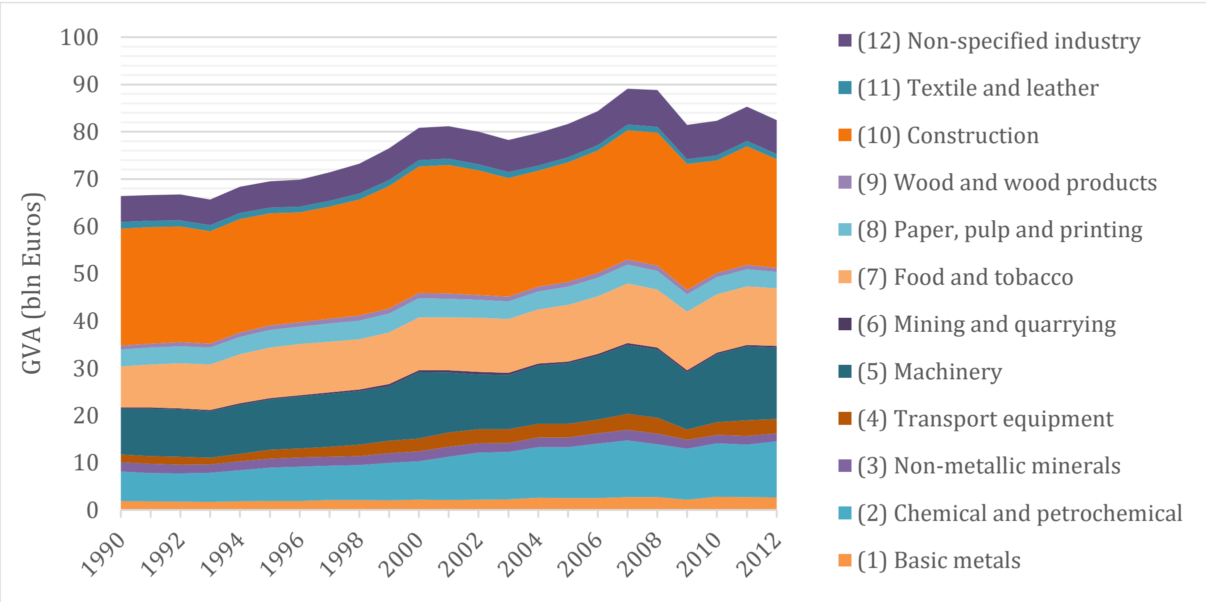

Figure 27 – Economic activity of the twelve industry sectors in gross value added (billion Euros in constant 2005 prices) between 1990 and 2012 (CBS, 2016c)

ENERGY INTENSITY

The effect due to a changing energy intensity was the second largest effect in the industry, mostly decreasing emissions with -574 kt yearly on average. The individual effects of the different industry sectors are given in Figure 28, the underlying trends are shown in Figure 29. The total trend of the industry was downwards (-10.8% by 2012), which means that the industry as a whole required 10.8% less final energy for the same economic output. Especially the transport equipment sector (4) tremendously decreased its energy intensity (-67.1%), but the energy intensity of GVA of the non-specified sector on the other hand almost increased fivefold by 2012. Figure 28 shows that the three top sectors again showed the largest effects, together with the machinery sector (5). The non-specified industry (12) and construction (10) scored particularly bad on energy intensity effects.

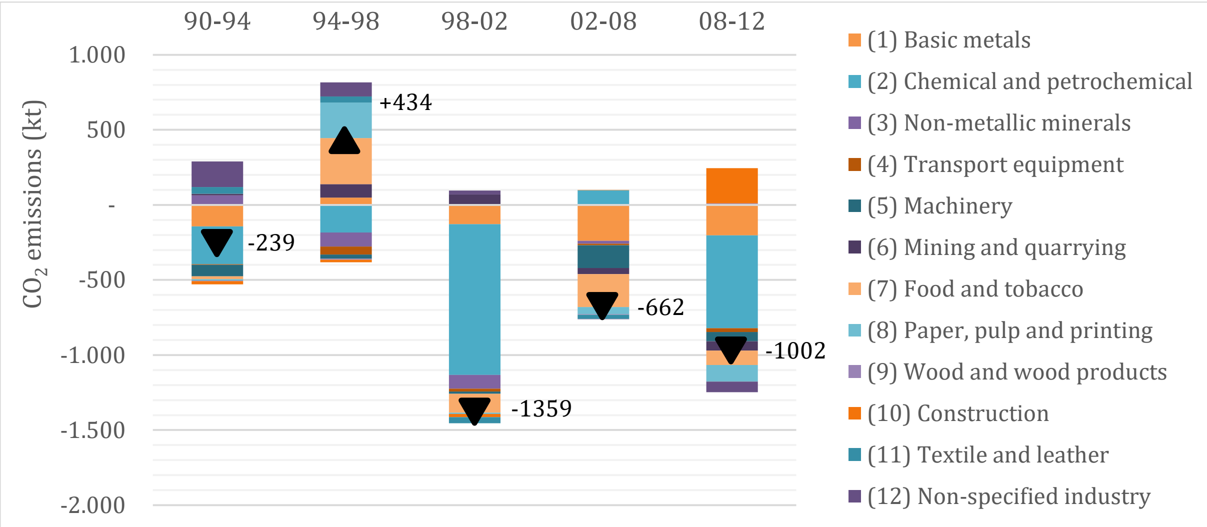

Figure 28 – The energy intensity effect split out for the twelve industry sectors (yearly)

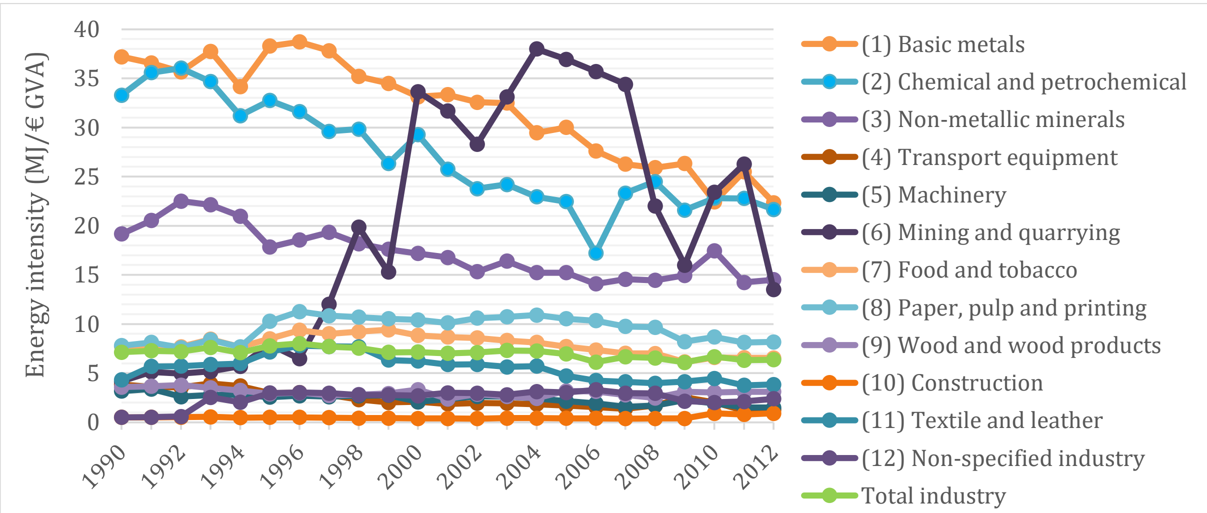

Figure 29 – The energy intensity of the twelve industry sectors in MJ final consumption per Euro gross value added (in constant 2005 prices) between 1990 and 2012 (CBS, 2016c; IEA, 2014)

By merging the factors of activity (A) and energy intensity (EI) in Formula F9, you remain with a factor that solely explains the CO_2 effect due to changes in total energy consumption (see also Figure 23). This combined effect was positive until 2008 (+ 490 kt on average) which means that until then the improving energy intensity was not able to offset the effect from increased activity. The energy use did not grow in the same pace as the economy, but it was not completely decoupled from this economic development. After 2008, when the energy intensity of GVA continued to improve but the activity level of GVA growth stagnated, the total energy consumption of the industry finally decreased, inducing emissions to reduce with -1075 kt yearly (see also Figure 25). Reductions in the final interval were however not sufficient to offset its earlier increasing effect on CO_2 emissions.

RENEWABLE ENERGY

The use of renewable energy in the industry only took place in the form of biomass use. Its decarbonizing effect in the industry has been negligible, with an average yearly effect of only -5 kt. Figure 30 shows that renewable energy effects only took place at six industry sectors, with the changes at the non-specified industry dominating the results. Figure 31 shows that in total the use of biomass has more than doubled by 2012, while increasing its share in total energy consumption from 0.35 to 0.70% (second axis). In fact, at four out of six sectors the share of biomass stayed below one percent. At the wood & wood products sector (9) the share was 35.3% and at the non-specified industry (12) it was 9.7% on average. A relatively high renewable energy share in combination with relatively large fluctuations taking place at sector 12 gave the largest renewable energy effect. On the second place is food & tobacco (7), due to its relatively large energy use. The total renewable energy effect was however still very small.

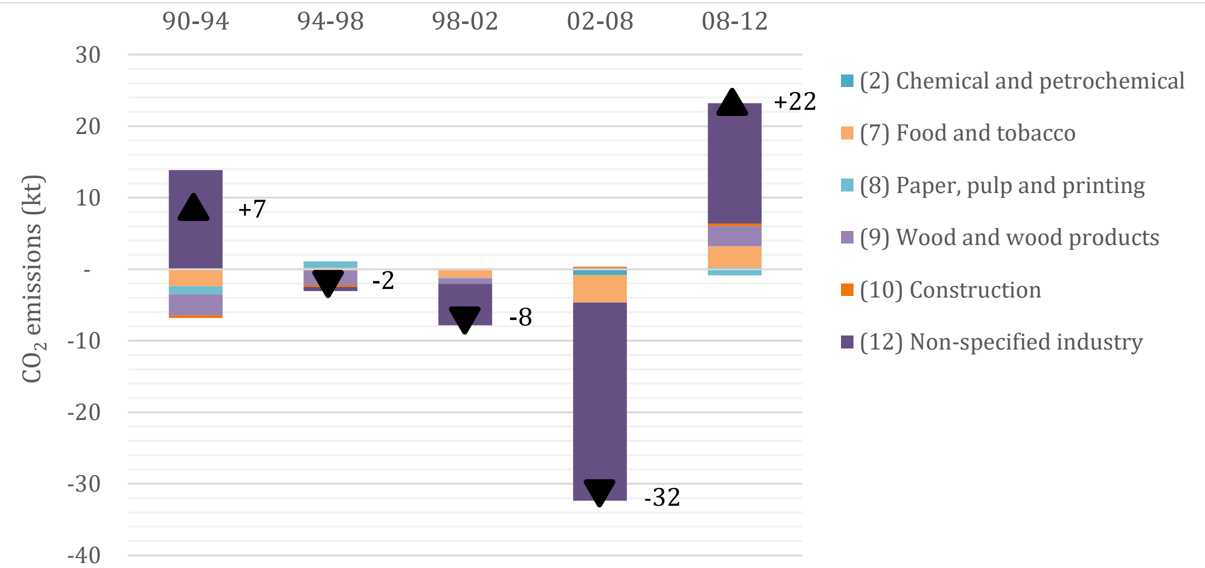

Figure 30 – The renewable energy effect split out for the twelve industry sectors (yearly)

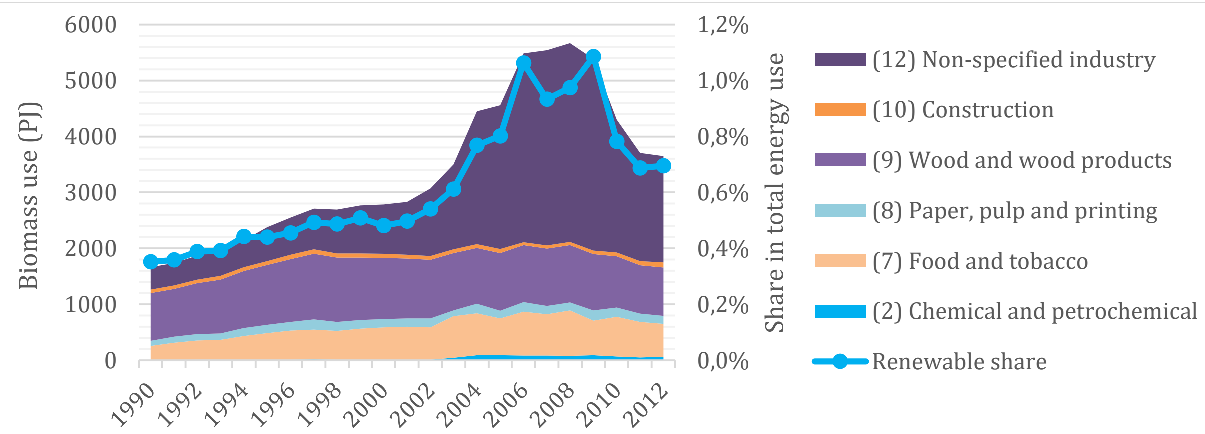

Figure 31 – The use of renewable energy (biomass only) in the industry for six industry sectors and on the second axis its share in total energy consumption, between 1990 and 2012 (IEA, 2014)

FUEL SUBSTITUTION

The individual effects on CO_2 emissions caused by changing fuel mixes within the industry sectors are shown in Figure 32: the effects from fuel substitution. The fuel mix varies a lot between the different industry sectors, as their industrial processes also vary. For example, the construction sector (10) uses relatively large amounts of oil, for the chemical & petrochemical sector (2) this is coal, for non-metallic minerals (3) it is gas, wood & wood products (9) use relatively much electricity and for mining & quarrying (6) heat comprises the largest share in energy sources that have carbon factors. Figure 32 shows that the developments at the chemical & petrochemical industry induced the largest fuel substitution effect. The fuel use of the total industry is shown in Figure 33. Until 2002 the main tendency was the substitution of gas by heat, inducing an average yearly effect of +193 kt. The sharp increase is the result of the newly formed collaborations with the energy distribution companies for CHP production. Produced heat by the installations at the industry is now visible in the data as heat, because it is sold from the energy company. Before, the heat was visible as inputs into the CHP installations. Theoretically a shift from own to exploited CHP installations should not affect emissions. However, due to the relatively large carbon factor of heat it gives a fuel substitution effect here. This is however partly cancelled out by the energy intensity effect, as the amount of heat in final amounts is smaller than the earlier plant input amounts. After 2002 the main tendency was the relative increase of oil at the expense of heat, growing from -16 kt yearly until 2008 and -62 kt yearly until 2012.

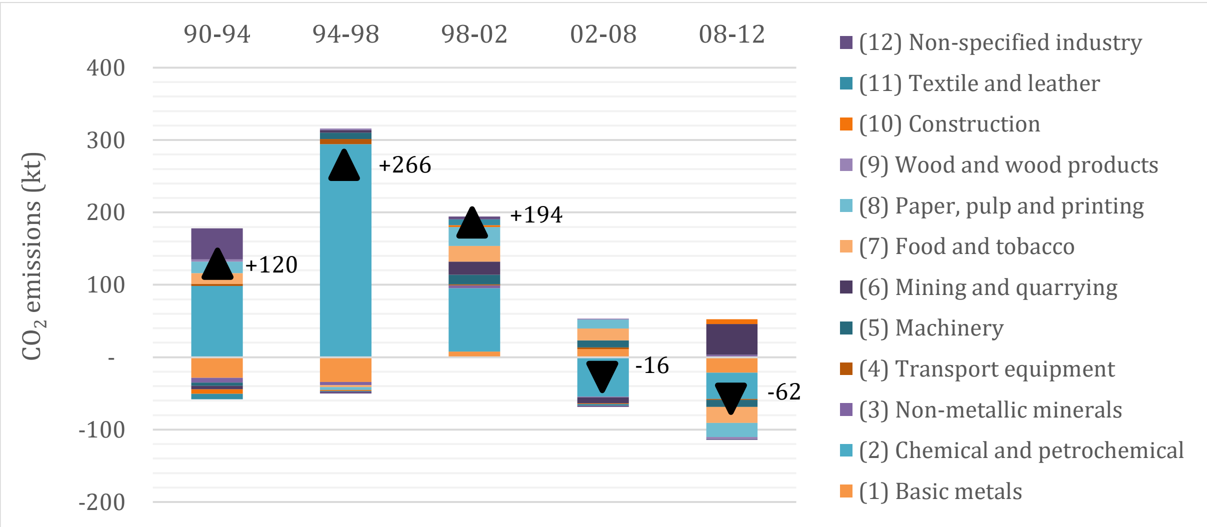

Figure 32 – The fuel substitution effect split out for the twelve industry sectors (yearly)

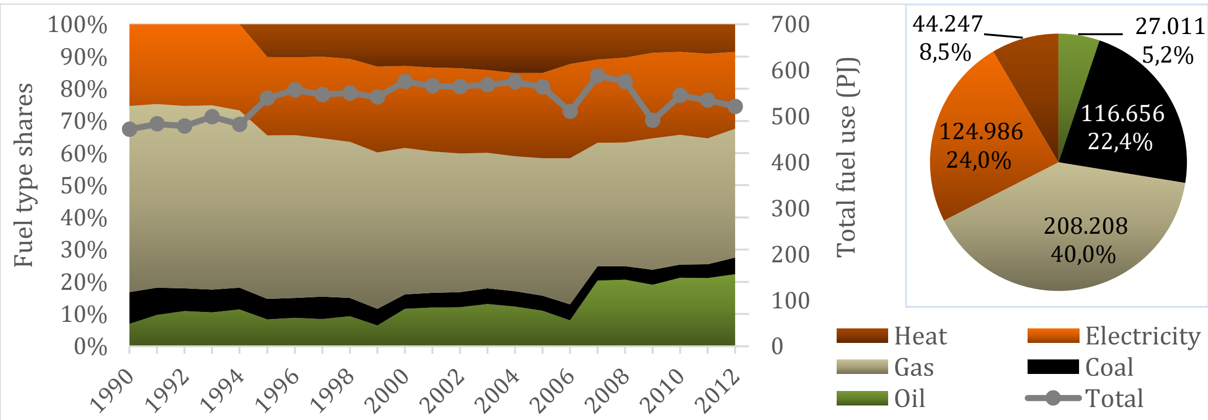

Figure 33 – Shares of five fuel type sources in total fuel use of the industry (second axis), including pie chart with 2012 amounts (TJ) and shares within total fuel use (IEA, 2014)

CARBON FACTOR

The carbon factors of electricity and heat have significantly improved with the developments at the energy and heat supply, as discussed in the former chapter (see also Figure 20). These developments now turn out as carbon factor effects at the industry (Figure 34). On average the carbon factor effect was -311 kt yearly. The effect was specifically large between 1994 and 1998 (-704 kt yearly), when the carbon factors improved much with the increased use of CHP. More than half of the effects can be assigned to the efficiency improvements, a little more than a quarter to the renewable energy use at electricity & heat production and a little less than a quarter to fuel substitution at the plant inputs.

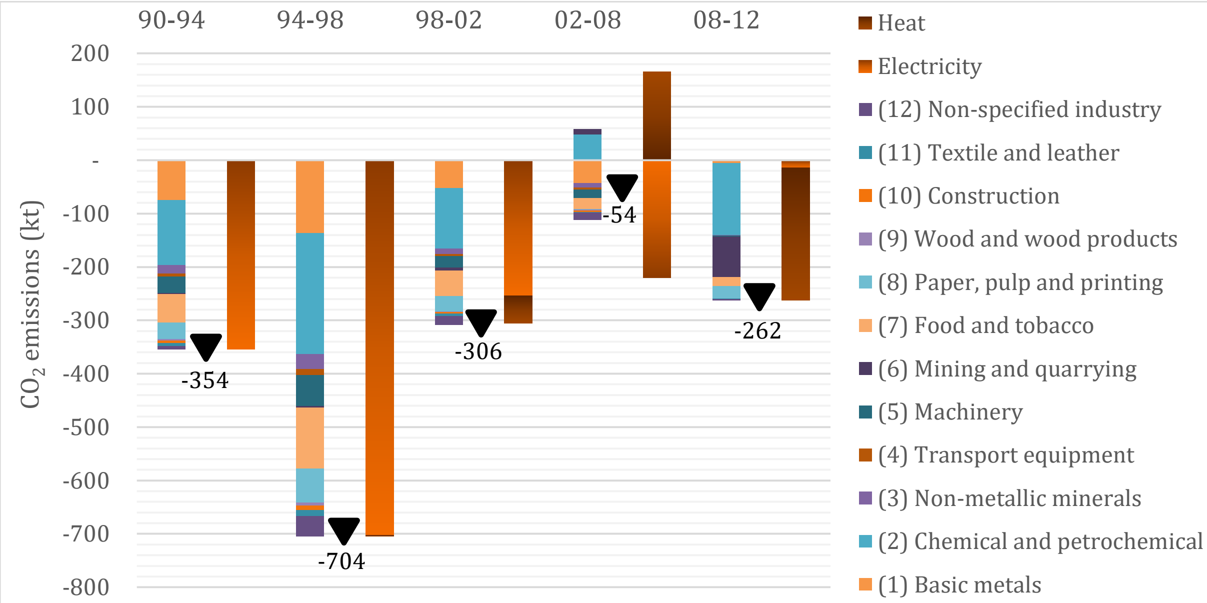

Figure 34 – The carbon factor effect split out for the twelve industry sectors and also for electricity and heat (yearly)

Figure 34 shows that the effects were largest at the top sectors: chemical & petrochemical (2), basic metals (1) and food & tobacco (7); in that order. The figure also shows that the carbon factor effect mostly comes from the use of electricity, partly due to the relative larger use of electricity. In fact, in the first two intervals the resulting effect completely originates from the changing carbon factor of electricity, because the heat use was zero until 1994, before the former explained CHP collaborations with the energy sector. Despite recorded heat use between 1994 and 1998, this interval has no carbon factor effect either, as the changed in carbon factor by 1998 is irrelevant because the carbon factor of 1994 was not relevant (when there was no heat use, Section 3.1). In the last interval the changing carbon factor of heat was especially influential due to a relatively large decarbonization at the heat supply.

5.3 LINK WITH ENERGY AND CLIMATE POLICIES AT THE INDUSTRY

The main measure for decarbonisation of the industry was energy conservation. For example by better housekeeping, energy monitoring and the use of new technologies energy would be saved – and money. Most instruments that were deployed between 1990 and 2012 are therefore reflected in the energy intensity effects, as conservation measures reduced the required energy for the same output. To a smaller extent instruments have focused on the penetration of renewable energy, to cause renewable energy effects. The most important instruments that played a role at the industry are shown in Figure 35. A short explanation of these instrument and their abbreviations can be found in Appendix D. The cornerstone of the policy strategy in the industry was the use of voluntary long-term agreements (LTAs and the benchmark covenant), which were then backed up by so-called carrots (subsidies like TIEB, BSET/NEWS, SPIRIT/BTS/EOS or indirect financial incentives like VAMIL, EIA, GDs) and sticks (regulation like Environmental permits, EU ETS). Also two programmes that were not officially governmental policy were in place (MAP and MPI), set up by energy distribution companies to support industrial companies with complying to their LTAs.

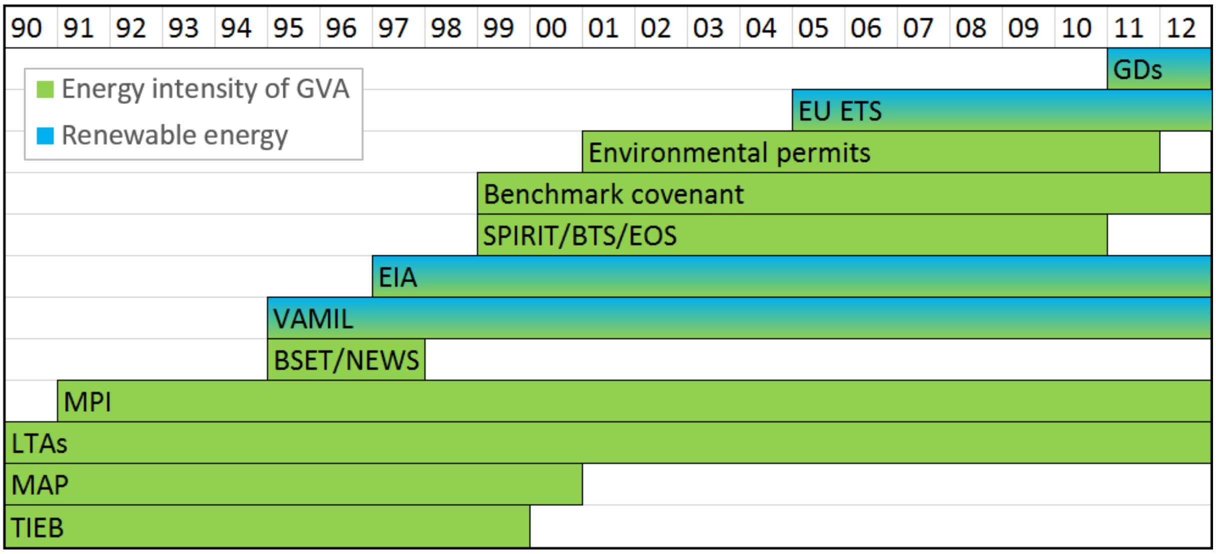

Figure 35 – Instruments targeted at the energy intensity of GVA and renewable energy in the industry sectors

Since all instruments in Figure 35 were to induce energy intensity effects, it is not difficult to see from the figure that the intensity of instruments increased until 2000 with the introduction of nine new instruments. After the turn of the century the number of instruments present remained more constant. The energy intensity effect was also largest and most constant in the latter three intervals (-958 kt yearly). Unexpected is the relative increase of emissions between 1994 and 1998 (+434 kt yearly), as one may have expected energy intensity improvement. The effect however seems to be dominated by the developments occurring at two specific sectors, but an explanation remains unclear here. Considering the differences between the individual industry sectors, it comes forward that better results were obtained at sectors with relatively high energy intensities and/or relatively large energy consumptions. Besides larger possible impact this can be explained by the fact that the instruments have also been more tailored for the intensive industries. The benchmark covenant and the EU ETS even specifically address companies with relatively high annual energy uses. Notice that the encouragement of CHP at the industry sector, especially until the nineties, also clearly came back indirectly as improving carbon factors of electricity and heat supply. In total the improved energy intensity of the industry contributed to the Kyoto target by decreasing the CO_2 level with -12.63 Mt by 2012.

Only four instruments have promoted the increased use of renewables in the industry between 1990 and 2012. In fact, the penetration of renewable energy into the industry sector was never specifically pronounced as a decarbonization strategy here. The four instruments above may be able to induce renewable energy effects, but rather in different sectors (as these instruments were typically cross-sectoral). The decomposition analysis has also shown that the renewable energy effect in the industry was negligible. There seems to be a relation between the relative increase of renewable energy in the 2002-2008 interval, with the introduction of the EU ETS. However, the non-specified industry was a non-ETS sector during the first Kyoto period (EC, 2016). Moreover, as the effect was reversed again in the following interval, the effective result was cancelled out again. In total between 1990 and 2012 the increased share of renewables caused emissions to reduce with only -0.11 Mt.

Instruments that may have affected the industry have not aimed to achieve activity, fuel substitution or carbon factor effects. In case of activity the country's ethos has always been one of continued economic growth. As the industries survive on profits they pursue to at least sustain their GVAs. According to the decomposition analysis their economic growth during Kyoto has however also had a large impact on emissions: +17.15 Mt, despite the recession. Considering the fuel substitution effect, energy and climate policies did not specifically mention that a switch to cleaner fossil fuels should be pursued. The EU ETS may have influenced fuel substitution, because the mechanism caps the industry's emissions which could indirectly trigger fuel substitution. In fact, for the first three intervals the fuel substitution effect has been positive (gas to heat) and became negative after the introduction of EU ETS. This was however not able to offset the earlier upwards effects; the fuel substitution effect over the whole Kyoto period was +1.98 Mt. Note that a part of this fuel substitution effect must be seen in combination with the energy intensity effect, because substitution of gas for CHP heat requires less energy consumption at the industry, which should give larger reductions than the fuel substitution effect. When the CHP products at the industry are sold to other users (public supply of electricity or heat), the developments here influence the carbon factors of electricity or heat, as was discussed in the former chapter. Its effect did also not remain unnoticed here: in total the decarbonisation of the electricity and heat supply caused the CO_2 emissions as a result of its use in the industry to decrease with -6.84 Mt between 1990 and 2012. -3.08 Mt can be assigned to energy efficiency improvements at the energy and heat supply (mostly CHP), -2.15 Mt to the increased production from renewables, which were the focus of the found instruments. -1.15 Mt is the result of a switch towards cleaner fuels at the plants, -0.56 Mt is due to the increased electricity import. The decreased production of electricity from nuclear energy and the worsening carbon factor of waste slightly increased emissions, with +0.20 and +0.25 Mt by 2012 as visible at the industry sector.

Other possible influences

According to the analysis above there seems to be a correlation between the energy and climate instruments and the demonstrated effects in CO_2 emissions, which was mainly the case for the energy intensity effect (the renewable energy effect is considered negligible). The energy intensity effect can however not completely be attributed to the deployed policies. This is specifically the case for the energy intensity, because the intensity in terms of energy consumption for each unit of economic output can also be influenced by other factors besides efforts aiming at more efficient energy use. It is than rather the economic output that changes in proportion to the energy consumption. To illustrate, this could for example happen if due to a certain exogenous factor a product becomes more in demand and the consumer prices can rise accordingly. For the company this means it will get higher GVAs, while producing the same amount of product (and using the same amount of energy for it). This is clearly not an efficiency effect, but it does affect the energy intensity factor. Moreover, energy conservation does not just influence the energy intensity by lowering the energy use for the production of a certain GVA, it also increases the GVA as energy conservation means less costs for fuel inputs (ergo higher profits). The energy intensity is clearly a very complex factor, but nevertheless its improvement over the years seems to be in correlation with the policy strategy. Finally, a part of the demonstrated effects may also have occurred without any policy intervention. Especially in the case of efficiency improvements companies can be expected to have invested in certain options either way, in case the reduction in production costs would have been feasible economically.

5.4 CONCLUSIONS INDUSTRY

The decomposition analysis showed that the effect of activity in terms of economic growth has been the most influential effect in the industry sector, especially before the global crisis. In total the constant search for higher GVA levels of the industry sectors led to a CO_2 increase of +17.15 Mt by 2012. The effects of energy intensity were also large, but in the other direction, in total decreasing emissions with -12.63 Mt. With that the energy effect of economic growth was not completely offset; the total energy consumption still increased (net CO_2 effect of +4.52 Mt by 2012). This was basically what the instruments focusing on improving the energy intensity factor (which was the main policy strategy for decarbonisation of the industry) aimed to achieve: to constrain the industry's energy consumption while sustaining economic growth. The calculated energy intensity effects are largely correlating with the intensity of deployed policy instruments, as its reducing effect became more influential with the introduction of more instruments. The improving energy intensity factor is however not solely the result of energy and climate policies. Different exogenous factors can influence the energy intensity; certain events taking place in society could for example increase the amount of GVA for a certain product. This would also reduce the energy consumption for each unit of GVA. Autonomous improvement is also expected to have been a substantial part of the energy intensity effect, since energy savings typically also save money, so a part of the efficiency measurements would have been carried out anyway. Some policy instruments also promoted the increased use of renewable energy, but these instruments were cross-sectoral and did not specifically target the increased use of renewables at the industry sectors. The total renewable energy effect at the industry was in fact almost very small (-0.11 Mt between 1990 and 2012). The effects due to fuel substitution were upwards at first with the substitution of gas by heat, but in the last two intervals the relative increase of oil at the expense of heat caused CO_2 emissions to reduce. The introduction of EU ETS may have influenced the later developments, as fuel substitution can be a strategy to be able to conform to the emissions cap. The latter fuel substitution developments were however not able to compensate for the earlier effects, as the total fuel substitution effect by 2012 was still +1.98 Mt. The demonstrated carbon factor effect is a result of the developments at the electricity and heat supply, of which the effects become visible at the industry as a relative decrease of (indirect) CO_2 emissions with a total of -6.84 Mt. Considerable differences in impacts were demonstrated between the twelve industry sectors, as these all have distinctively different industrial processes. Some are therefore more or less energy intensive, suitable for renewables, able to switch between fuels or use substantial amounts of electricity and heat to be able to induce carbon factor effects. Without going too much into these differences, the analysis showed that the largest energy users were responsible for the largest part of the effects (except at the renewable energy effect). These top sectors were the chemical & petrochemical sector (2), basic metals (1) and tobacco & food (7). An additional explanation to this is that energy and climate instruments aimed at the industry have also specifically targeted the most polluting industries.

6. SERVICES

6.1 TREND OF CO_2 EMISSIONS BETWEEN 1990 AND 2012 (SERVICES)

The services sector has been responsible for 20.7 up to 30.1 Mt energy-related CO_2 emissions during the first Kyoto period (Figure 36). More than half of these emissions (56.0% in 2012) took place indirectly due to the use of electricity and heat. Over 2008-2012 the average yearly emissions of the sector reached 33.6% above base year level (+7.0 Mt). In case of a frozen scenario – where the carbon intensity of the total service sector is kept constant – these emissions would have been much higher, up to 64.0% (+13.3 Mt) above base year level, as shown in Figure 37. Historically the carbon intensity of the GVA of services was however able to decrease allowing emissions to increase with a lower rate than the sector's activity level (second axis in Figure 37). Between 1990 and 2012 the carbon intensity of its GVA eventually decreased from 94 to 73 tCO_2/mln Euro GVA. The following decomposition analysis shows how different drivers affected the changes in emissions from services.

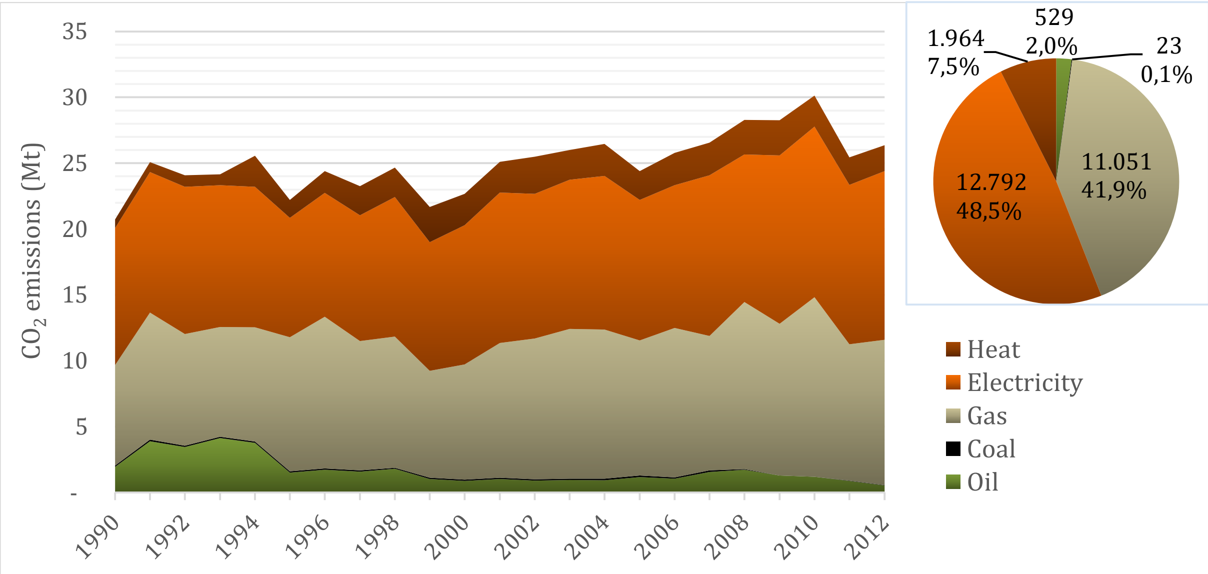

Figure 36 – Carbon dioxide emissions of the service sector from five different fuel types between 1990 and 2012, including pie chart with 2012 amounts (in kt) and shares (IEA, 2014; IPCC, 2006)

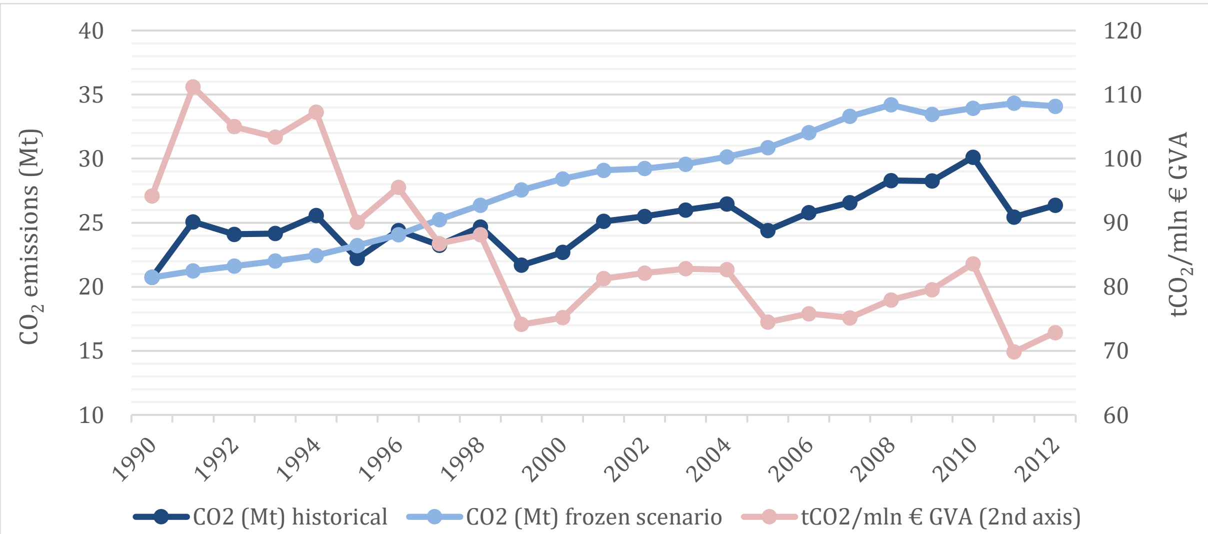

Figure 37 – Carbon dioxide emissions from services (historical and for a frozen scenario) and on the second axis the historical carbon intensity of GVA 2005 constant prices (IEA, 2014; CBS, 2016c)

6.2 DECOMPOSITION ANALYSIS SERVICES

Using Formula F9 the carbon dioxide emissions of the service sector were decomposed for the intervals between 1990 and 2012. The results are given in Figure 38, showing the effects due to: activity in terms of the GVA, energy intensity of GVA, renewable energy penetration, substitution of fuels and changing carbon factors of fuels. In the following paragraphs each effect and its underlying trend is discussed.

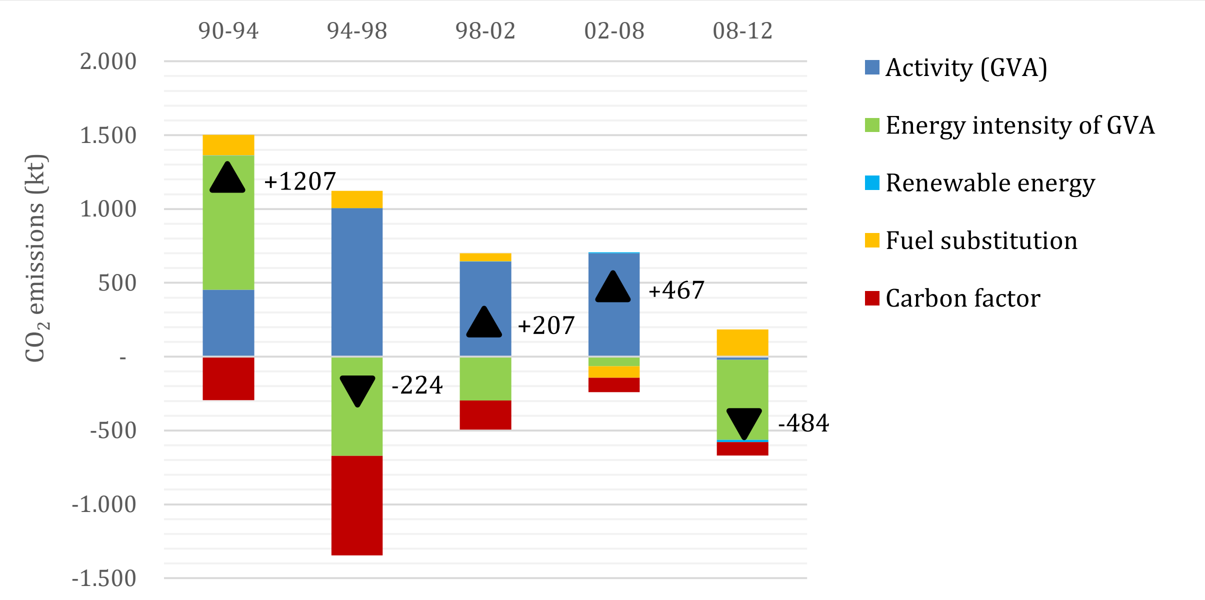

Figure 38 – Results of the decomposition of services, showing five yearly effects in the intervals between 1990 and 2012

ACTIVITY

The activity effect indicated by the economic activity has been the most influential effect on CO_2 emission at the service sector. Until the global crisis the activity effect was on average +701 kt yearly. Decreased activity levels in the final interval – the recession – actually had a slight reducing effect of -22 kt yearly. This development is clearly presented in Figure 39: until 2008 the GVA of services increased from 220.1 to a maximum value of 353.0 billion Euros, but by 2012 this value decreased again slightly to 361.9 billion Euros, still 64.4% above base year level.

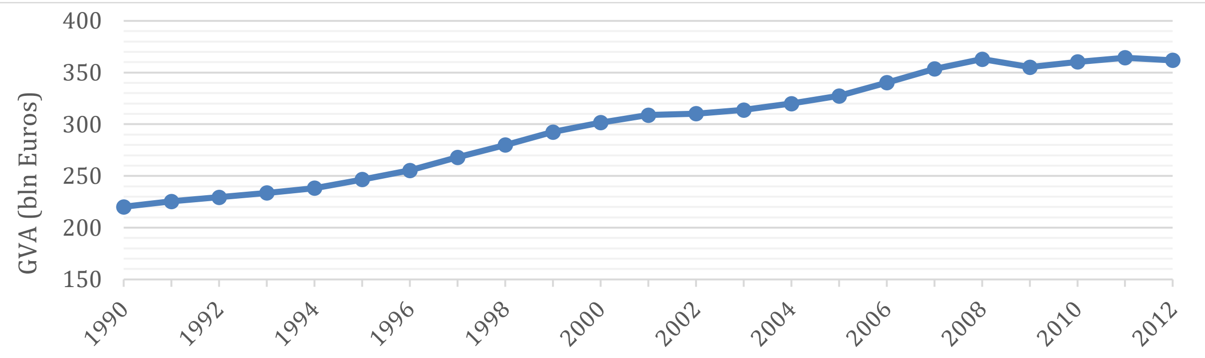

Figure 39 – Economic activity of the service sector in gross value added (billion Euros in constant 2005 prices) between 1990 and 2012 (CBS, 2016c)

ENERGY INTENSITY

The trend in energy intensity of the GVA for services was less straight forward (Figure 40): overall downwards, inducing a relatively large reduction effect. During the first interval the energy intensity actually went up, from 1.10 to 1.25 MJ/€ GVA, giving an increase in emissions of +906 kt yearly. After

1994 a decreasing trend set in, on average reducing emissions with -394 kt yearly until 2012. By then the energy intensity had decreased again to a value of 1.00 MJ/€ GVA, -8.7% below its base year level.

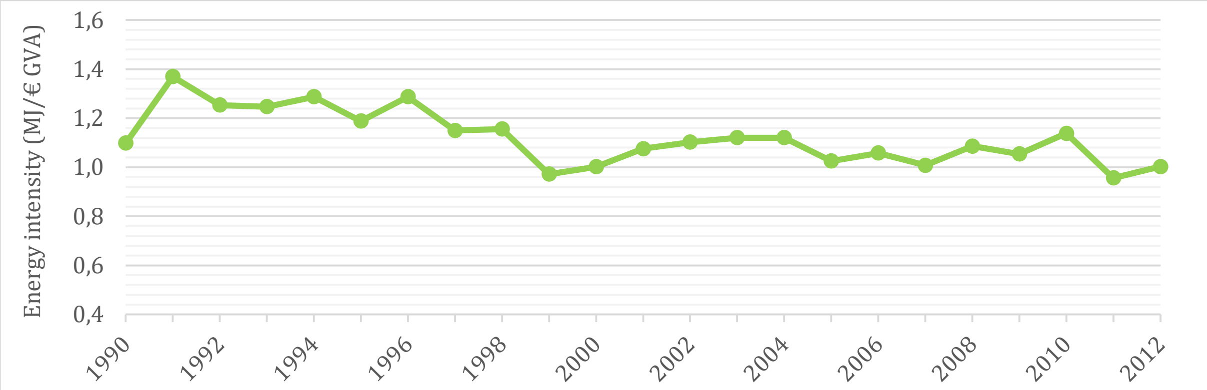

Figure 40 – The energy intensity of the service sector in MJ final consumption per Euro gross value added (in constant 2005 prices) between 1990 and 2012 (CBS, 2016c; IEA, 2014)

The effect from energy intensity improvements has partly (mostly after 1994) been able to offset the effect due to activity growth. This means that the total energy consumption at services did not grow accordingly with its GVA growth. The effect from energy consumption growth alone is therefore the sum of both effects (by taking out GVA from Formula F9 and merge the activity (A) and the energy intensity (EI) factor). This combined effect was on average +442 kt yearly, as the total energy consumption of services showed a much more stable increase. Its growth was particularly large in the first interval, but slightly negative in the last interval after the crisis.

RENEWABLE ENERGY

Renewable energy use at services mostly occurs in the form of biomass use; a smaller part of the renewables (6.2% of the renewables in 2012) is due to the use of the category solar/wind. For final energy this only comprises solar energy, wind electricity is part of decentral electricity production. The total share of renewable energy (in total energy consumption) has been very small, staying below 0.7% (Figure 41). In absolute amounts the renewable energy consumption has increased (from 1.6 to 2.4 PJ between 1990 and 2012), but this was not able to outweigh the increase in fossil energy consumption. The resulting renewable energy effect in terms of CO_2 emissions has been accordingly negligible. Until 2008 its decreasing share in total consumption even increased emissions annually with +3 kt on average. In the last interval the increased share gave a yearly effect of -14 kt, with that cancelling out the earlier results achieved (Figure 42). Table 6 also shows how most of the effect occurred at biomass use.

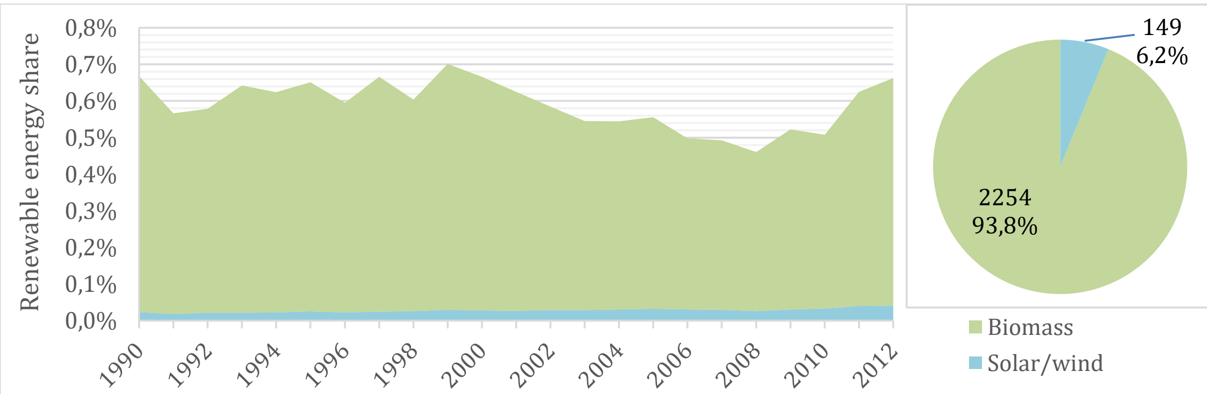

Figure 41 – The share of renewable energy sources in total energy consumption of the service sector between 1990 and 2012, including pie chart with 2012 amounts (in TJ) and shares within the category of other energy sources (IEA, 2014)

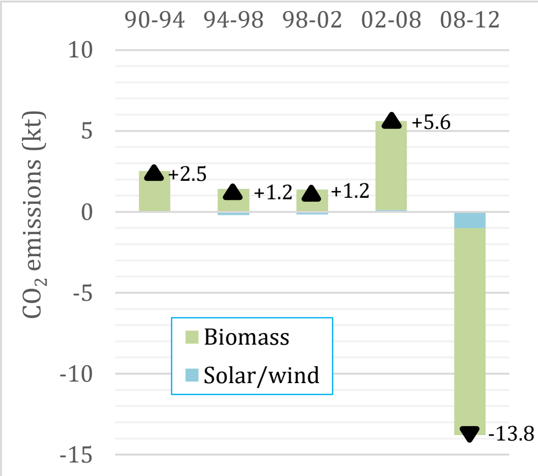

Table 6 – The individual effects (yearly) of the two renewable energy sources together causing the renewable energy effect at services

Renewable energy source	90-94	94-98	98-02	02-08	08-12
Solar/wind	+0.0	-0.2	-0.2	+0.1	-1.0
Biomass	+2.5	+1.4	+1.4	+5.5	-12.8
Renewables	**+2.5**	**+1.2**	**+1.2**	**+5.6**	**-13.8**

← *Figure 42 – The renewable energy effect (yearly) of the service sector decomposed for solar/wind and biomass, values in Table 6*

FUEL SUBSTITUTION

At services the shift in fuels has mostly been in the direction towards energy sources with relatively higher carbon factors, giving a small average yearly effect of fuel substitution of +69 kt. Only between 2002 and 2008 the effect induced emission reductions (-78 kt yearly), when heat was substituted by oil. Figure 43 shows that the substitution took place less distinguished, but the overall trend was the substitution of oil by electricity and heat. The relative increase of heat can be explained by the CHP joint venture developments with the energy distribution companies. The relatively large increase of electricity (especially between 1994 and 1998) is the result of the IT developments (Jeeninga et al., 2002). As electricity serves a different purpose than the other fuel types, this development is therefore rather a shift in functions as opposed to a shift in substitution.

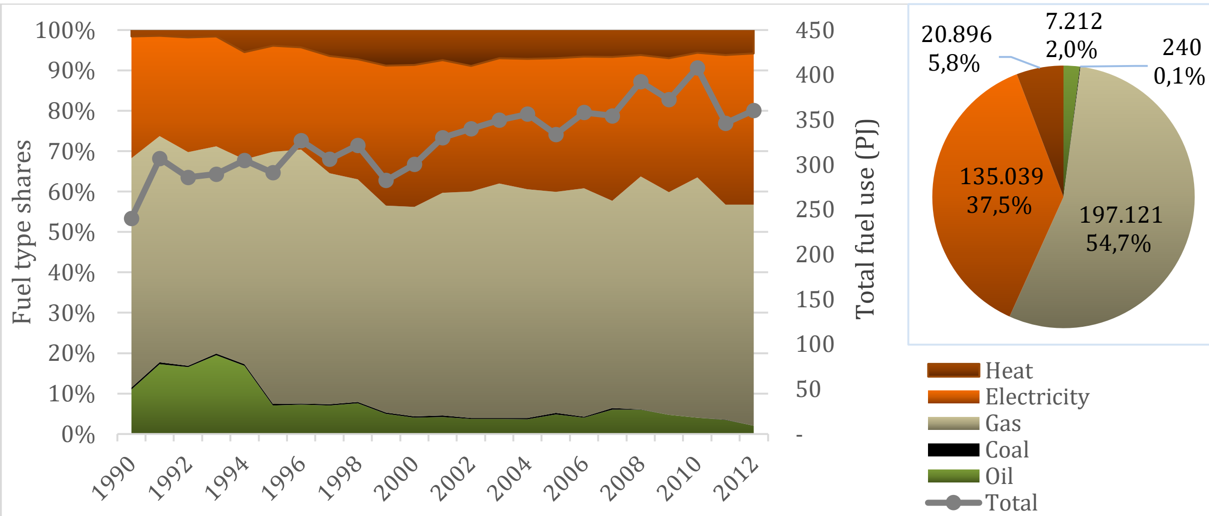

Figure 43 – Shares of five fuel types sources in total fuel use of the service sector (second axis), including pie chart with 2012 amounts (TJ) and shares within total fuel use (IEA, 2014)

CARBON FACTOR

The effects due to the improving carbon factors of electricity and heat have led to an average reduction of -255 kt yearly as came forward at the service sector (Figure 44), comparable in size with the energy intensity effect. About 80% of the carbon factor effect originates from the use of electricity, as its use was also much higher at the service sector than the heat use. During the second interval (between 1994 and 1998) the largest carbon factor effect can be observed, due to the relatively large improvements of the carbon factors (see also Figure 20). About half of the effects were the results of (CHP) efficiency improvements, about a quarter from the renewable energy effect occurring at the electricity & heat supply and another quarter from the fuel substitutions between plant inputs.

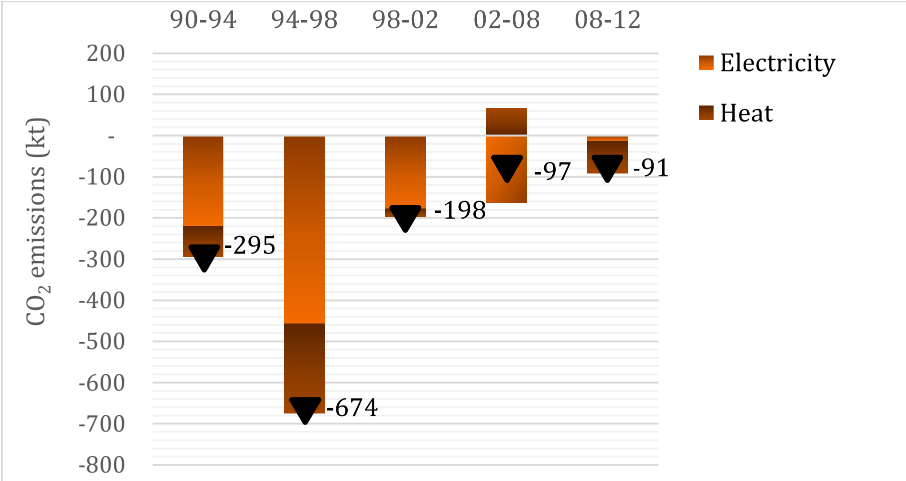

Figure 44 – The carbon factor effect at the service sector from electricity and heat (yearly)

6.3 Link with energy and climate policies at services

The keyword of the policy measures taken at the service sector is: energy conservation. As the energy use of the service sector is mostly building related, the measures focused on the reduction of energy for space heating and electric appliances. Efforts in energy conservation can induce energy intensity effects, because the aim is to reduce the energy use while keeping the same level of activity. Some deployed instruments were also able to induce renewable energy effects, but this was not expressed as one of the goals to be achieved at services. The most important instruments with the aim to influence energy-related carbon dioxide emissions from services are given in Figure 45; Appendix D gives a clarification of these instruments. The strategy involved a package of regulatory, economic and informing instruments, backed up by the Energy tax. LTAs were established on energy efficiency efforts, as agreed on by different branches of the service sector. The EPN is an important regulatory instrument concerning buildings standards, that needed to be tightened with the 2003 EU Directive (EPBD). MAP and EPA were mostly informative, offering advice on the energy performance of existing buildings. Lastly economic instruments would support the actual investment in energy saving options: BSET/NEWS, VAMIL, EIA and EINP.

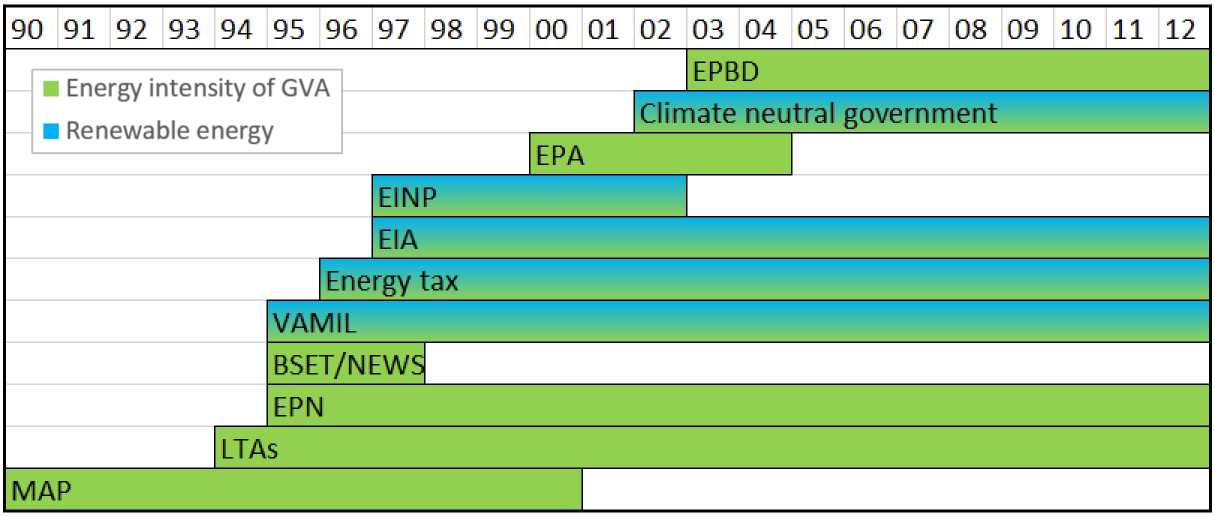

Figure 45 – Instruments targeted at the energy intensity of GVA and renewable energy in the service sector

The intensity of instruments that were to induce energy intensity effects increased a lot after 1994 and stayed almost constant after 2002. The demonstrated energy intensity effects at services were also largest between 1994 and 1998 (-672 kt yearly) and about half that size between 1998 and 2002 (-296 kt yearly) when less new instruments were introduced, but the intensity stayed high. Unexpected is the large energy intensity effect in the final interval (-542 kt yearly), because no new conservation instruments had been introduced there. In the first interval, when only the MAP was deployed, the energy intensity had worsened with such an extent that it increased emissions with +906 kt yearly. In total the energy intensity effects reduced emissions with -2.81 Mt between 1990 and 2012.

Five of the deployed instruments were able to promote the renewable energy use, but the renewable effect that came forward in the decomposition analysis was very small. In the last interval the largest effect was present (-14 kt yearly), but this only cancelled out all the earlier effects from the relatively large increase of fossil fuel use, coming down to a total reduction in CO_2 emissions of -0.002 Mt between 1990 and 2012. The first four deployed instruments that (financially) promoted the renewable energy use, have been more effective at other sectors (like electricity and heat supply), as they were cross-sectoral and rather influenced decentral public electricity production. As for the intentions of governmental buildings and operations to become climate neutral, the renewable energy component meant the purchase of renewable electricity. Both developments may thus have influenced the Dutch electricity mix and indirectly improved the carbon factor of electricity, but it does not induce a renewable energy effect at services itself. The policy documents accordingly did not express an explicit strategy for the penetration of renewable energy at final use of the service sector.

Energy and climate policies focusing on services did not express intentions to achieve activity, fuel substitution or carbon factor effects. For activity the mainstream policy is to increase the economic growth, which caused a large increasing effect on emissions: +12.53 Mt by the end of Kyoto despite the weakening effect due to the economic crisis. According to a report by the CBS (2014) the digitalization of the economy has been responsible for an important part of the economic growth, which could also be linked to the economic activity of services. If the increase of the service sector with the widespread digitalization was at the expense of the more energy-intensive sectors, this may have induced an economic structure effect, which is analysed in Chapter 8. A fuel substitution effect could be an indirect result of the instruments that focused on energy conservation. This has to do with the fact that the instruments have mostly focused on saving energy for space heating, which may favour the savings of a certain fossil fuel type (gas or heat). More efficient electric appliances on the other hand specifically targeted electricity savings. None of these dynamics were however reflected in the fuel substitution effect. If any trend was to be distinguished, it would be the substitution of oil by electricity and heat. This caused a total effect of +1.51 Mt over the whole research period, possibly indirectly influenced by the widespread digitalization and the encouragement of joint venture CHP. Note that also at the service sector, if the CHP heat substitutes own heating by fossils, the total effect combined with its energy intensity improvement must combined still mean emission reductions. The effects due to the (indirect effect of) improving carbon factors of electricity and heat had the best reducing effect (twice as large as the total energy intensity achievements) on emissions from services: -5.63 Mt in total, due to relatively large consumption levels of electricity and heat. Instruments that had focused on improving these carbon factors were targeted at the energy efficiency (mostly CHP) and the renewable energy penetration on the level of the supply, which can be quantified as effects of -2.98 Mt and -1.31 Mt respectively, when passed on as resulting effects in the service sector. Another -1.19 Mt can be assigned to fuel substitution at the electricity and heat supply and -0.43 Mt to the increased electricity import. +0.15 Mt was due to the worsening carbon factor of waste as fuel input and +0.14 Mt is the effect from the reduced use of nuclear power from electricity by 2012.

OTHER POSSIBLE INFLUENCES

The focus of energy and climate policies was to induce energy intensity effects. The energy intensity effects did increasingly reduce emissions with the introduction of more instruments, but the demonstrated energy intensity effect in the final interval is striking because no new instruments were introduced here. The explanation to this may probably be found in the global crisis, which forced the sector to be more efficient with their energy use. Another explanation could be the relative decrease in operations (i.e. less energy consumption), while the accordingly reductions in GVA lag behind. The use of floor space as an indicator may provide better clarifications behind the trend, as the GVA (and therefore also the energy intensity of GVA) can still be influenced by different hidden factors. Another explanation may be the found in the reliability of the statistical data, as the residual energy use is usually assigned to the service sector, possibly explaining the unexpected results. Lastly the energy intensity effects could also not completely be assigned to the discussed policy efforts, as a part of the energy improvements would also have occurred without policy intervention, depending rather on the cost-effectiveness of the options.

6.4 CONCLUSIONS SERVICES

According to the decomposition analysis the effect of activity growth in the service sector caused a large increasing effect, of +12.53 Mt in total by 2012. A part of the GVA growth is linked to the digitalization of the economy. The energy intensity effect on the other hand partly counteracted the activity effect, with -2.81 Mt in total. In total the net CO_2 effect due to increased energy consumption levels was therefore +9.73 Mt. This can be considered the goal of the deployed instruments focusing on energy intensity effects: to keep the effects from increased activity down. An energy conservation strategy has been the main strategy at the service sector. The deployed instruments that would accordingly induce energy intensity effects, have shown a clear correlation with the observed effects over the intervals. The only striking result showed itself after 2008, when the energy intensity went down while no new instruments were introduced. An explanation is expected to be found in the global crisis, which may have had its influence on the rather complex ratio of energy consumption to GVA. Also the autonomous improvements are responsible for a part of the observed energy intensity effects. Nevertheless, the correlation between the main strategy at services focusing on improving the energy intensity and the shown effects before the economic crisis was clearly indicated. Some of the instruments were also able to induce renewable energy effects, but these were not suitable for the service sector. This is also reflected in the total renewable energy effect, which was only -0.002 Mt by 2012. The carbon factor effect on the other hand was even more effective than the energy intensity effect, reducing emissions with -5.63 Mt by 2012 as mostly the result of the efficiency development (from CHP), renewables and coal to gas fuel substitution. Fuel substitution at services themselves resulted in a total increase of +1.51 Mt due to the substitution of oil by electricity and heat, indirectly influenced by the IT developments and possibly joint venture CHP.

7. AGRICULTURE

7.1 TREND OF CO_2 EMISSIONS BETWEEN 1990 AND 2012 (AGRICULTURE)

Energy-related CO_2 emissions from the agricultural sector (excluding fishery) had first shown an increase, from 9.0 in the base year level to the maximum emissions of 11.5 Mt in 1996; afterwards the emissions decreased again almost back to base year level (Figure 46). To be exact, over 2008-2012 the average emissions that were the responsibility of the agricultural energy use, were only 0.7% higher. Most of the energy is used for heating, specifically important at horticulture which is responsible for 80% of the CO_2 emissions (NC4, 2005). Electricity is rather used at other sectors for machines (like milk cooling), oil is for the use of mobile machinery such as tractors (CLO, 2015). If no developments would have occurred at the sector (a frozen scenario), emissions would have reached 12.4 Mt on average over 2008-2012, 3.4 Mt higher and 37.9% above base year level instead (Figure 47). The carbon intensity of the agricultural (economic) activity has thus historically been able to decrease, from 1313 to 945 tCO_2/mln € GVA between 1990 and 2012 (second axis in Figure 47). The decomposition analysis that follows, gives insight into the different drivers that have influenced these historical CO_2 emissions.

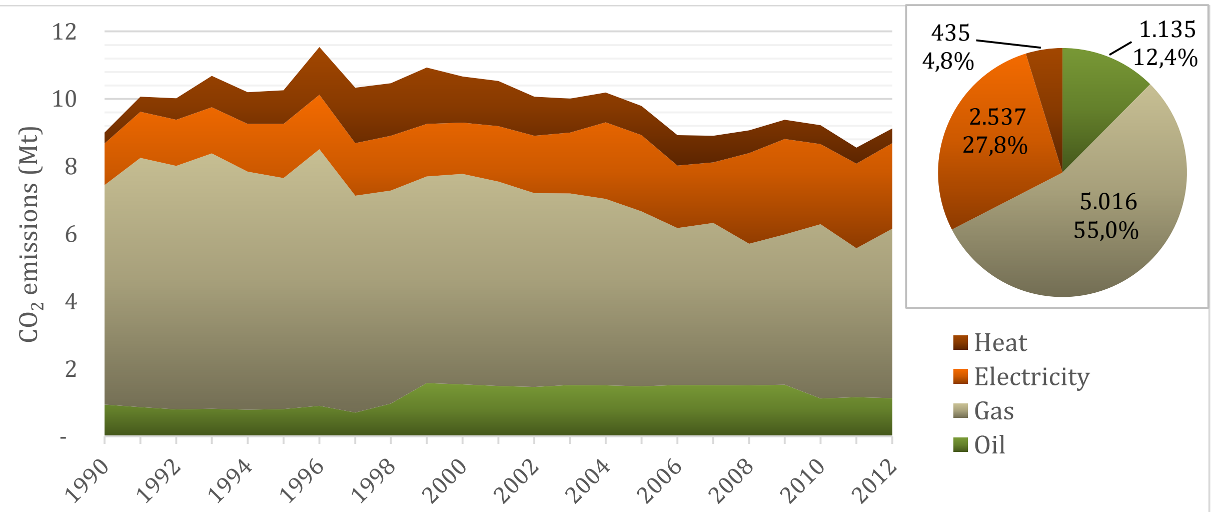

Figure 46 – Carbon dioxide emissions of the agricultural sector from four different fuel types between 1990 and 2012, including pie chart with 2012 amounts (in kt) and shares (IEA, 2014; IPCC, 2006)

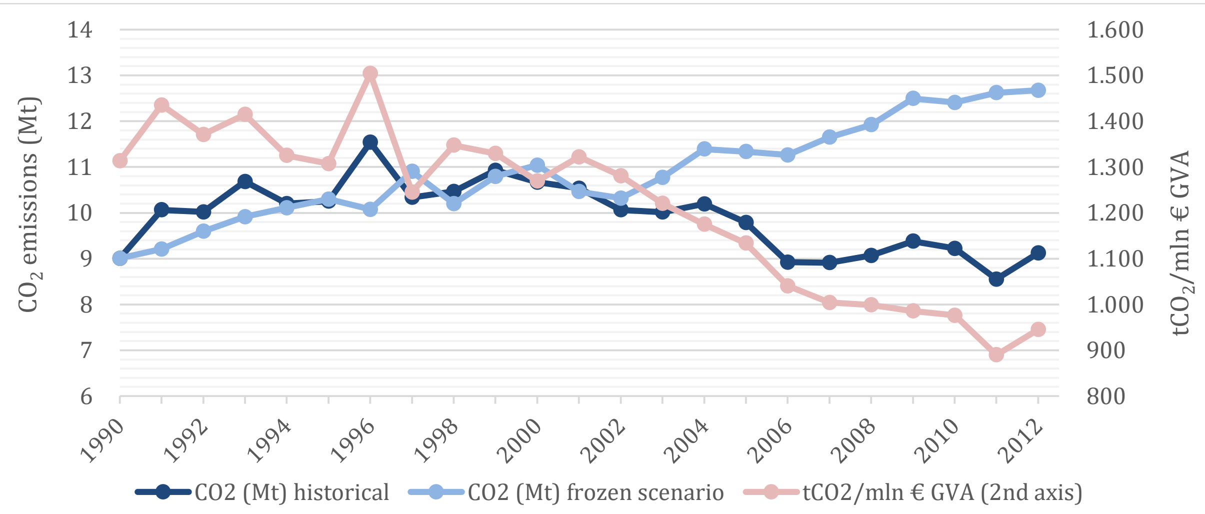

Figure 47 – Carbon dioxide emissions from the agricultural sector (historical and for a frozen scenario) and on the second axis the historical carbon intensity of GVA in 2005 constant prices (IEA, 2014; CBS, 2016c)

7.2 Decomposition analysis agriculture

By means of Formula F9 the energy-related CO_2 emissions of the agricultural sector were decomposed into the five effects of: activity (in economic output GVA), energy intensity of GVA, renewable energy share, fossil fuel substitution and the changing carbon factor of the fuels. The results are given in Figure 48. The sections that follow subsequently discuss these effects and their underlying trends.

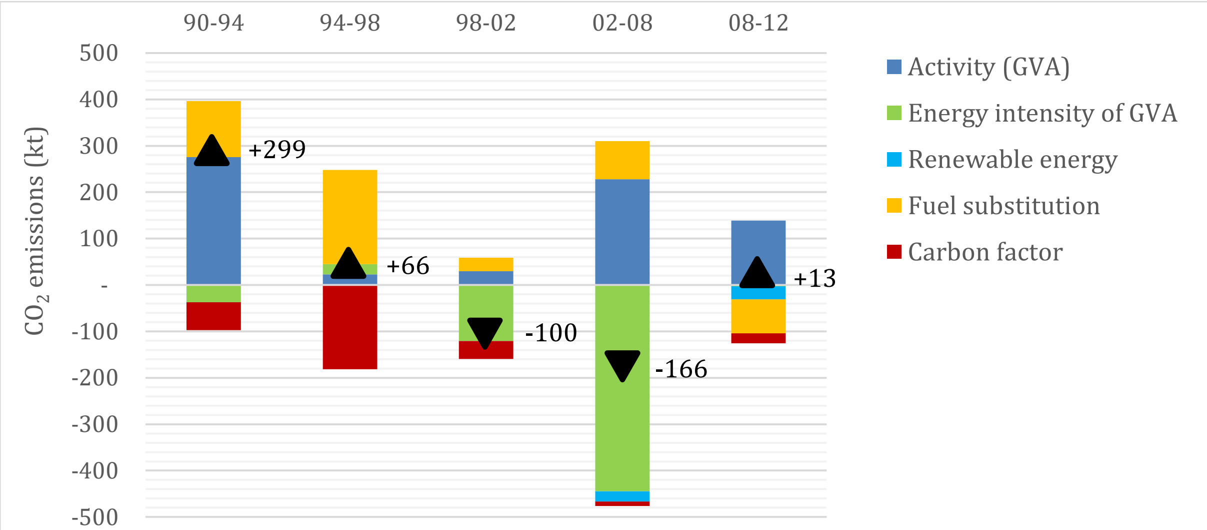

Figure 48 – Results of the decomposition of agriculture, showing five yearly effects in the intervals between 1990 and 2012

Activity

The activity, in terms of economic output (GVA), has been the largest factor to influence the CO_2 emissions from energy use in agriculture. During the researched period the GVA has increased from 6.9 to 9.7 billion Euros (Figure 49), an increase of 40.7%. The relatively small effects demonstrated between 1994 and 2002 are mostly the result of short-term fluctuations, the overall trend is clearly rather constantly upwards. On average this increase caused emissions to rise with an effect of +147 kt yearly.

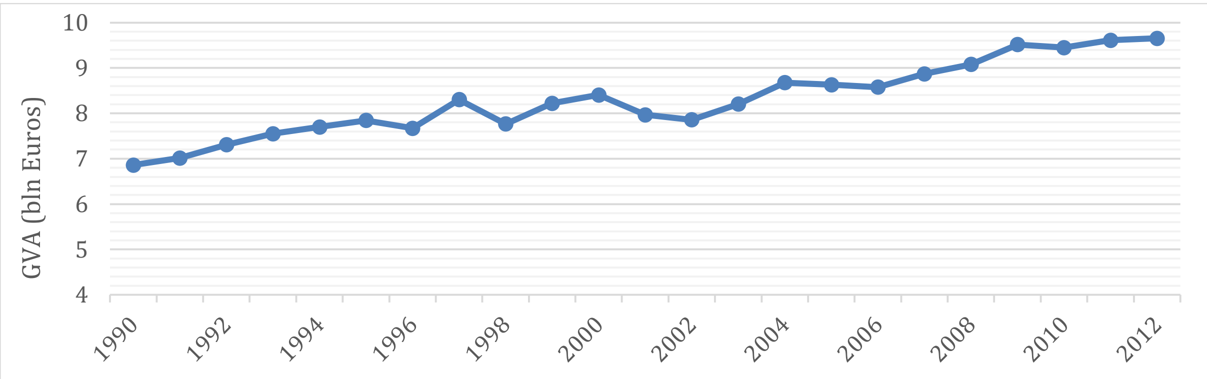

Figure 49 – Economic activity of agriculture in GVA (billion Euros in constant 2005 prices) between 1990 and 2012 (CBS, 2016c)

Energy intensity

The energy intensity also seems to show a constant trend, but in the downward direction instead (Figure 50). The resulting effects have however fluctuated: between 1994 and 1998 a small upwards trend was distinguished (+22 kt yearly) and between 2002 and 2008 on the other hand the energy intensity improved so much that it induced a very large reducing effect of -444 kt yearly. On average the energy intensity effect has caused emissions to decrease with -146 kt yearly, as its value decreased from 20.3 to 14.5 MJ/€ GVA, with fluctuations especially influential in the beginning and at the end.

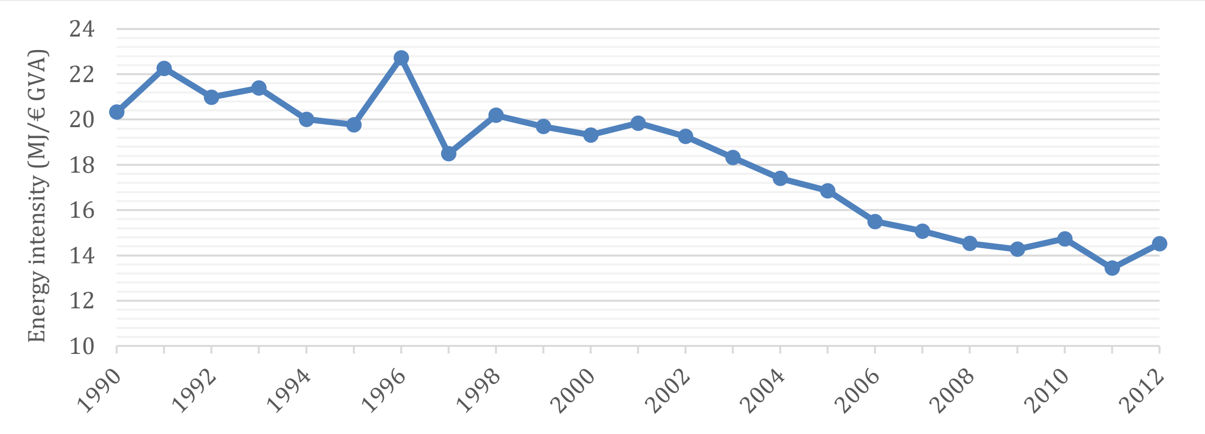

Figure 50 – The energy intensity of the agricultural sector in MJ final consumption per Euro gross value added (in constant 2005 prices) between 1990 and 2012 (CBS, 2016c; IEA, 2014)

In most intervals the energy intensity effect was not able to offset the increase in emissions as caused by the activity effect. However, the extremely large observed effect between 2002 and 2008 almost completely made up for the other intervals, as the total average energy intensity effect was on average almost as large as the average yearly activity effect. Their combined effect sums up to only +1 kt yearly, which basically means that the energy use itself (by taking out the GVA from the Formula F9) increased only a little, causing a very small overall CO_2 effect. In other words, the energy intensity has improved so much over the years, that despite the 40.7% increase of GVA, the energy use was almost brought back to the base year level by 2012.

RENEWABLE ENERGY

Until 2004 the use of renewable energy in the agricultural sector was negligible. Its effect on CO_2 emissions was accordingly negligible, as the share in total consumption stayed around 0.04% (47 to 64 TJ biomass use only). After 2004 however, the use of renewables at agriculture rocketed, up to a total of 3710 TJ: 2.7% in the total mix (Figure 51). The growth mostly comes from biomass use, but 13.3% of the renewables in 2012 was made up by geothermal energy. In the last two intervals the renewable energy effect amounted to -25 kt yearly on average, despite its increase still the least influential driving effect on emissions from agriculture. Figure 52 and Table 7 show that the largest part of the effect can be assigned to biomass, but especially in the last interval about a quarter of the effect is the result of geothermal increase.

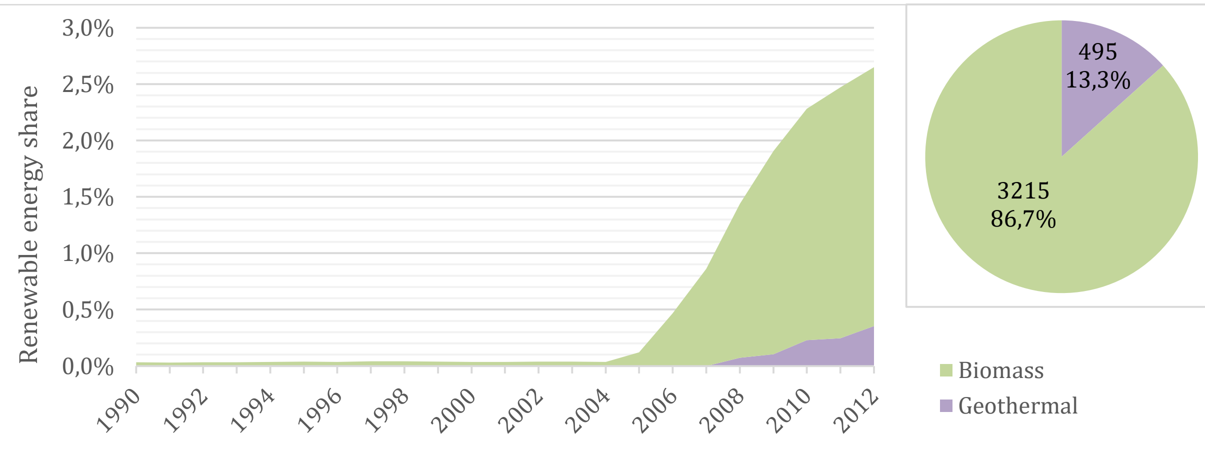

Figure 51 – The share of renewable energy sources in total energy consumption of the agricultural sector between 1990 and 2012, including pie chart with 2012 amounts (in TJ) and shares within the category of renewable energy sources (IEA, 2014)

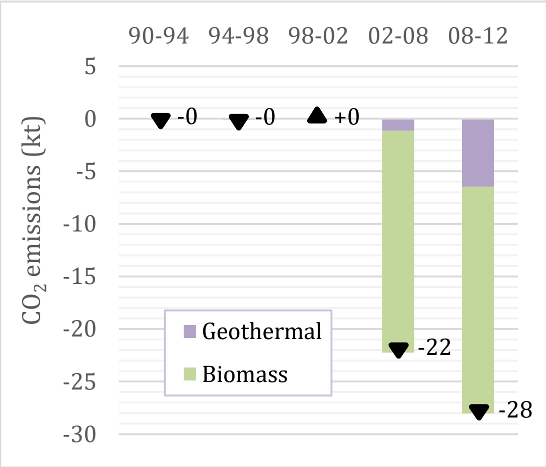

Table 7 – The individual effects (yearly) of the renewable energy sources together causing the renewable energy effect at agriculture

Renewable energy source	90-94	94-98	98-02	02-08	08-12
Geothermal	0.0	0.0	0.0	-1.2	-6.5
Biomass	-0.0	-0.1	+0.1	-21.1	-21.5
Renewables	**-0.0**	**-0.1**	**+0.1**	**-22.3**	**-28.0**

← Figure 52 – The renewable energy effect (yearly) at agriculture, decomposed for geothermal and biomass, values in Table 7

FUEL SUBSTITUTION

Fuel substitution at agriculture has mostly caused an increasing effect on emissions. Until 2008 its effect was on average +106 kt yearly. The main trend behind this increase was an increased share of electricity use and a decreased use of gas, as is shown in Figure 53. Between 1998 and 2008 the relative increase of oil contributed substantially to the increase of emissions. Until 1998 the relative increase of heat also played an important role in the increase of emissions, as the result of increased use of CHP heat, to substitute the heating from gas. As discussed before, this type of substitution effect is distorted because of the relatively high carbon factor of heat and the fact that the use of CHP heat instead of own heat production also induces energy intensity improvement, which should weigh out the upwards substitution effect. This complex process will be further discussed in the discussion section. After 1998 the use of heat decreased again, when there was a shift to own exploitation of CHP, instead of in the form of joint ventures (CLO, 2015). In the last interval there was a shift back to gas, at the expense of all other fuels, causing a decreasing effect in emissions of -73 kt yearly.

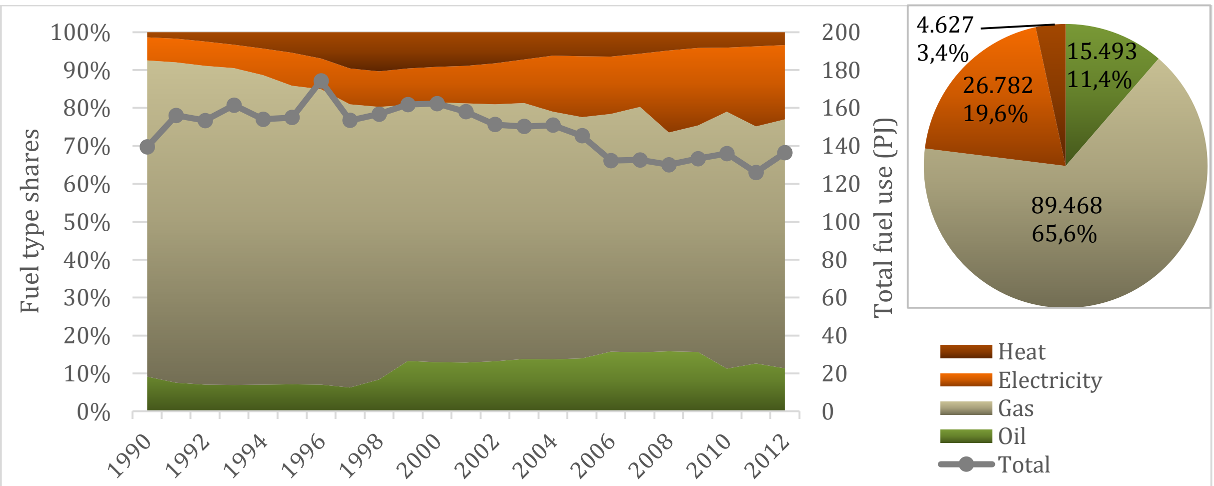

Figure 53 – Shares of four fuel type sources in total fuel use of the agricultural sector (second axis), including pie chart with 2012 amounts (TJ) and shares within total fuel use (IEA, 2014)

CARBON FACTOR

The improving carbon factors of electricity and heat have caused substantial CO_2 reductions indirectly from their use at the agricultural sector. Even though the emission factor of heat went up slightly between 2002 and 2008, the total effect was still negative (Figure 54). On average the carbon factor effect due to the use of electricity and heat at this use sector was -56 kt yearly. The large carbon effect between 1994 and 1998 is mostly the result of the increased CHP at public electricity and heat supply. In total more than half of the total carbon factor effect here can be assigned to the improved energy efficiency, about a quarter to fuel substitution of plant inputs and the remaining part to the increased use of renewables at electricity and heat production. Considering the two fuel types, more than half of the effect (54.0%) emanates from electricity use.

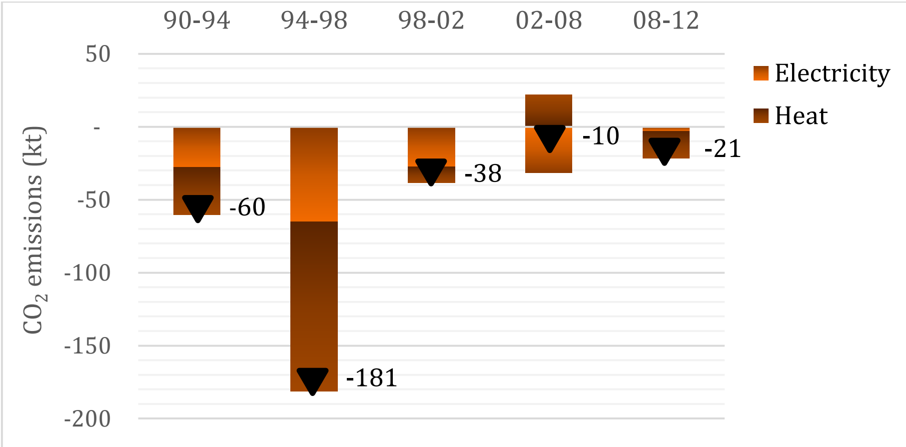

Figure 54 – The carbon factor effect at the agricultural sector from electricity and heat (yearly)

7.3 Link with energy and climate policies at agriculture

The main measure to reduce energy-related CO_2 emissions at agriculture has been energy savings in horticulture, as this branch is responsible for about 80% of the sector's emissions. For forestry the main strategy was afforestation, but this measure does not induce energy-related CO_2 effects. Energy savings in agriculture are reflected in the energy intensity effects. Only in the last five years of the studied period the use of renewable energy was added as a measure to decarbonize the agricultural sector. Figure 55 shows the most important deployed energy and climate instruments as deployed between 1990 and 2012; a short clarification of these instruments can be found in Appendix D. The core of the strategy at this sector was once more the establishments of voluntary agreements (LTAs, GLAMI and the AgriCovenant), focusing on efficiency improvement targets. Financial instruments would foster the efficiency improvements, like the special gas price for CHP, BSET/NEWS and EIA. The MAP was informative, offering companies energy screenings by the energy sector. The Geo guarantee offered financial support for the investment in geothermal energy. Lastly two regulatory instruments were in place which restricted the energy use (Orders in Council) and CO_2 emissions itself (national ETS system).

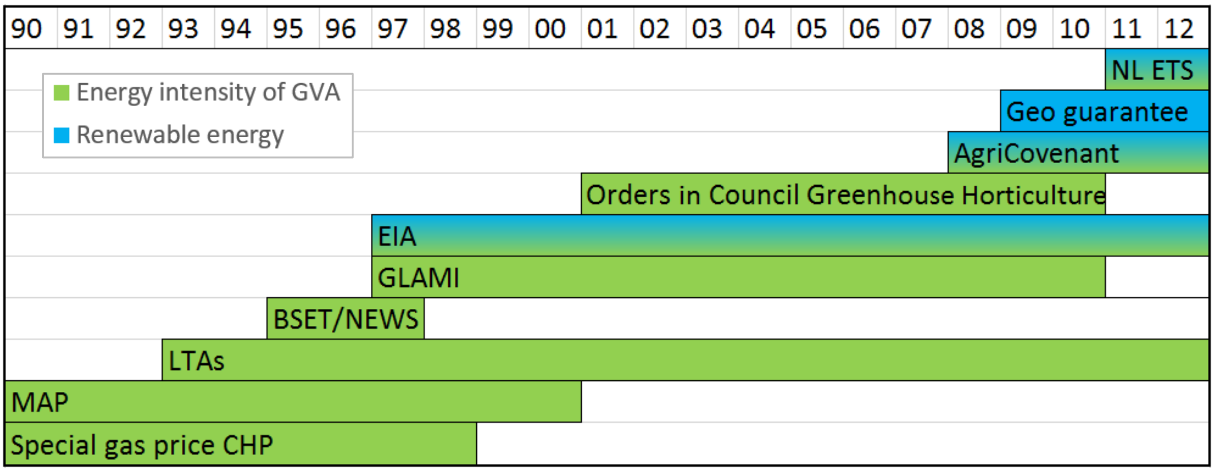

Figure 55 – Instruments targeted at the energy intensity of GVA and renewable energy in the agricultural sector

Almost all instruments aimed to improve the energy intensity of the agricultural sector. The focus of these instruments was to encourage the use of CHP heat to reduce the primary inputs for the same energy demand. The primary inputs would now occur at a CHP plant and therefore cause energy intensity effects at the sector. Note that the encouragement of certain CHP collaborations also had large effects on the overall carbon factors of publicly available electricity and heat supply. More incremental efficiency improvements at agriculture were aimed to be achieved by the (fiscal) encouragement of energy saving techniques that would increase the amount of product (i.e. GVA) for the same energy consumption. The focus was on isolation and machines (like condensers); savings for mobile machinery does not come forward in the policy documents. Especially before 2000 new instruments that were able to improve the energy consumption for each unit of GVA were introduced regularly. Unexpectedly however, the largest energy intensity effect was present when the intensity of instruments was lowest: between 2002 and 2008 with -444 kt yearly. In the second interval the energy intensity effect was also influential (-121 kt yearly), but in all other intervals its effect was insignificant. As discussed in the former section, the energy intensity did overall improve, but due to its fluctuating start (and end) it did not always induce CO_2 effects accordingly (thus representing short-term fluctuations). This may indicate that the earlier launched policies needed time to be able to systematically achieve results. Another explanation might be that the GLAMI covenant and the related Orders in Council standards were able to give the final push for energy intensity improvement. In total the energy intensity effect was still the largest factor to reduce emissions between 1990 and 2012, with -3.22 Mt.

The use of renewable energy was already encouraged by the EIA since 1997, but only since 2008 the intention to increase the share of renewables in the agricultural sector became an explicit strategy. Accordingly instruments to promote the use of renewables were specifically high in the final research interval. The demonstrated renewable energy effect according to the decomposition analysis was also largest towards the end of Kyoto, with -22 kt yearly between 2002 and 2008, -28 kt yearly in the final interval. The largest part of the effect can be assigned to the use of biomass, but especially between 2008 and 2012 the effect from geothermal was substantial too. In total by 2012 these renewables had caused emissions in agriculture to decrease with -0.21 and -0.03 Mt respectively.

At agriculture none of the energy and climate policies explicitly aimed to achieve decarbonisation through activity, fuel substitution of carbon factor effects. Activity effects are the result of economic growth of the agricultural sector. The overall growth was rather stable, inducing a total effect on CO_2 emissions of +3.24 Mt by 2012. As for fuel substitution, this may have been encouraged indirectly by the national emission trading scheme for horticulture as introduced in 2011. This was also when the only reducing fuel substitution effect was observed in the decomposition analysis, of -73 kt yearly due to a shift back to gas. The total effect from fuel substitution was however still +1.61 Mt by 2012. The CHP developments have also played a role at fuel substitution, but it was mostly the increased use of electricity at the expense of gas that led the substitution effect here. This development rat signifies a shift in the function towards more electricity use especially for lighting in horticulture (Wetzels et al., 2007). The focus on isolation also indirectly causes the substitution of gas. Lastly the carbon factor effect was the result of the developments at the electricity and heat supply. Here instruments mostly focused on the energy efficiency (through CHP) and the renewable energy, which caused total emissions to reduce with -0.73 Mt and -0.20 Mt respectively at the agriculture sector. Furthermore, fuel substitution at electricity and heat supply can be assigned with reductions of -0.32 Mt, increased electricity import gave -0.07 Mt and decreased nuclear energy caused a small increase here at agriculture of +0.02 Mt.

OTHER POSSIBLE INFLUENCES

Energy and climate policies had mostly focused on improving the energy intensity at agriculture through energy saving, but later also the use of renewables became an important strategy to decarbonize the agricultural sector. These decomposed effects can however not solely be ascribed to the deployed instruments. For the observed energy intensity effects, it was argued that these may have been lagging behind, as the small energy intensity effects seem to be due to short-term fluctuations. However, the energy intensity could also have been influenced by other exogenous factor. For example, agriculture is very dependent on the weather conditions; high temperatures could for example improve the energy intensity requiring less energy for heating for the same (economic) output. Considering the observed renewable energy effects by the end of Kyoto, it is expected that the preference for biomass is also due to the fact that biogas production (by the agricultural sector) has been stimulated. This was done for example by MEP/SDE/SDE+ to green the public electricity supply. The stimulated production may therefore also have influenced the use of this renewable energy source by the agricultural sector itself, due to its proximity to the energy source. Lastly, a part of the observed energy intensity and renewable energy effects must also be assigned to autonomous developments, though the correlation between the observed effects and the instruments is shown.

7.4 CONCLUSIONS AGRICULTURE

The decomposition analysis showed that the activity effect had the largest increasing effect, of +3.24 Mt by 2012, as the result of the rather constant growth of GVA in the agricultural sector. The effect from the improved energy intensity was almost able to cancel out the effect from activity growth, as it induced a reduction of -3.22 Mt by 2012. In other words, the improved energy intensity was almost completely able to decouple energy consumption from economic growth at agriculture, as the energy consumption of the sector was almost brought back to its 1990 level. Energy savings accordingly came forward as the main decarbonisation strategy at agriculture, through CHP and other efficiency measures that would improve the economic output ratio to the required energy consumption. The correlation between instruments does not perfectly come forward from the analysis, but this may partly be caused by short-term fluctuations. Moreover, it could be the case that a threshold of deployed instruments needed to be introduced before systematic results would present themselves, possibly pushed by the GLAMI and Orders of Council standards. It is important to notice that the energy intensity can also be influenced by other factors besides the deployed instruments. A number of exogenous factors could influence the GVA, rather than the ratio of energy use to GVA. At the agriculture also the weather must be an important exogenous factor. In the final two intervals the penetration of renewable energy was added as a strategy to decarbonize the agricultural sector. Here a clear correlation was found between the increased deployment of instruments that foster the use of renewable energy and the observed effects. In total its effect was however still only -0.25 Mt. This effect could mostly be assigned to the use of biomass, which may indirectly be caused by the sector's proximity to the source when its production was encouraged to green the electricity production. Geothermal energy caused 13.4% of the renewable energy effect which was specifically large in the final interval, simultaneous with the introduction of the 'geo guarantee'. The carbon factor effect induced reductions of -1.27 Mt as a result of the developments at the electricity and heat supply, where policies also had focused on efficiency improvements (mostly CHP) and renewable energy use. Also the fuel substitution at the plant inputs contributed substantially to the improvements of the carbon factors of heat and electricity. Lastly fuel substitution also took place at the agricultural sector itself, where it caused a total increase of +1.61 Mt mostly due to the substitution of gas by electricity.

8. ECONOMY STRUCTURE EFFECT

The former three chapters covering the so-called economy sectors (industry, services and agriculture) showed that each increased economic activity has caused large CO_2 effects of: +17.15, +12.53 and +3.23 Mt respectively by 2012. The total effect due to the economic development can therefore be quantified as an effect of +32.92 Mt. Using Formula F10 this effect was split out into the effect of total economic activity and an economy structure effect. These results are shown in Figure 56.

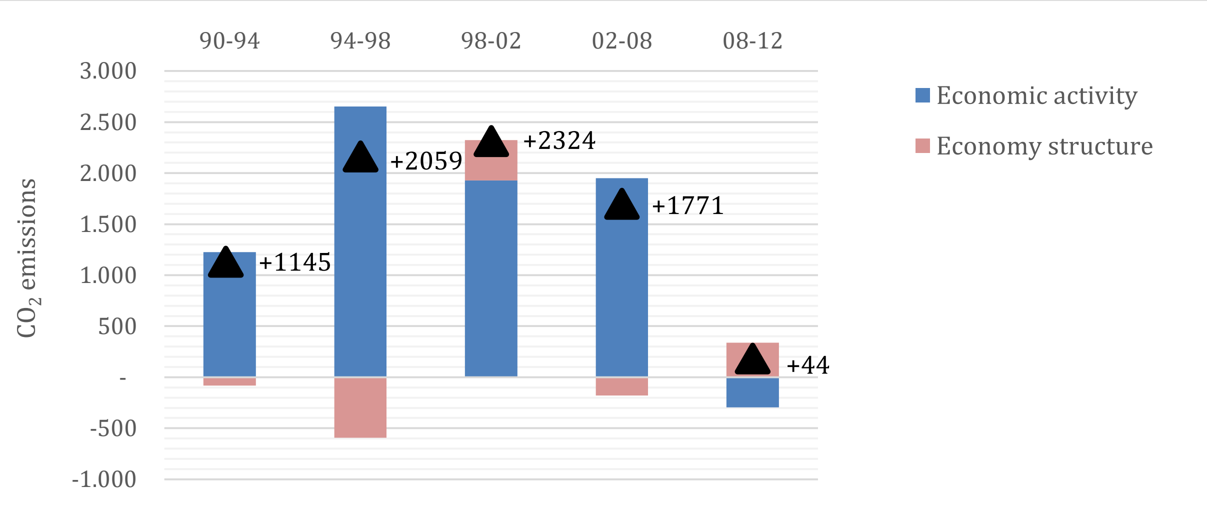

Figure 56 – Results of the additional decomposition showing the effects of economic activity and economy structure from the economy sectors (industry, services and agriculture) in yearly effect within the intervals between 1990 and 2012

The economic activity is now the effect due to (the increase of) the total economic activity from these three economy sectors altogether. Figure 57 shows that the total GVA has almost constantly increased until 2008, from 293.4 to 460.9 billion Euros. By 2012 it decreased again to 454.0 billion Euros, still 54.7% above base year level. These economy sectors are responsible for about 92.1 % of the country's GDP. The large increase up to 2008 caused an average effect of +1941 kt yearly. In the final interval this effect was -294 kt yearly as a result of the financial crisis. This effect of total economic activity basically represents the effect due to the search for a growing economy for the Netherlands. The effect itself is thus the effect due to the economy growing as a whole.

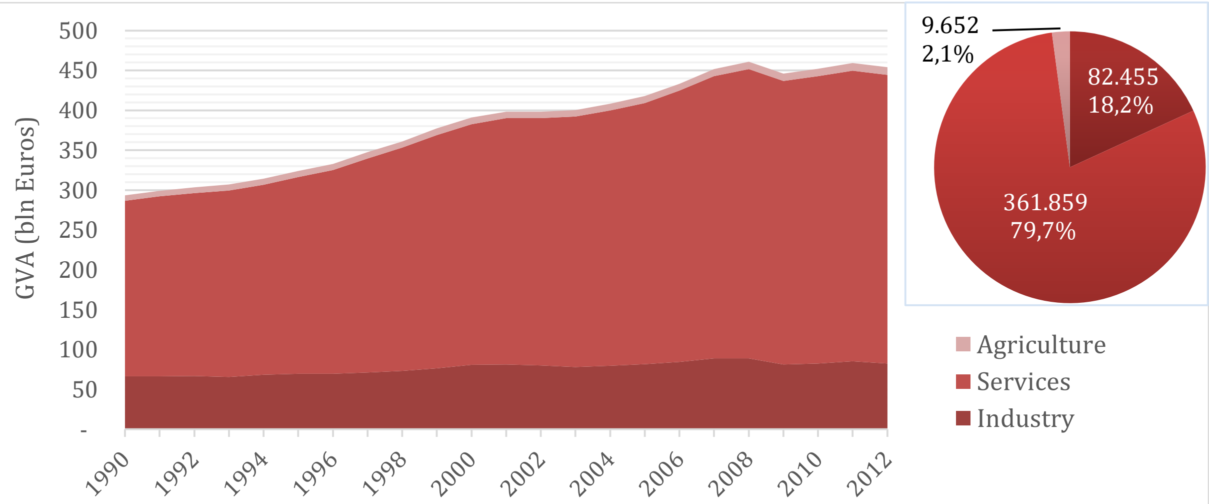

Figure 57 – The economic activity (billion Euros GVA in 2005 constant prices) of the three economy sectors between 1990 and 2012, including pie chart with 2012 amounts (in million Euros) and shares within the total sum of the GVAs (CBS, 2016c)

As sectors differ in the way they use energy, they have distinctively different carbon intensities (Figure 58). When there is a shift towards less carbon intensive sectors, this will cause an economy structure effect that reduces emissions. The main determinant for the differences between these sectoral carbon intensities is the energy intensity of the sectors. This was already shown to be especially small for the service sector (around 1 MJ/€ GVA) and relatively large for agriculture (13 to 23 MJ/ GVA). For the industry it was about 6 to 8 MJ/€ GVA, with large differences between the twelve distinguished industry sectors (see also Figure 29).

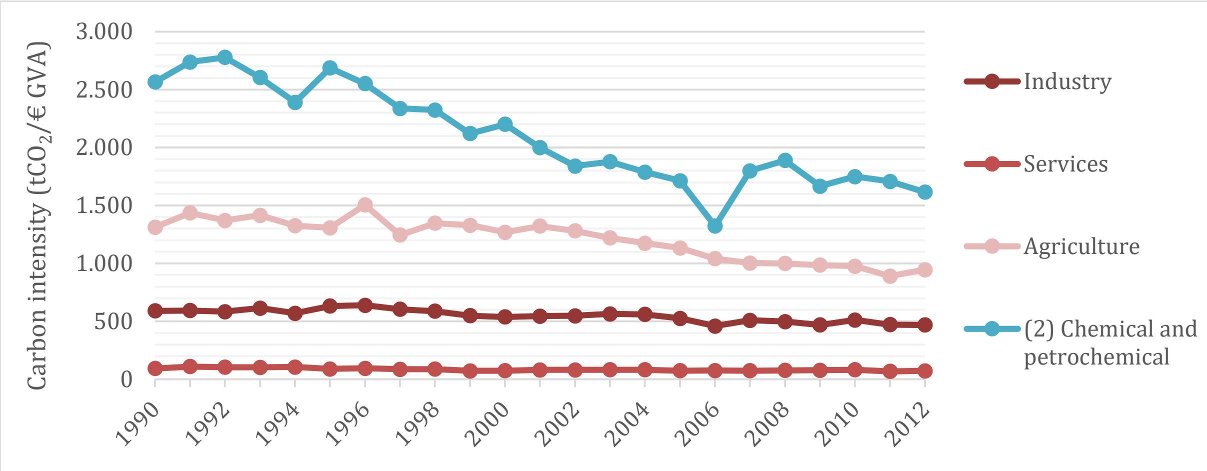

Figure 581 – Carbon intensities of the three economy sectors and the chemical and petrochemical sector (CBS, 2016c; IEA, 2014)

The main trend as shown in Figure 57 seems towards the less energy-intensive service sector, at the expense of the industry. However, this shift only clearly induces an emission effect between 1994 and 1998 (-594 kt yearly) and to a lesser extent between 2002 and 2008 (with -180 kt yearly). The upwards economy structure effects (+395 kt yearly between 1998 and 2002, +338 kt yearly between 2008 and 2012) are the result of the relatively large increase of the chemical and petrochemical sector within the industry. This sector has a very high energy intensity (22 to 30 MJ/€ GVA in these intervals) and accordingly a very high carbon intensity (Figure 58), with that able to induce a large increasing structure effect on emissions, overruling the shift towards services. The share of agriculture within the economy has been both up and down, with that contributing to or on the other hand weakening the observed trends. In the first interval the increase of agriculture was the clear cause for the small economy structure effect (only -81 kt yearly), while the service sector did clearly increase at the expense of the industry. Between 1998 and 2002 on the other hand, the decrease of agriculture weakened the effect due to the chemical and petrochemical industry.

In total the shift towards the less energy-intensive sector has only caused emissions to decrease with -0.85 Mt between 1990 and 2012, with that only offsetting the effect from total economic activity increase (+33.77 Mt) by -3.2%. Despite the constant large relative increase of services, because this overall shift towards this low energy-intensive sector was weakened by both the relative increase of the chemical & petrochemical sector and agriculture.

9. Transport

9.1 Trend of CO_2 emissions between 1990 and 2012 (transport)

The transport sector has historically been responsible for 26.6 to a maximum value of 35.7 Mt CO_2 in 2006. By 2012 emissions had decreased again to 33.3 Mt (Figure 59). Most of these emissions emanate from oil sources (98.0% in 2012). Over 2008-2012 emissions from transport were 28.6% above base year level. The transport sector here only includes road and rail transport (covering 96.2 to 98.2% of all CO_2 emissions of transport), aviation and navigation are excluded from the decomposition analysis as explained in the method Section (3.3). In case of a frozen scenario the emissions from transport would have been lower, signifying a worsening of the carbon intensity at transport over the years. Over 2008-2012 CO_2 emissions would have reached 32.0 Mt on average, -2.2 Mt below the historical values, but still 20.3% above base year level (Figure 60). The carbon intensity of transport has worsened from a value of 137 in 1990 to 146 tCO_2/mln pkm+tkm. The following sections give insight into the different drivers that altogether caused the emission changes in transport between 1990 and 2012.

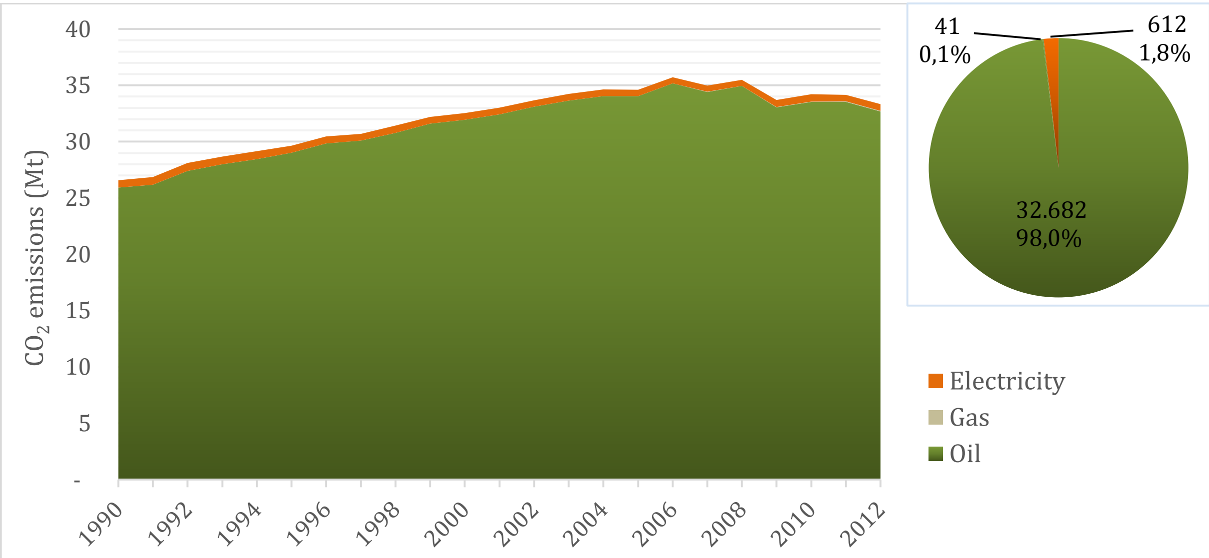

Figure 59 - Carbon dioxide emissions of the transport sector (excluding aviation and navigation) from three different fuel types between 1990 and 2012, including pie chart with 2012 amounts (in kt) and shares (IEA, 2014; IPCC, 2006)

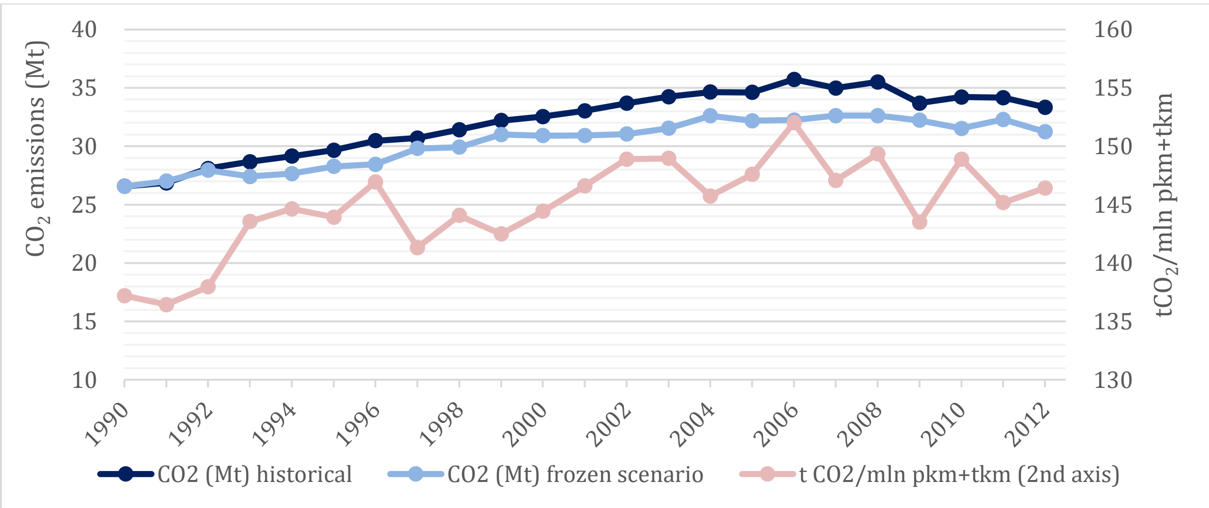

Figure 60 – Carbon dioxide emissions from the transport sector (historical and for a frozen scenario) and on the second axis the historical carbon intensity of the traveled distance (IEA, 2014; CBS, 2016d-h)

9.2 DECOMPOSITION ANALYSIS TRANSPORT

Carbon dioxide emissions from the transport sector were decomposed into five effects, using Formula F11. The effects are: activity (in travelled distance), the energy intensity of the travelled distance, the renewable energy effect, fuel substitution and the effects due to changing carbon factor of fuels (Figure 61). In the section below each of these effects is discussed.

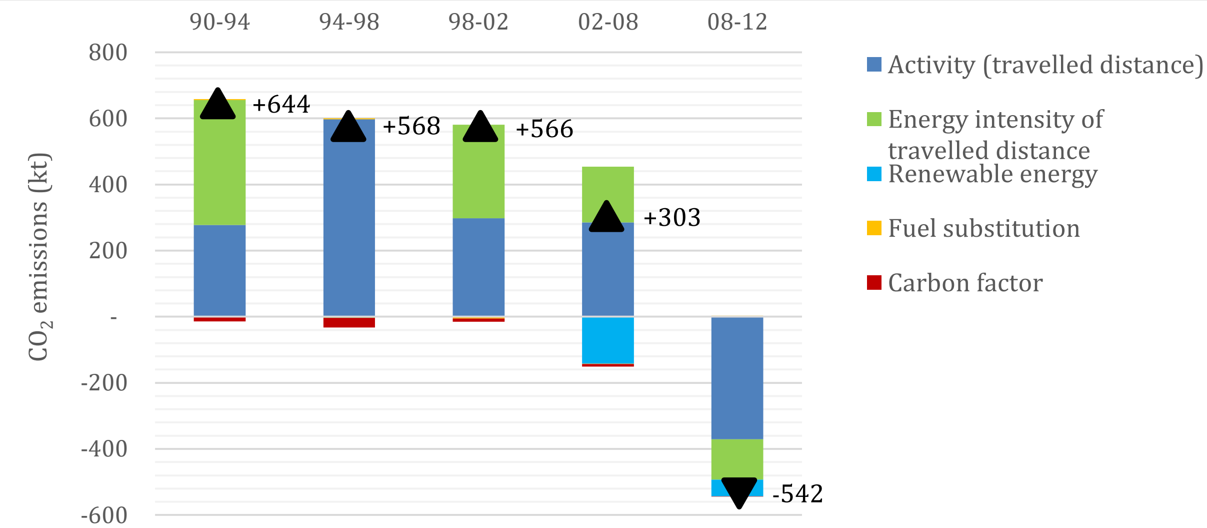

Figure 61 – Results of the decomposition of transport, showing five yearly effects in the intervals between 1990 and 2012

ACTIVITY

The effect due to activity change has historically been the largest effect to influence emissions in the transport sector. Until 2008 the increased travelled distance can be quantified as an average yearly effect of +356 kt. This trend is shown in Figure 62: the travelled distance increased from 194 to 238 pkm+tkm in 2008. Especially the travelled distance by car drivers, but also the travel modes road freight, other road transport', rail passenger and rail freight were responsible for the increase. By 2012 the travelled distance decreased again, with especially large reductions at road freight, to 228 pkm+tkm, still +17.6% above 1990 level, inducing an opposite emission effect of -371 kt yearly.

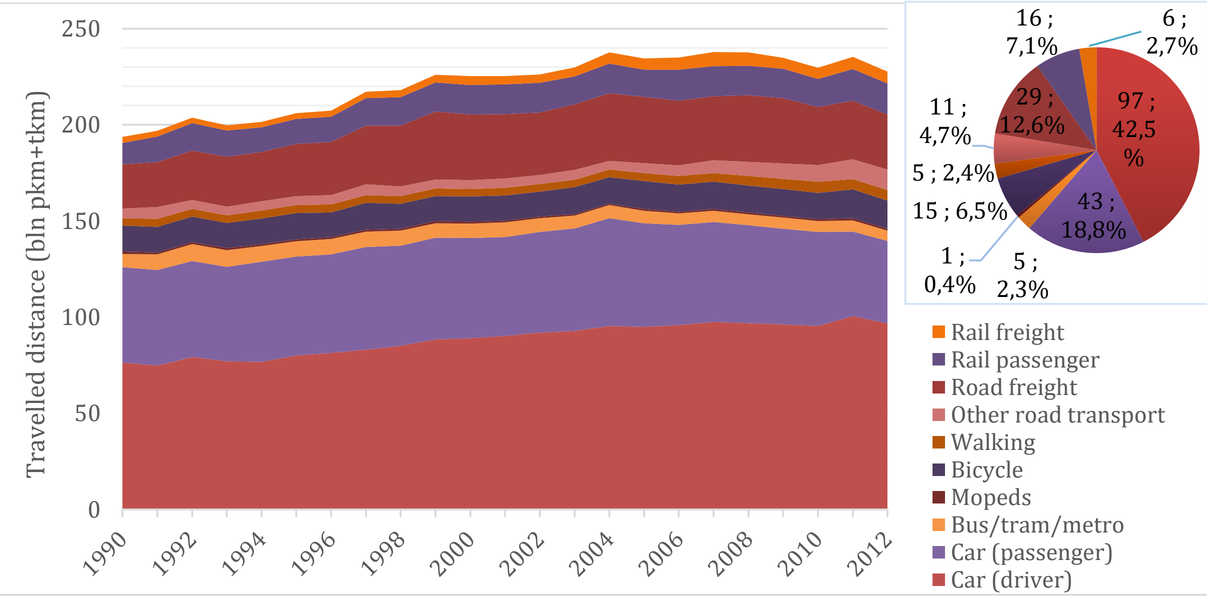

Figure 62 – Travelled distance for road and rail transport, split out to different types of passenger and freight transport between 1990 and 2012, including pie chart with 2012 amounts (in billion passenger-km+tonne-km) and shares (CBS, 2016d-h)

ENERGY INTENSITY

The trend of the energy intensity in transport, in terms of energy consumption for each unit of travelled distance, showed a fluctuating trend upwards (Figure 63). This means that over the first Kyoto period, higher amounts of (final) energy were required to transport units of passengers and freight. Until 2008 this trend therefore mostly led to an increase of CO_2 emissions, +203 kt yearly on average as the energy intensity rose from 1850 to 2081 kJ/(pkm+tkm) in 2008. By 2012 the energy intensity of transport slightly decreased again, to a value of 2052 kJ/(pkm+tkm), still +10.9% above base year level. This latter decrease did cause CO_2 reductions, of -122 kt yearly for the final interval.

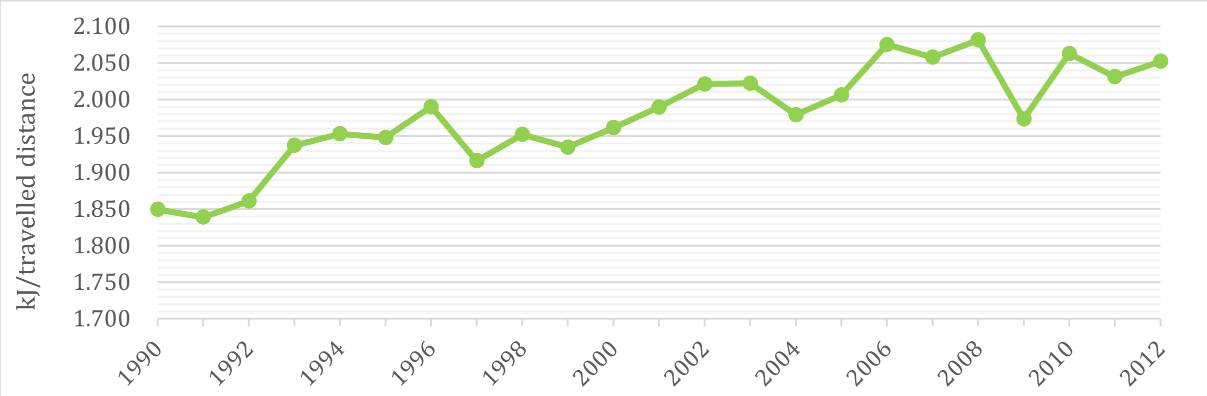

Figure 63 – The energy intensity of the transport sector in kJ final consumption per (passenger+tonne) kilometre travelled distance, between 1990 and 2012 (CBS, 2016d-h; IEA, 2014)

As both the energy intensity and the level of activity in transport went up, the total energy use at transport increased even faster. At least until 2008 the total energy use grew relatively constantly from 372 to 507 PJ (+558 Mt). By 2012 this level decreased again to 475 PJ (-493 Mt).

RENEWABLE ENERGY

Until 2006 no use of renewable energy sources was recorded in the transport sector. After 2006 the use of biomass started to emerge at road transport, with relatively large fluctuations (Figure 64). By 2012 the consumption of biomass had increased its share in the total energy consumption to 3.0% (14.0 PJ). Its reducing effect on CO_2 emissions in the last two intervals was substantial, on average -105 kt yearly.

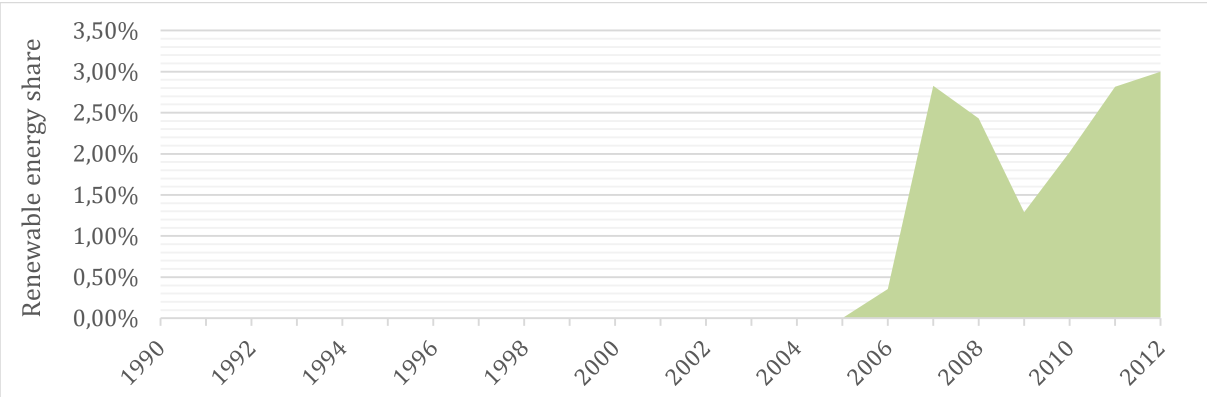

Figure 64 – Share of renewable energy (biomass) in total energy consumption at transport between 1990 and 2012 (IEA, 2014)

FUEL SUBSTITUTION

The effect from fuel substitution has been negligible (+0.2 kt yearly on average). This is caused by the fact that on average 98.7% of the final energy consumption of the fuels emitting CO_2 consisted of oil use (Figure 65). Note that this figure gives a different picture compared to Figure 59, as the vertical axis starts at 97%. The remaining share is mostly fulfilled by electricity use from rail transport (1.4% in 2012). Car transport covered only 1.1% within the electricity use in transport in 2012. As of 2005, gas entered the fossil fuel mix, covering 0.2% of the total fossil fuel consumption in transport in 2012. These developments were however too small to induce significant fossil fuel effects.

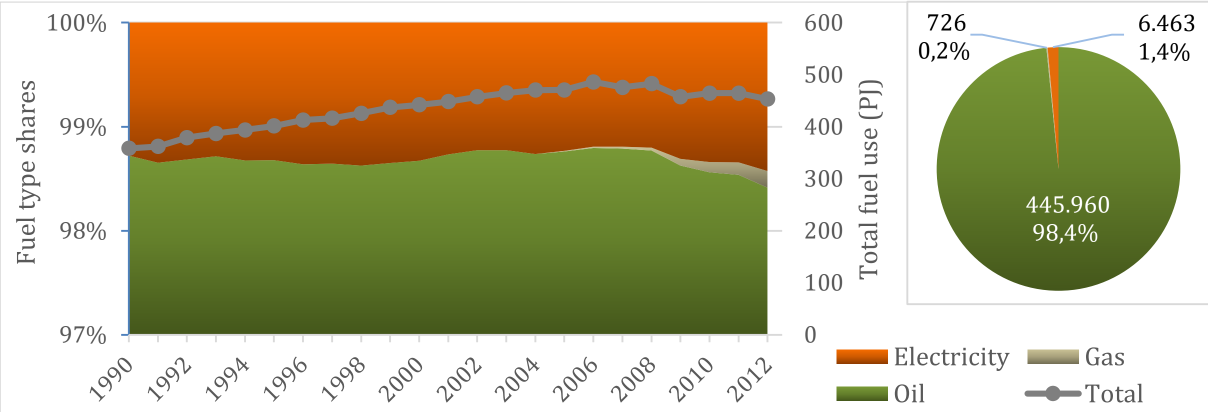

Figure 65 – Shares of three fuel type sources in total fuel use of the transport sector (second axis), including pie chart with 2012 amounts (TJ) and shares within total fuel use (IEA, 2014)

CARBON FACTOR

The carbon factor effect at transport can almost completely be assigned to the electricity use at rail transport. The total effect in transport was small, as the electricity use was small compared to the oil use, with an average effect of only -12 kt yearly. The carbon factor effect is the result of the improving carbon factor of electricity; especially with the increased use of CHP in the nineties the carbon factor effect was relatively large (-29 kt yearly in the second interval). Between 1990 and 2012 more than half of the carbon factor effect at transport is the result of CHP, the remaining effect was mostly due to the fuel substitution at electricity production and the increased use of renewable energy there.

9.3 LINK WITH ENERGY AND CLIMATE POLICIES AT TRANSPORT

Since the publication of the first national communications the Netherlands had set targets for CO_2 emissions from both passenger and freight transport, with a focus on road transport. Specific measures with clear time frames are however often lacking. Moreover, policies at transport are inherent to have safety and accessibility of transport as primary goals, with CO_2 reductions as additional effect (like measures to reduce congestion). Especially very general strategies like 'improving public transport', 'having better spatial planning and parking policies' or 'improving logistics for goods transport' which were often expressed in (early) documents, lacked concrete instruments. In general the policy strategy at transport can be divided into four main categories. The first category covers instruments that aimed to improve the fuel efficiency of cars through technical measures on the vehicles. The second category aims to improve fuel efficiency through influencing driving behavior. Thirdly, modal-split was encouraged to induce a shift to lower impact modes like public transport. The fourth category covers 'other' instruments, that could not be categorized in the former three categories, like the obligatory blending of biofuels through the regulatory Transport biofuels act. Figure 66 covers the more specific instruments in the transport sector that have been introduced between 1990 and 2012; a short explanation of these instruments can be found in Appendix D. Striking is the amount of communication instruments that were deployed: KZRZ and energy labelling at passenger transport, the 'Transport avoidance project' and 'Lean and Green' for freight transport. Also economic instruments were represented well, to promote the investments in more efficient and/or renewable transport (EIA, subsidies for other fuels, the CO_2 differentiation on the BPM tax and the Efficient leasing scheme). Also a regulatory instrument (Tranport Biofuels Act) and one voluntary agreement (ACEA covenant) were present.

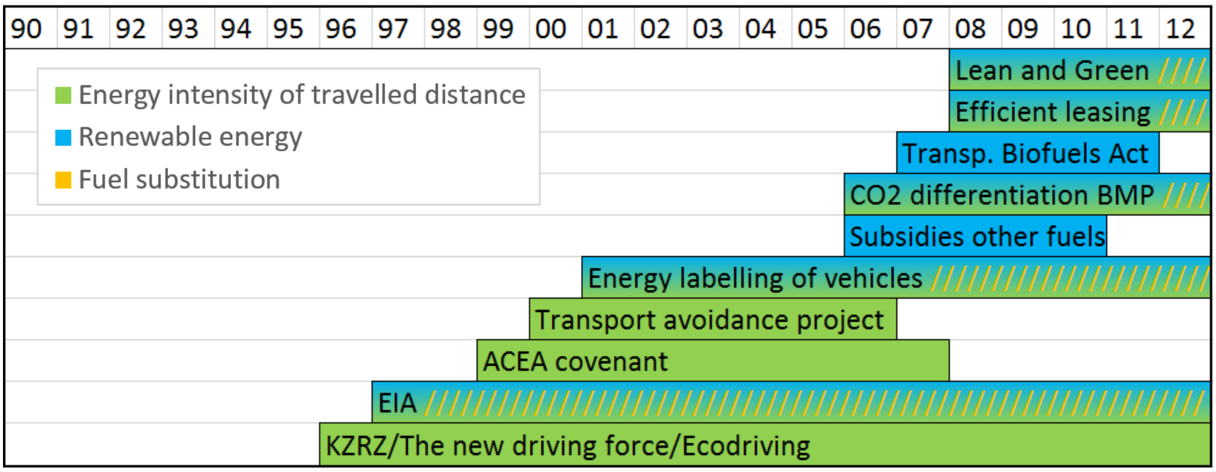

Figure 66 - Instruments targeted at the energy intensity, the renewable energy use and fuel substitution in the transport sector

More than half of the instruments had aimed to improve the energy intensity of the travelled distance in the transport sector. The instruments focused on efficient use by car drivers (the people behind the wheel) to efficient management of logistics and from the technical efficiency improvements of the cars itself to the encouragement of the purchase of more efficient cars. Since 1996 almost yearly new energy intensity instruments were introduced. The decomposition analysis showed however that especially until 2008 the energy intensity of pkm+tkm worsened, inducing large CO_2 increases. A part of this may be explained by the fact that an increasing share of the distance was travelled by car drivers as opposed to car passengers, as was shown in Figure 62, which is a more energy intensive transport mode. Either way until 2008 the efforts to improve the energy intensity were not able to induce emission reductions through intensity effects. By 2012 the energy intensity effect was finally downwards, which was also when the highest intensity of instruments was found. Part of the answer here may however again be found in the modal-split, as the share of road freight decreased and the share of 'other road transport' increased. To shift towards cleaner modes was very generally mentioned in all published policy documents, but no specific instruments focused on this. Moreover, the data (as presented in Figure 62) do not show a shift towards cleaner transport modes between in the other intervals at all. Despite the latter reducing energy intensity effect, the overall worsening energy intensity of the travelled distance caused CO_2 levels to increase as much as +3.16 Mt between 1990 and 2012.

Also more than half of the deployed instruments encouraged the penetration of renewable energy into the transport sector. The EIA instrument was already favoring the investment in renewable energy options since 1996, as did the energy labelling instrument since 2001, but especially since 2006 the intensity of instruments that aimed to induce renewable energy effects on CO_2 emissions was high. Accordingly, renewable energy (biofuels) have been used in the transport sector since 2006, inducing substantial effects in the final two intervals before the Kyoto deadline. In total the renewable energy effect caused emission reductions of -1.05 Mt by 2012.

Fuel substitution towards cleaner fuels was encouraged by half of the instruments. This was mostly done through promoting the purchase of less carbon intensive cars, which encourages the investment in electric cars or even vehicles on electric gas. The use of electricity and natural gas in road transport did show an increase, but its share within all fuels was too small to induce substantial fuel substitution effects. Moreover, the electricity use by rail transport largely overrules the electricity use in transport. Even the relative increase that was observed of electricity use in rail transport compared to oil use in the whole sector (possible modal-split effect), did only cause a fuel substitution of +0.004 Mt by 2012. This small shift towards electricity should even be weighed out by the simultaneous occurring energy intensity effect, as electricity requires less final energy units for the same function (distance travelled).

Energy and climate instruments for the transport sector did not aim to achieve CO_2 reductions through activity or carbon factor effects. For the case of activity, intentions to reduce the travelled distance have vaguely been mentioned in the policy documents, but concrete instruments lacked. To give an example, the general measure considering spatial planning argued for strict land use policy to reduce commuting by assigning appropriate areas for the establishment of companies and the allocation of new residential projects. Despite the expression of certain general intentions, the total activity in transport showed a large increase, which was quantified as +4.92 Mt CO_2 by 2012, the largest CO_2 effect at the transport sector. Note that the 'Transport avoidance project' seems to specifically aim to reduce the activity of (freight) transport, but looking closer at the project intentions, the focus is on reducing the distance travelled by the vehicles itself, which does not reduce the distance travelled in tonne-kilometre and therefore only induces energy intensity effects. The achieved carbon factor effects at last were the result of the developments at the electricity (and heat) supply, in total inducing a small reduction of only -0.26 Mt by 2012. As there was no heat use at transport only the improving carbon factor of electricity contributed to this effect. -0.14 Mt of this carbon factor effect coming forward at transport could be assigned to the efforts of efficiency improvements (CHP) and -0.07 to the increased use of renewable energy. Fuel substitution at electricity production itself caused a decrease here of -0.04 Mt and the increased electricity import amounted -0.02 Mt. The decreased use of nuclear energy and the worsening carbon factor of waste were responsible for a small increase of +0.008 Mt and +0.005 Mt respectively.

OTHER POSSIBLE INFLUENCES

The energy and climate policies at transport focused on achieving energy intensity effects, renewable energy effects and fuel substitution effects. Only for renewable energy significant reductions were achieved in clear correlation with the policy focus, but especially at energy intensity it seems that other factors besides policy efforts have played a role in the development of the energy intensity of travelled distance. As was already mentioned above, the modal-split must have caused a structure effect still incorporated in the (worsening energy) intensity (more travelled distance by solo drivers as opposed to car passengers), while the policy intentions to move to cleaner modes does not come forward here at all. Besides policy efforts it is expected that the income of the transport users (which in general increased) must also have influenced the modal-split, as higher incomes allow more people to own their own cars, which clearly increased over the years (CBS, 2012). Moreover, this may also mean that more people are able to buy larger cars which are less energy efficient. Higher incomes may also have led to a shift towards (international) aviation. This certain trend would actually keep down the travelled distance, and even positively affect the energy intensity (if aviation replaces road transport only), while aviation in reality has an increasing effect on CO_2 emissions. As emissions from international flights are excluded from Kyoto emissions, this possible shift now comes forward as advantageous, which is highly debatable. The economic crisis may accordingly have caused opposite trends towards less energy-intensive transport modes. Changes in income levels may also have had affected the activity itself (less travelled distance after crisis) and even a possible fuel shift (from a shift towards train transport). Especially the link of transport activity and economic sectors (freight mostly) clearly comes back in reduced activity levels after 2008. Another exogenous factor of influence besides energy and climate instruments are the excise duties on motor fuels. This instrument has a revenue-raising function, but as this led to higher fuel prices over the years it may also have been responsible for a part of the CO_2 reductions. Higher fuel prices may have affected the energy intensity through a shift towards less energy-intensive transport modes (bicycles), the fuel substitution effect through a shift towards modes that use other fuels (trains) or even an activity effect if the raised fuel prices would lead to reduced travelled distance. Lastly, especially apliccable for the technical efficiency improvements of the cars and the increased use of renewables as transport fuels, a part of the changes would also have occurred without any policy intervention. However, for the renewable energy effect the correlation between instruments and effects remains clearly evident.

9.4 CONCLUSIONS TRANSPORT

The largest effect at the transport sector was the activity effect. By 2012 the increased travelled distance was responsible for an increase of +4.92 Mt. The increase was especially caused by car transport (drivers), but also by road freight, 'other road transport', rail passenger and rail freight. None of the deployed instruments focused specifically on reducing the travelled distance, but more vaguely mentioned measures like 'improved spatial planning' may have limited the activity growth. The income of both private users and the commercial transport users (freight especially) are also able to explain the trend in travelled distance; including its reduced level since the economic recession. More clearly expressed in energy and climate policy were the intentions to achieve energy intensity, renewable energy or fuel substitution effects. The main strategy focused on improving the energy intensity, through more efficient (car) driving. Despite the regular introduction of efficiency instruments, the energy intensity went up (except during the crisis). In total this caused a large emission increase of +3.16 Mt. Besides specific instruments focusing on energy efficiency, there were also general policy intentions to influence modal-split. In reality however a shift towards more energy intensive transport modes like car drivers was observed. This development is expected to also be rather influenced by generally rising personal incomes instead. The only substantial reducing effect comes from the use of renewable energy sources at transport, i.e. biofuels. Especially since 2006 this became another main strategy in the transport sector, showing a clear correlation with the found effects in these years. In total the increased use of renewable energy at transport caused a reduction of -1.05 Mt by 2012. A third pillar of the energy and climate policies was to shift towards electricity in the road sector. The observed increase in electricity use at transport was however due to the increased activity of rail transport. Compared to the large amount of oil use at road transport mostly, this rather modal-split effect amounted to only +0.004 Mt CO_2 by 2012. All former discussed effects were also influenced by the exogenous factor of the excise duties. The historical rise in motor fuels could potentially have caused less growth of travelled distance (activity effect), a shift towards less energy-intensive transport modes (energy intensity effect), the use of more electricity (fuel substitution effect) or even renewable energy sources (renewable energy effect). Also without policy intervention a part of these effects would have occurred, especially the autonomous improvements at the fuel efficiency of transport modes which were part of the energy intensity effect. Lastly the observed carbon factor effect at transport was the result of the developments occurring at the electricity and heat supply (mostly CHP, but also increased use of renewables at plants and fuel substitution), causing a total decrease of -0.26 Mt by 2012, mostly arising from the electricity use at rail transport.

10. RESIDENTIAL SECTOR

10.1 TREND OF CO_2 EMISSIONS BETWEEN 1990 AND 2012 (RESIDENTIAL SECTOR)

Between 1990 and 2012 the residential sector has been responsible for CO_2 emissions in the range of 25.0 to 33.1 Mt. About two thirds of these emissions emanates from gas use, of which a ratio of 80/20 is for space and water heating (Milieu Centraal, 2016). Almost another third of the emissions comes indirectly from electricity use, used for a variety of appliances. In general the energy-related CO_2 emissions from the residential sector have shown a slightly decreasing trend (Figure 67). Over 2008-2012 emissions were on average 27.7 Mt, 2.9% below 1990 emission level of 28.6 Mt. In case the 1990 carbon intensity of households would not have improved (according to a frozen scenario as shown in Figure 68) emissions from the residential sector would have reached 21.8% above base year level, up to 34.8 Mt over 2008-2012. The carbon intensity has historically improved sufficiently to limit the CO_2 emissions by the end of Kyoto: by 2012 it was 3.64 tCO_2/household, compared to 4.72 in 1990. The decomposition analysis that follows allows to give insight into the different factors influencing the energy-related CO_2 emissions from households between 1990 and 2012.

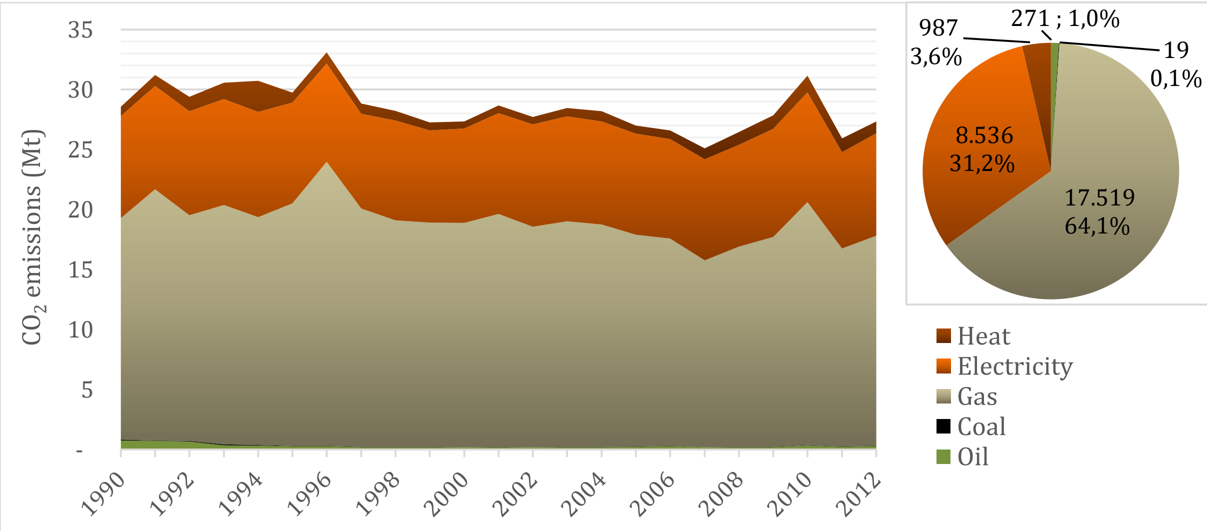

Figure 67 – Carbon dioxide emissions of the residential sector from five different fuel types between 1990 and 2012, including pie chart with 2012 amounts (in kt) and shares (IEA, 2014; IPCC, 2006)

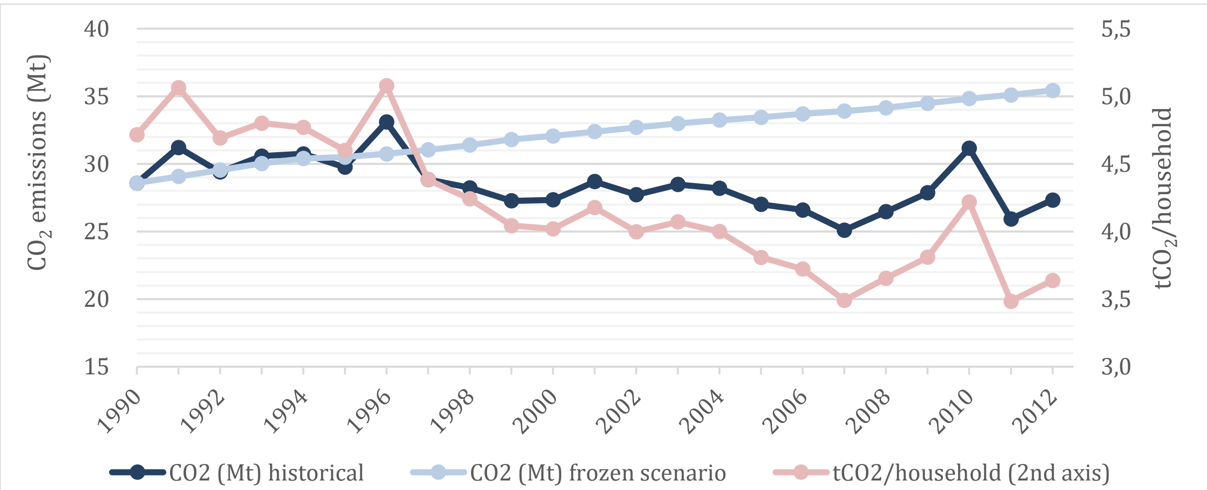

Figure 68 – Carbon dioxide emissions from the residential sector (historical and for a frozen scenario) and on the second axis the historical carbon intensity of the households (IEA, 2014; CBS, 2016i)

10.2 DECOMPOSITION ANALYSIS RESIDENTIAL SECTOR

Residential CO_2 emissions were decomposed into the five effects of: activity (in number of households), energy intensity of the households, renewable energy use, fuel substitution and the effects due to the changing carbon factors of the fuel types. This was done using Formula F12, the results are shown in Figure 69. Below each of these effects is subsequently discussed.

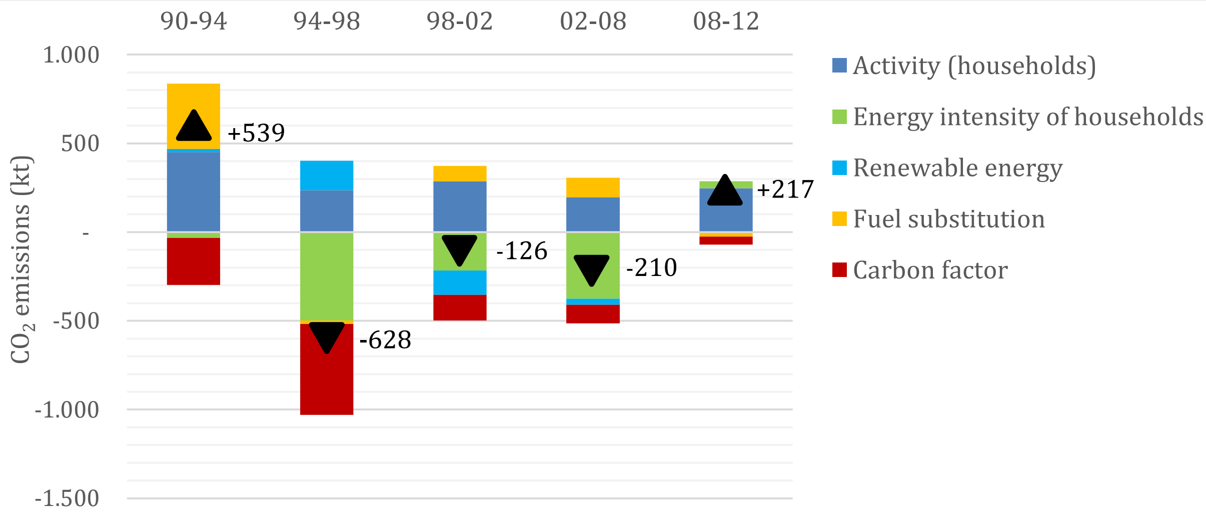

Figure 69 – Results of the decomposition of residential, showing five yearly effects in the intervals between 1990 and 2012

ACTIVITY

The effect due to the growth in the number of households has induced a nearly constant activity effect of +275 kt yearly. On average the number of households increased with about 62.5 thousand new households annually, as shown in Figure 70. By 2012 the number of households amounted to 7.5 million, a growth of 23.9% compared to 6.1 million households in 1990. What stands out is that over the years the share of single person households went up from 29.9% in 1990 to 36.8% of the total number of households in 2012. This trend was accordingly accompanied by a decreasing average number of residents per household: from 2.4 to 2.2 residents per household (second axis in Figure 70).

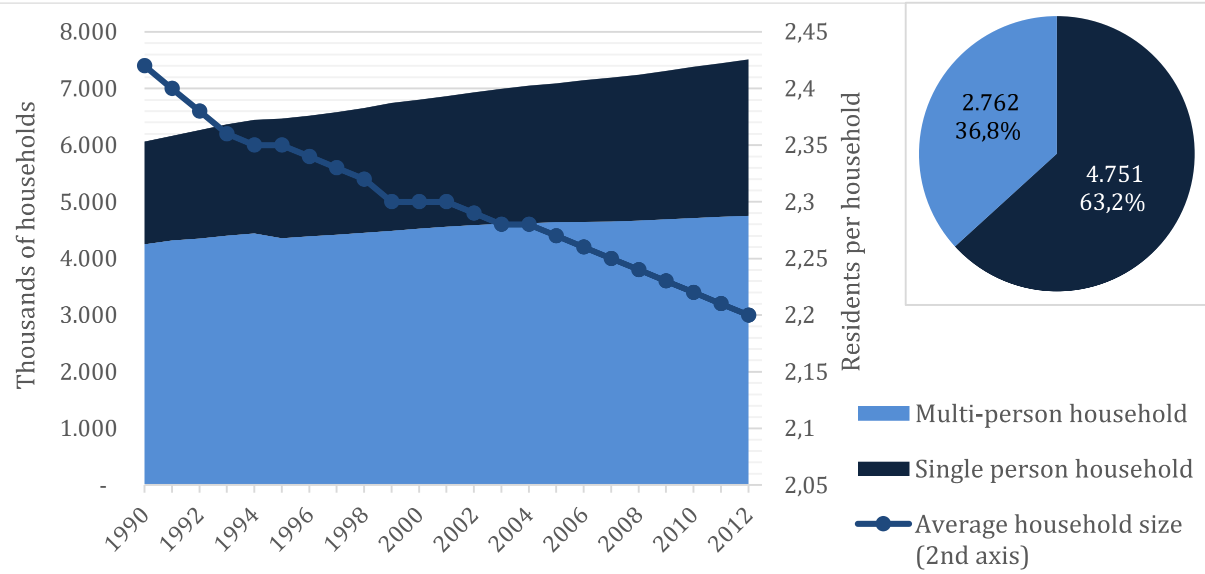

Figure 70 – Number of households at the residential sector, split out to single and multi-person households, average household size (second axis) between 1990 and 2012, including pie chart with 2012 amounts (x1000 households) and shares (CBS, 2016i)

ENERGY INTENSITY

The energy intensity of the residential sector has predominantly improved, as shown in Figure 71. The improvement especially took place between 1994 and 2008, causing average reductions of -365 kt yearly. During the first interval the improvement only caused an effect of -33 kt yearly, in the final interval the energy intensity slightly worsened, giving +40 kt yearly. By the end of Kyoto the energy intensity of households had decreased from 68.7 in 1990 to 57.3 GJ/household in 2012, with fluctuations in between, which are mostly accounted for by fluctuations in gas use (see also Figure 67).

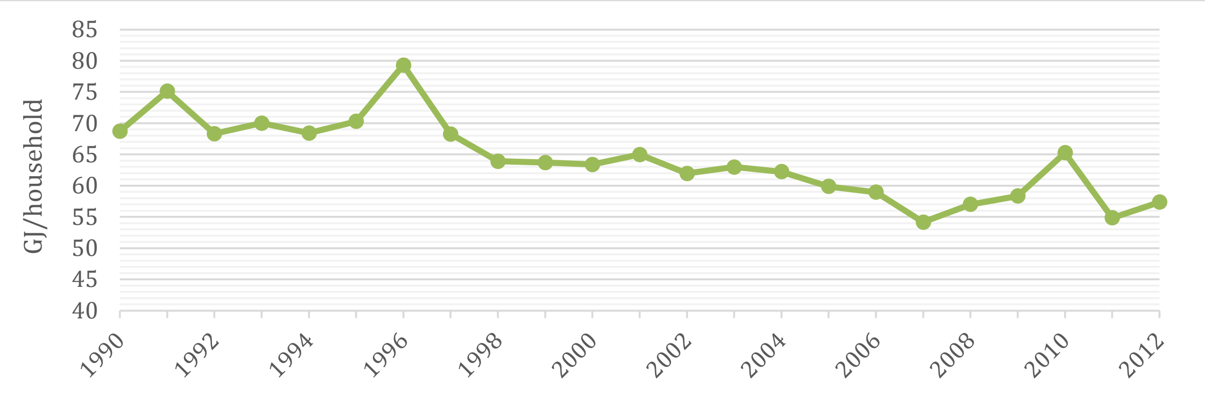

Figure 71 – The energy intensity of the residential sector in GJ final consumption per household, between 1990 and 2012 (CBS, 2016i; IEA, 2014)

RENEWABLE ENERGY

Renewable energy use at households consists of biomass sources and the combined category of solar/wind. Over the whole period the share of renewables did not increase much, comprising only 3.2% of the total energy use in 2012 compared to 3.0% in 1990. The biomass part is much larger than solar/wind, covering 93.4% of the renewables in 2012, compared to 6.6% by solar/wind (Figure 72).

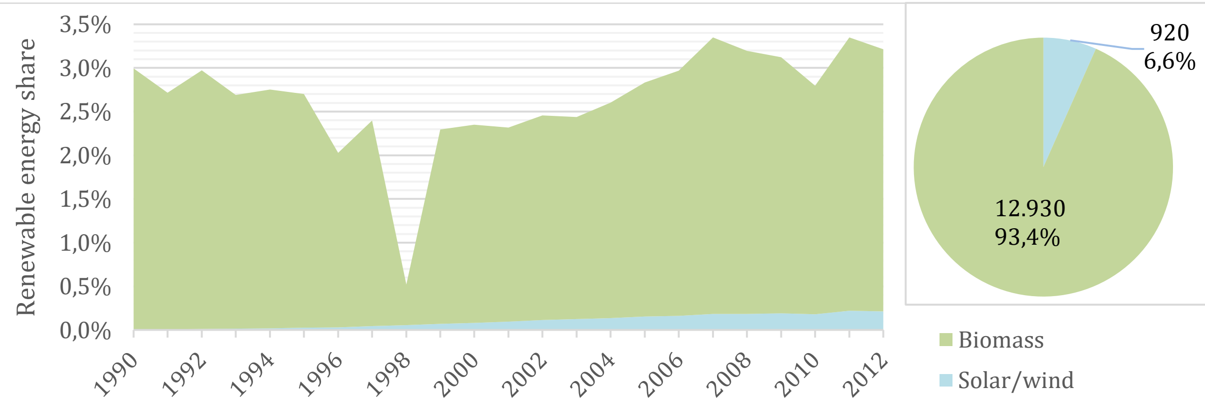

Figure 72 – The share of renewable energy sources in total energy consumption of the residential sector between 1990 and 2012, including pie chart with 2012 amounts (in TJ) and shares within the category of renewable energy sources (IEA, 2014)

At households, biomass is mostly used in the form of wood in wood stoves or as charcoal on barbecues. The biomass use fluctuated, with a remarkably large dip in biomass use in the year 1998. This particular data point is assumed to be caused by a data inconsistency. The effects over 94-98 and 98-02 are therefore relatively large, as the result of this data error. As the 1998 decrease rebounds these effects cancel each other out. This is also clearly shown in Figure 73 and Table 7. Due to the large fluctuations of biomass use no clear trend can be distinguished, but altogether its changes induced an average increase of +1.6 kt yearly. The observed increase of renewables is therefore instead due to the steady increase of the solar/wind category, causing an average effect of -2.7 kt yearly. This combined category only consists of solar energy, as the use of wind energy is not favorable for households (CBS, 2016j). In total the effect from the small increase of the total renewable share of final energy at households counts up to only -1.1 kt yearly, a negligable effect compared to the other effects present.

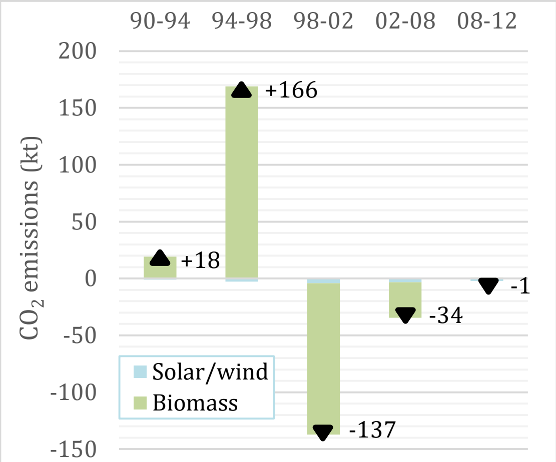

Table 7 – The individual effects (yearly) of two renewable energy sources causing the renewable energy effect at residential

Renewable energy source	90-94	94-98	98-02	02-08	08-12
Solar/wind	-1.1	-2.6	-4.1	-3.2	-2.1
Biomass	+19.3	+168.9	-133.3	-31.2	+0.9
Renewables	**+18.2**	**+166.3**	**-137.4**	**-34.4**	**-1.2**

← *Figure 73 – The renewable energy effect (yearly) at the residential sector, for solar/wind and biomass, values in Table 7*

FUEL SUBSTITUTION

The fuel substitution effect as present at the residential sector has predominantly induced CO_2 increases, with an average annual effect of +104 kt. Especially in the first interval the fuel substitution effect was large (+368 kt yearly). This was mostly the result of the relatively large increase of heat consumption, which has a rather high carbon factor. In the subsequent interval the trend of heat bounced back, offsetting its earlier effect (Figure 74). Moreover, increases in CO_2 emissions due to the substitution by heat as opposed to own heat production will be cancelled out by the energy intensity effect and give overall CO_2 reductions. The decreasing share of oil contributed to substantial reductions in the first interval. Effects from decreased coal also induced a small fuel substitution effect. The main trend that can be distinguished is however an increase of electricity in total fuel use, together with a decrease of the gas share, causing the relative increase of emissions due to the fossil-based electricity mix. At the residential sector the use of certain fuels is very dependent on the functions fulfilled: gas is mostly used for space heating, while electricity is used to fuel electric appliances. These trends therefore do not so much demonstrate a fuel substitution effect, but rather the substitution of functions: less demand for space heating and more use of electric appliances.

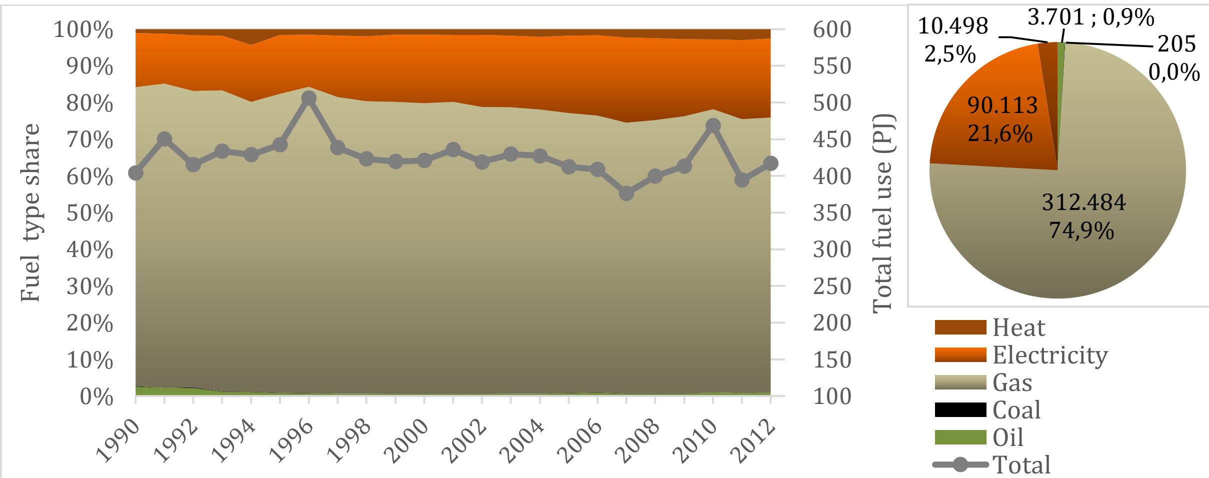

Figure 74 – Shares of five fuel type sources in total fuel use of the residential sector (second axis), including pie chart with 2012 amounts (TJ) and shares within total fuel use (IEA, 2014)

CARBON FACTOR

The carbon factor effect at the residential sector is the result of the changing carbon factors of both electricity and of heat. The induced reductions (Figure 75) were almost in the same order of magnitude as the energy intensity effect, due to the relatively large use of especially electricity at households. The electricity effect was almost four times as large as the effect caused by changes at heat. More than half of the carbon factor effect can be assigned to the efficiency improvements taking place at the supply, mainly caused by CHP. The increased installed capacity of CHP in the nineties therefore also explains the relatively large carbon factor effects until 1998, with a maximum effect of -512 kt yearly between 1994 and 1998. Another quarter of the efficiency effect can be assigned to the increased use of renewables at electricity and heat supply, the remaining is the result of fuel substitution at the plants.

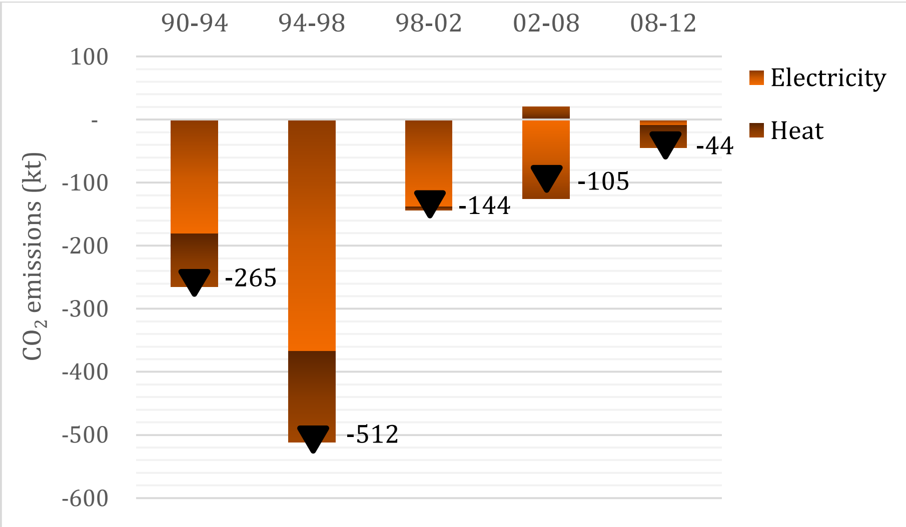

Figure 75 – The carbon factor effect at the residential sector from electricity and heat (yearly)

10.3 LINK WITH ENERGY AND CLIMATE POLICIES AT THE RESIDENTIAL SECTOR

Energy and climate policies that were influential in the residential sector largely match the policies applicable at the service sector, as most of the energy use is also building related. Energy conservation is therefore again the key strategy, focusing on improving the efficiency of buildings (both existing and new) and appliances. Certain efforts are able to induce energy intensity effects as these would specifically lower the average energy consumption per household. The encouragement of renewables was to a much smaller extent a strategy at households. The most important instruments aimed at the residential sector to induce CO_2 reductions are given in Figure 76. The policy mix consists of four main types of instruments. Financial instruments were deployed to encourage the investment in energy saving measures, like MAP, EPA, EPR and the subsidy scheme for PV. The energy tax additionally also encouraged the use of renewables by discouraging the fossil energy consumption. Since 1990 instruments have been mentioned that focused on the financial support of specific technology options, like high efficient boilers or insulating glazing. However, for these schemes clear time frames were lacking, so they could not be included here (except solar energy 'PV' in 2012). Regulatory instruments were also largely represented, focusing on the efficiency of buildings (EPN and EPBD) or the efficiency of appliances (energy labelling and Ecodesign). The third type of instruments involve voluntary agreements concerning the efficiency of buildings: LTAs with the social housing sector and three other voluntary agreements with relevant organizations pooled together in the so-called Koepel covenant. A fourth category could be added covering informative instruments. Public awareness campaigns, educational projects or informative websites in order to induce behavioural change were specifically relevant at the residential sector over the whole period. As these do not cover specific instruments, these are not further analysed here. Some of the above mentioned instruments also had an informative character, like the MAP, EPA and all instruments that involved labels.

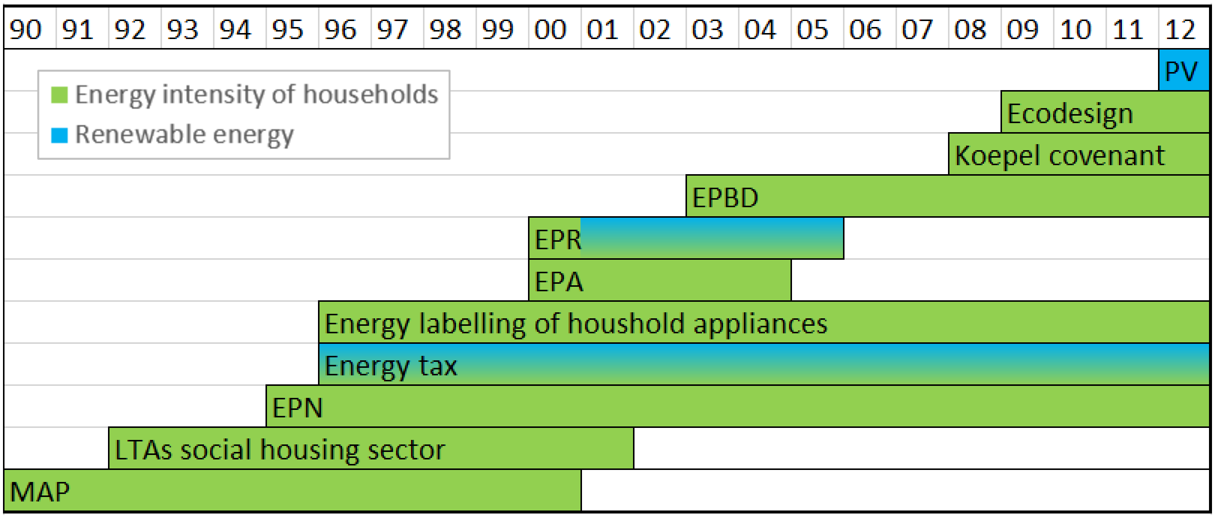

Figure 76 – Instruments targeted at the energy intensity of travelled distance and renewable energy in the residential sector

All instruments but one focused on improving energy efficiencies (of houses and household appliances), which were able to cause energy intensity effects. Almost every two years a new instrument was introduced with the aim to reduce the households' energy use. Especially between 1994 and 1998 a relatively high amount of new instruments was introduced, in clear correlation with the effect observed at the decomposition analysis which was largest during that interval. Only after 2003 a decrease in intensity of instruments is observed. The effect between 2002 and 2008 was however still very large, which might be explained by the lagged effect of former instruments or even a large effectiveness of the Koepel covenant, of which the negotiations had already started before 2008. An explanation for the increase in emissions in the final interval may be sought at other factors; the intensity of instruments was not as high as before and only 'Ecodesign' was introduced here, but still a worsening of the energy intensity is unexpected. In total the reductions due to the overall improvement of the energy intensity amounted -5.09 Mt.

Only three instruments were deployed which fostered the penetration of renewable energy at the residential sector. The PV subsidy scheme was most specific, the EPR included renewable provisions since 2001 and the energy tax only indirectly encouraged the use of renewable energy sources. The focus has clearly been on solar energy, which is the most suitable renewable energy source at households. The decomposition analysis showed that the increased use of solar energy caused growing reductions, in line with the increased deployed instruments. By 2012 solar energy was responsible for -0.06 Mt reductions. The relative decrease of biomass use on the other hand (mostly wood for rather old-fashioned wood stoves) caused an increase of +0.04 Mt. The total effect from renewables therefore amounted up to only -0.02 Mt by the end of 2012, negligible compared to the other effects.

The deployed energy and climate policies at the residential sector did not aim to achieve activity, fuel substitution or carbon factor effects to decarbonize the sector. Activity comprises the number of households, influenced by housing policy and policies that influence population growth itself (on birth control and migration for example). Between 1990 and 2012 the population increased with about 81.8

thousand inhabitants yearly, due to a birth surplus and only to a small extent a positive migration balance (CBS, 2015b). To influence the households like this is not part of a strategy to influence CO_2 emissions. Especially discussing the impact of population size is (still) a taboo (Ehrlich, 2008). The increased number of households was larger for the single person households, enhancing the population growth effect on numbers of households, as a result of the aging population and other societal developments (CBS, 2013b). The activity effect from increased households was responsible for the largest increase of CO_2 emissions, amounting to +6.06 Mt by 2012. The fuel substitution effect also caused substantial increases in emissions (+2.30 Mt), which can mostly be assigned to a relative increase of electricity use, with at the same time a relative decrease in gas use. This trend is not necessarily a substitution between fuels, but rather a substitution of functions. The increased electricity use at households can be assigned to the introduction of newer and larger appliances, despite their electric efficiency improvements (van Dril et al., 2012). Gas use (for heating mostly) is very dependent on the outside temperature, which explains the large fluctuations present at gas use. This especially comes forward in 1996 and 2010, when the peaks in gas use correspond with the low average recorded annual temperatures (CBS, 2016k). The overall decrease of gas use can be assigned to better isolation and more efficient heating boilers (van Dril et al.,, 2012) which was part of the policy focus and therefore has also indirectly caused fuel substitution effects. A possible shift from cooking on electricity instead of on gas – which would be a genuine fuel substitution effect – certainly occurs, but its effect on emissions would be very small as only 2% of the gas use is for cooking (van Dril et al., 2012). Lastly the carbon factor effect here is not affected by energy and climate policies at the residential sector, but on the developments occurring at electricity and heat supply. Its effect from the improving carbon factors of both electricity and heat, was very large (due to a relatively large use of electricity mostly) and in the same order as the energy intensity effect: -4.49 Mt. Within this effect -2.45 and -0.88 Mt can be assigned to respectively the improving energy efficiency (mostly through CHP developments) and increased renewable energy use at plants, which were the focus points of energy and climate policies here. Fuel substitution at the energy plants caused a substantial decrease of -1.06 Mt and increased electricity import is held responsible for -0.32 Mt. The decreased nuclear energy use and the worsening carbon factor of waste slightly increased emissions with +0.11 and +0.10 Mt respectively.

OTHER POSSIBLE INFLUENCES

The deployed energy and climate policies at the residential sector have focused on achieving energy intensity effects and to a smaller extent renewable energy effects. For both effects a correlation with the observed effects was largely present, but the observed energy intensity effect in the final interval was remarkable looking at the deployed instruments only. Especially for the energy intensity other factors have however also been of influence. At first the household composition must have affected the energy intensity. The number of residents per household have constantly decreased over the years, mostly as a result of an aging population. It is argued that that an increasing household size may signify the economic recession, but as Figure 70 also showed a certain trend does not come forward in the Netherlands (Smit et al., 2014) and can therefore not explain the unexpected trend in the final interval. The trend of overall decreasing household sizes causes that energy functions (space heating, watching television) could be shared less. This development therefore counteracted the efficiency effects as it increases the energy use per household. Looking at the different energy sources per household shows that the decreased energy demand was mostly in decreased gas use, which may be assigned to isolation and boiler improvements, despite the household size effect. The exogenous factor of average outside temperatures has also influenced the gas use, showing a perfect correlation with the gas fluctuations

(CBS, 2016k). Despite the cold years of 1996 and 2010, the average annual temperature slightly increased which therefore also explains a part of the energy intensity effect. The relatively low annual temperature in 2012 may therefore be responsible for the worsening energy intensity in the final interval. Electricity use per household on the other hand showed a steady increase despite the efficiency improvements of electric appliances, with the introduction of newer and larger appliances. Lastly also autonomous improvements are partly responsible for the observed effects, especially concerning efficiency improvements of household options like insulation, boilers and appliances applicable at the energy intensity effect. Also the accelerating learning curve of solar energy has influenced the improved cost-effectiveness of the technology, which would also have occurred without the financial policy instruments.

10.4 CONCLUSIONS RESIDENTIAL SECTOR

At the residential sector the changes in activity caused the largest (increasing) effect on emissions. By 2012 the constant increase in number of households caused +6.06 Mt CO_2 increase. The increase was mostly present in number of single person households. This trend is a result of both population growth and societal changes, but is not influenced by energy and climate policies. The decreasing household size must have worsened the energy consumption per household (energy intensity) and therefore counteracted the efforts to improve the energy efficiency of households. This has been the main strategy of energy and climate policies in the residential sector; to reduce the energy demand of households by improving the efficiency of the houses and the electric appliances. All deployed instruments but one were able to induce energy intensity effects, which were introduced regularly. A correlation between the observed energy intensity effects was largely found. The unexpected result in the final interval could be explained by the relatively low temperature of 2012, which influenced the gas use that is for 80% space heating. The overall slightly increasing temperature might on the other hand be responsible for the generally improving energy intensity. The decreasing energy intensity was predominantly the result of the gas use reductions; energy use in the form of electricity per household has steadily increased. This is expectedly the result of the introduction of newer and larger appliances, despite the improved electric efficiencies. Efforts focusing on the efficiency of buildings reducing the gas use were therefore responsible for the overall energy intensity improvements, altogether resulting in a total effect of -5.09 Mt. The relative increased share of electricity and decreased share of gas in the fuel use of households also caused a fuel substitution effect of +2.30 Mt. This effect resulting in more CO_2 emissions is however rather an effect due to the substitution of functions (more appliance use compared to heating) rather than a genuine fuel substitution effect, indirectly caused by the improvement of buildings and the increased use of electric appliances. Moreover, it is accompanied with a downward energy intensity effect. Encouraging the penetration of renewable energy was a secondary strategy at the residential sector, covered by only three instruments with a focus on solar energy. Over the years the use of solar energy did increase, causing a correspondingly increasing effect. More than half of this effect from solar energy was cancelled out by the decreased us of wood stoves, resulting in an almost negligible renewable energy effect of only -0.02 Mt by 2012. The effects from the improved carbon factors of heat and mostly electricity have caused large reduction at the residential sector of -4.49 Mt over the whole period. The efficiency (CHP) improvements and increased use of renewable energy were the pillars of energy and climate policies at electricity and heat supply, which were accordingly responsible for the largest part of the reductions here. Also fuel substitution (coal to gas) and increased electricity import caused a smaller part of these reductions, slightly counteracted by the decreased use of nuclear energy and the worsening carbon factor of waste.

11. SYNTHESIS

The former decomposition analyses (Chapter 5 to 10) allowed to reveal the effects due to activity growth of the main demand sectors, the changed energy intensities, the renewable energy use, substitution between fuels and the changes in the carbon factors of electricity and heat. An aggregation off the results of these demand sectors (industry, services, agriculture, transport and the residential sector) shows how these different types of effects have altogether affected the emissions in the Netherlands in the five researched time intervals, as shown in Figure 77. Within the carbon factor effect lie the effects that were demonstrated in Chapter 4 on the electricity and heat supply, as were shown aggregated for both types of supply in Figure 19. The activity effect in Figure 19 was accordingly the result of the developments at the demand sectors. Figure 77 shows that direct and indirect CO_2 emissions from energy use of the demand sectors showed declining growth rates due to the different effects occurring at all sectors, eventually leading to falling figures in the final interval.

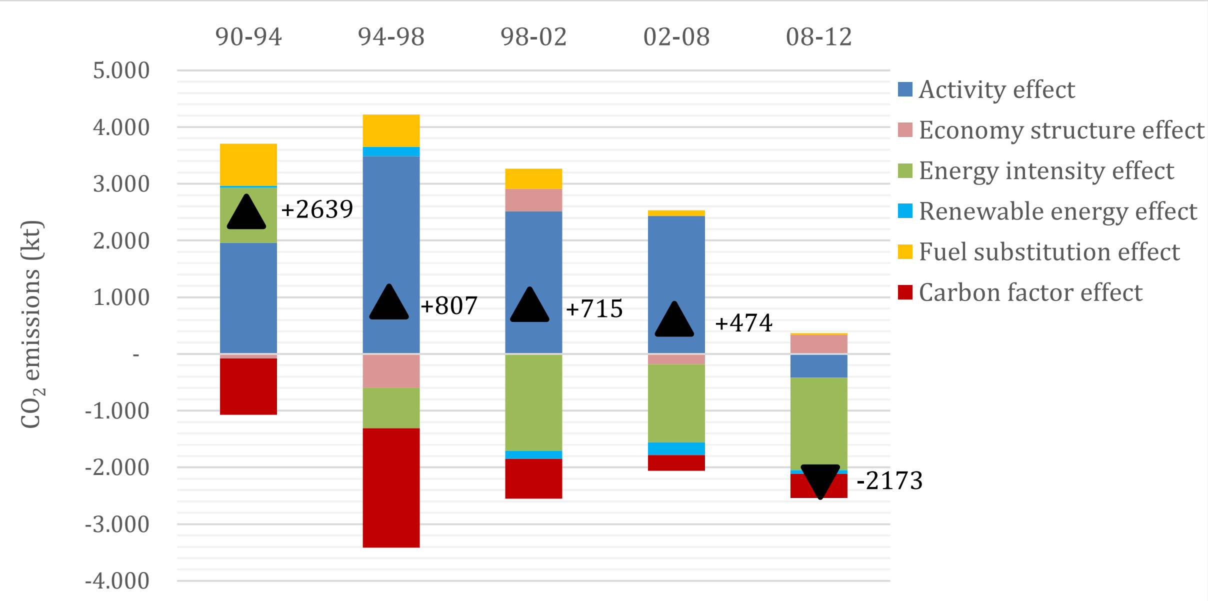

Figure 77 – Aggregation of decomposition results of the main demand sectors (industry, services, agriculture, transport and the residential sector), decomposed into six total effects in yearly carbon dioxide emissions

Considering the Kyoto target, 2008-2012 was the accounting period, where all the effects with their underlying developments that took place in the different researched intervals have all led up to. A separate decomposition analysis with average 2008-2012 values of each sector allows to show which effects were eventually achieved in the target period. Besides the emissions from the demand sectors, also the emissions originating from the other energy use of the energy sector and the 'other demand sectors' which could not be included in the decomposition analyses are included in this total picture. These sectors were in fact responsible for 17.0% of the energy-related CO_2 emissions in 2012, as shown in Figure 78. The waterfall chart in Figure 79 on the other hand shows how each of the sectors contributed to the changes in emissions in the Netherlands over 2008-2012. Notice how these figures show a slightly different picture compared to the total effects achieved by 2012 as stated at the end of each sectoral chapter. This is because averages are considered here; as the (decarbonizing) effects continued up to 2012, the average over 2008-2012 are slightly higher than the 2012 amounts.

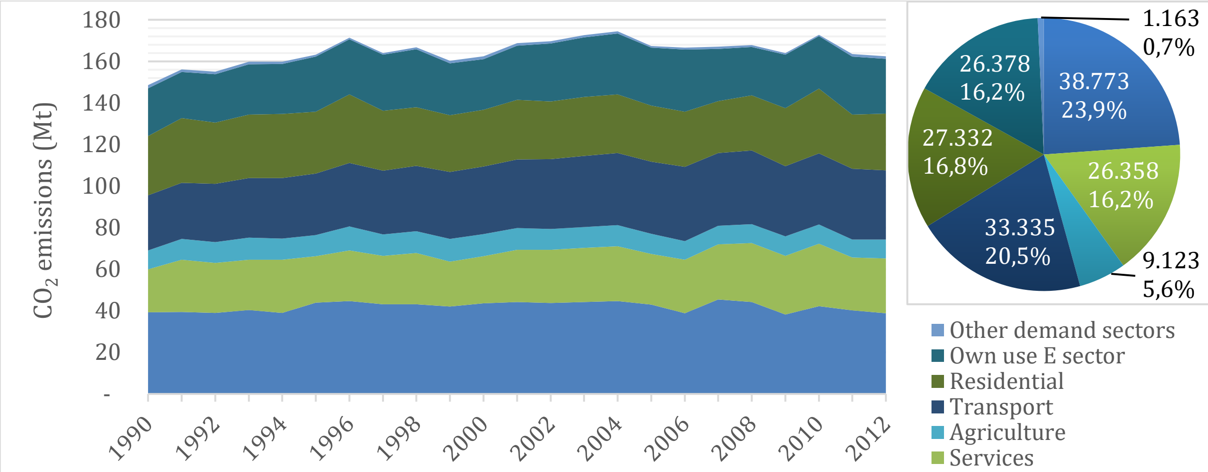

Figure 78 – Carbon dioxide emissions from energy use (direct and indirect) of the five main demand sectors, from other (non-plant inputs) energy use of the energy sector and from the other demand sectors, between 1990 and 2012, including pie chart with 2012 amounts (in kt) and shares (IEA, 2014)

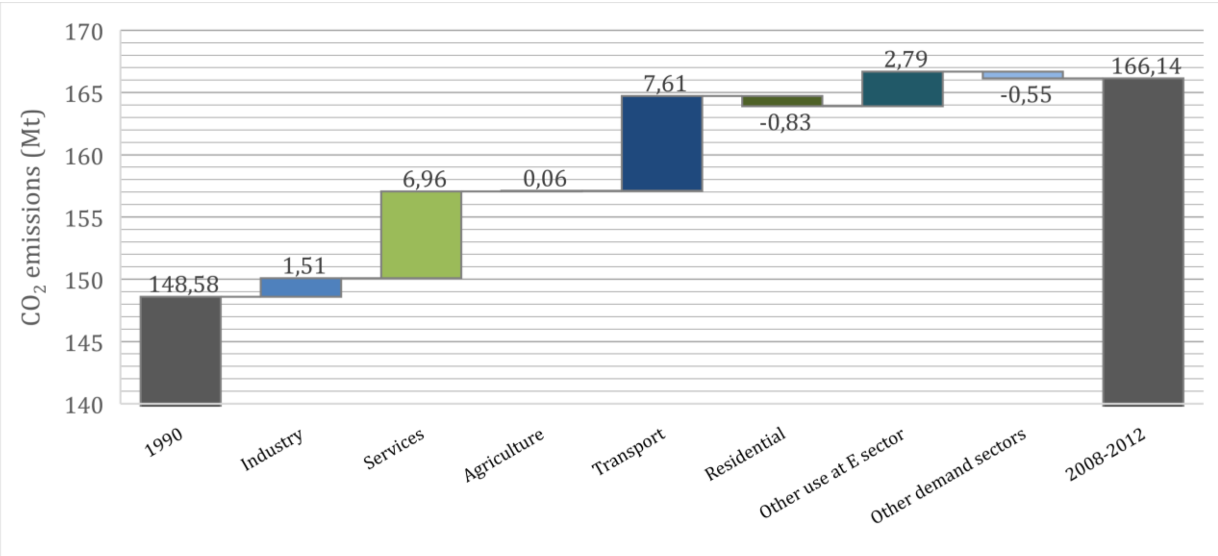

Figure 79 – Waterfall chart with contributions to energy-related CO_2 emissions from the different sectors to the 2008-2012 Kyoto target period with constructed amounts using IEA (2014)

Figure 78 shows that considering the different sectors, the industrial sector was historically responsible for the largest part of the emissions (23.9% in 2012). Considering the contribution to the Kyoto target period, especially the developments at transport and services have caused large increases in energy-related CO_2 emissions, as shown in Figure 78. Of the main sectors, only the residential sector showed slight reductions compared to 1990. In case of a frozen scenario – if all 'technology' factors would have stayed the same and only the activity determined CO_2 emissions – the emissions would have reached +25.62 Mt higher. Considering the overall (growth) developments, it can be expected that the energy sector's own use and the use by the other demand sectors would also have increased in a frozen scenario. Results of the LMDI decomposition calculations using 2008-2012 amounts are shown in Figure 80, revealing which effects were 'achieved' by the target period. The carbon factor effects as demonstrated at the sectoral decomposition analyses from electricity and heat use cover the largest part (90.1%) of the total effects from changes at electricity and heat supply. 10.9% of these effects is the result of electricity and heat use by the energy sector itself. Below each of the effects are shortly discussed, taking into account all developments that were found at the sectoral analyses that occurred in the different intervals up to 2012, which led to the final achieved emission levels over 2008-2012.

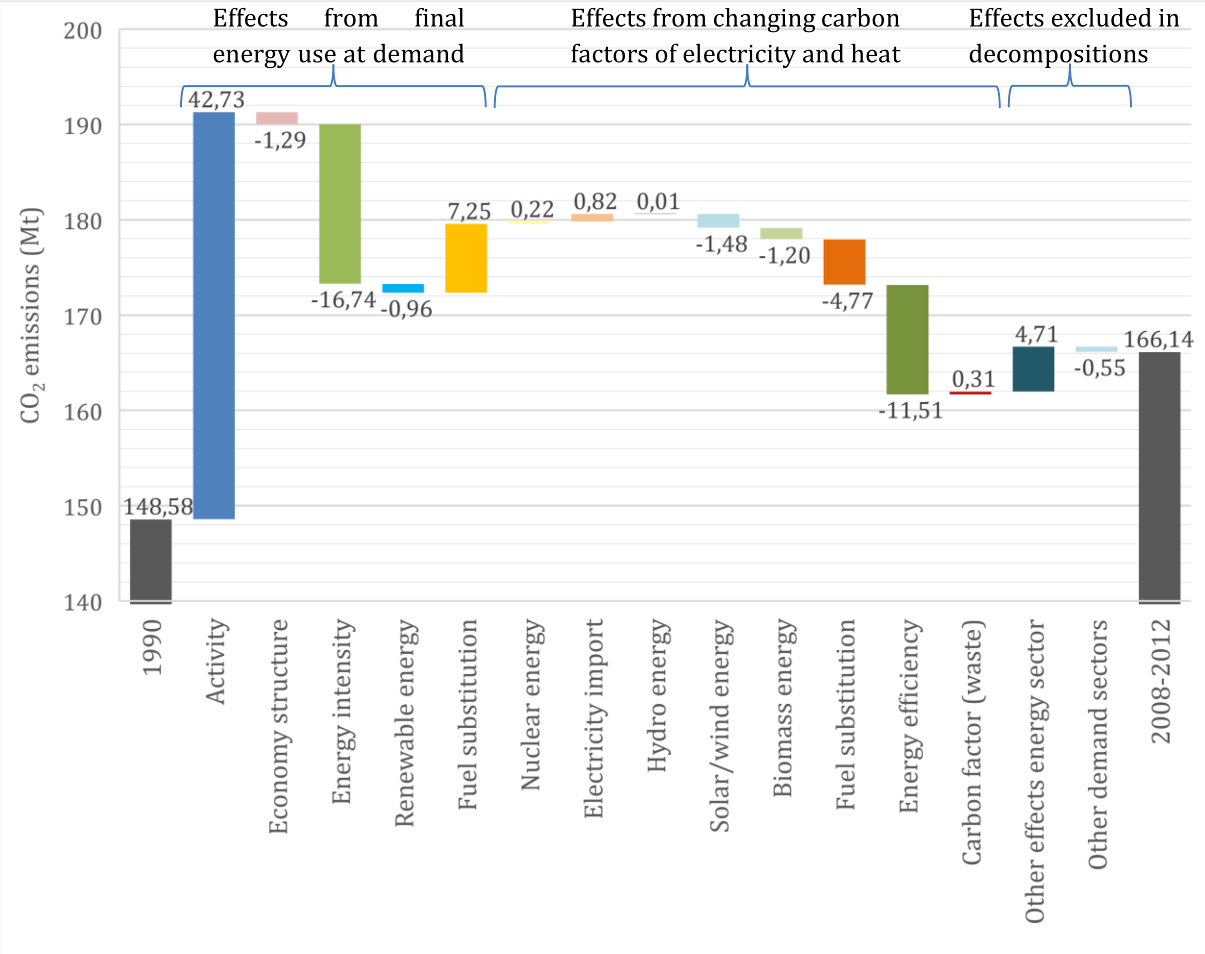

Figure 80 – Total effects achieved by the Kyoto target period considering energy-related carbon dioxide emissions. The first five effects took place at final energy use of the demand sectors, the following eight effects were due to the overall improving carbon factors of electricity and heat (taking place at electricity and heat supply) and the final two remaining effects are other effects at the energy sector and at the 'other demand sectors', which could not be included in the decomposition analyses

ACTIVITY EFFECT

This is the effect caused by the activity change occurring at the main demand sectors, responsible for a grand total of +42.73 Mt over 2008-2012. For the economy sectors (industry: +17.30, services: +10.42 and agriculture +3.89 Mt) this is the result of the economic growth, for transport the increase in travelled distance (+5.59 Mt) and for the residential sector the increased number of households (+5.53), as shown in Figure 81. The separate decomposition analyses showed that the activity effect was at each sector the largest effect to determine emissions, therefore responsible for large CO_2 increases. Only in the final interval downwards activity effects were found at all sectors but the residential sector, due to the global economic crisis (see also Figure 77). The economic development is expected to also have affected the level of activity at transport, but it did not come forward in the Netherlands as a reduced growth in number of households in the final interval. In case the upwards trend would have continued after 2008, inducing similar (average) yearly activity effects, the total activity effect would have reached up to +56.74 Mt by 2012. This is a simple estimation of the recession effect, not able to show its effect over 2008-2012, but it does show that the recession had a large impact as the activity was +42.73 Mt instead. Doubts were raised whether the chosen activity indicators are able to properly represent the energy use, which may have led to an overestimation of the effects, subsequently partially offset by overestimated energy intensity effects. For none of the sectors energy and climate policies aimed to restrain the level of activity in order to reduce CO_2 emissions.

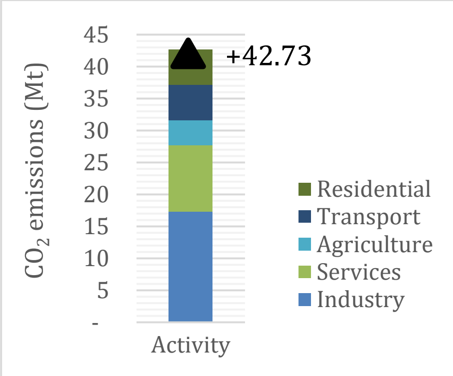

Figure 81 – The activity effect achieved by Kyoto 2008-2012 at the main demand sectors

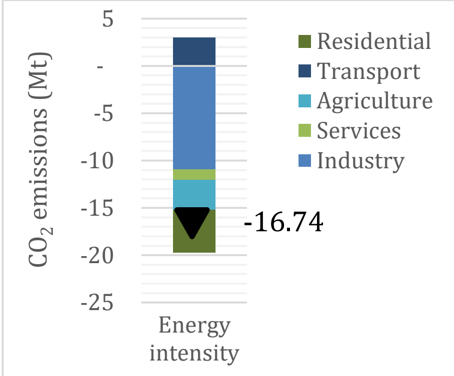

Figure 82 – The energy intensity effect achieved by Kyoto 2008-2012 at the main demand sectors

ECONOMY STRUCTURE EFFECT

A part of the activity effect of the economy sectors from its total economy growth in the Netherlands was cancelled out by a negative economy structure effect: -1.29 Mt. This is a 4.1% offset of the activity growth of the economy sectors. The separate analysis of the economy structure (Chapter 8) showed that the main shift over the years has been towards the service sector, at the expense of the energy-intensive industry and agriculture. Within the industry especially the developments at the chemical and petrochemical industry were influential due to its relatively large importance and high energy intensity. Despite the large upwards effect found in the final interval (a shift back to intensive industry and agriculture, see also Figure 77), the changed economy structure that came forward over 2008-2012 was clearly towards the less intensive service sector. This is not an effect to be influenced by energy and climate policies, but rather an effect due to a changing society demanding more tertiary activity.

ENERGY INTENSITY EFFECT

The energy intensity effect is the result of the changing energy intensity of the activities at the demand sectors. Over 2008-2012 all sectoral energy intensities had immensely improved compared to 1990 (Figure 82), except the energy intensity of transport (+2.96 Mt). Energy intensity improvements at the industry were responsible for the largest reductions (-10.94 Mt), followed by the residential sector (-4.50 Mt), agriculture (-3.13 Mt) and finally services (-1.13 Mt). At each sector the main policy strategy was to improve the efficiency of energy use, with that possibly inducing energy intensity effects. The efficiency measures are essentially different between sectors, as each have inherently different processes and accordingly energy demand. At all sectors but transport a clear correlation with the deployed instruments was demonstrated, as new instruments were introduced regularly up to halfway the research period, after which the intensity stayed more stable. This also clearly comes forward in Figure 77. The energy intensity is however a complex factor, significantly influenced by the choice of activity indicator. For the economy sectors this mostly implied that the effect is probably overestimated because the GVA may not best describe the energy use, therefore giving apparent effects which are not really energy intensity effects. At transport the energy intensity effect still withholds a structure effect as a result of the use of an aggregated activity indicator (pkm+tkm). The observed shift towards more energy-intensive transport modes is expected to have been an important cause of the worsening energy intensity that occurred here, despite the efforts to improve the energy efficiency at transport. At the residential sector a structure effect from changing household sizes is ought to be an important effect affecting the energy intensity of households, giving an underestimation of the achieved conservation effects. For all energy intensity effects, a part must also be ascribed to autonomous improvements.

RENEWABLE ENERGY EFFECT (AT FINAL DEMAND)

The renewable energy effect due to the use of renewable energy sources in final energy units at the demand sectors has been small compared to the other effects occurring at the demand sectors. Altogether reductions of only -0.96 Mt were achieved over 2008-2012 (Figure 93). Large differences in renewable energy use were observed between sectors, due to the applicability of these sources at the sectors. At services an upwards effect was found (+0.03 Mt), mostly caused by the reduced use of biomass, despite the (also small) constant increase of solar energy use. At the industry the use of biomass increased, used at only six of the twelve subsectors, responsible for -0.05 Mt. The energy and climate policies in these two sectors had however also not expressed the intent to achieve renewable energy effects. This was different for the residential sector, where a similarly small effect was found of only -0.04 Mt. Looking deeper into the data shows that it was solar energy that caused sustained reductions, counteracted by reduced biomass use (wood stoves). At agriculture a larger effect was found of -0.19 Mt from biomass use and to a smaller extent geothermal energy, both part of the policy strategy. At transport the renewable effect was largest: -0.71 Mt by 2008-2012 due to increased biofuel use that was promoted to decarbonize this sector. For the latter three sectors (residential, agriculture and transport) a correlation with the deployed energy and climate instruments was very clearly indicated, which were all introduced in the second half of the research period. This also comes forward at Figure 77, where the renewable energy effect is only visible in the final three intervals. Despite the clear correlation, a part of the effect must also be accounted for by autonomous improvements.

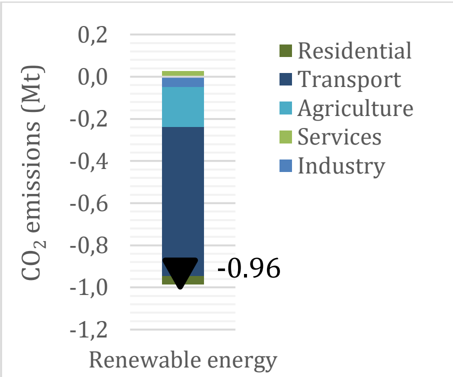

Figure 83 – The renewable energy effect achieved by Kyoto 2008-2012 at the main demand sectors

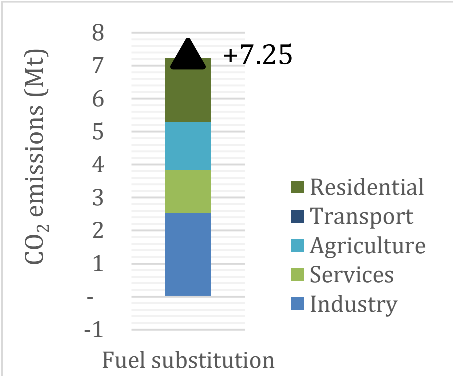

Figure 84 – The fuel substitution effect achieved by Kyoto 2008-2012 at the main demand sectors

FUEL SUBSTITUTION EFFECT (AT FINAL DEMAND)

The fuel substitution effect at the final demand sectors induced CO_2 increases of +7.25 Mt in total over 2008-2012 compared to 1990 (Figure 84). At the industry the largest effect occurred (+2.53 Mt), caused mostly by the increased use of CHP heat with its relatively large carbon factor. A part of this effect will be cancelled out by a simultaneously occurring energy intensity effect, as heat requires less units of final energy. This CHP trend also caused a part of the fuel substitution effects as observed at agriculture (+1.45 Mt) and services (+1.32 Mt), which explains why the largest fuel substitution effects were found in the nineties (see also Figure 77). At agriculture the increased use of electricity as opposed to gas overruled the CHP trend (which also reversed back to own CHP exploitation). At services the increasing share of electricity also played an important role, caused by the widespread digitalization, which rather signifies a shift in functions. This function shift towards electric appliances was also the main trend at the residential sector, enhanced by the reduced energy use required for space heating, together causing a fuel substitution effect of +1.95 Mt for 2008-2012. Only at transport the fuel substitution effect was downwards, though negligible (-0.27 kt) with the introduction of gas as transport fuel. The transport sector was however the only sector where fuel substitution was part of the decarbonization strategy. The increased electricity use however counteracted substitution by gas, due to its large carbon factor, which should again be accompanied and compensated for by an energy intensity effect. The fuel substitution effect may also have been indirectly affected by other policies in place, also in other sectors, like those that promote CHP, instruments that more generally promoted CO_2 reductions (ETS, car labels), the indirect influence of the fuel mix by instruments targeting certain specific fuels (energy tax) or the targeting of specific functions (heat demand of buildings versus electric appliance use).

NUCLEAR ENERGY EFFECT

The use of nuclear energy takes place at the production of electricity, therefore affecting the carbon factor of electricity. Its slight decrease in the electricity mix caused small CO_2 increases over the years (see also Figure 11), inducing an effect of +0.22 Mt over 2008-2012 compared to 1990. Due to the disadvantages of radioactive waste, increasing the use of nuclear plants is not part of the decarbonization strategy in the Netherlands.

ELECTRICITY IMPORT EFFECT

The effect due to net electricity import slightly increased emissions over 2008-2012 with +0.82 Mt, as a result of its decreased share in the electricity mix. Over the years the import has fluctuated a lot causing unstable effects (see also Figure 11)← , as it is very dependent on the electricity prices abroad compared to domestic production costs. This explains why the effect achieved by 2012 was upside down, when total CO_2 reductions were quantified as -1.52 Mt. To achieve domestic CO_2 reductions through increasing the electricity import was not expressed in Dutch energy and climate policy documents.

HYDRO ENERGY EFFECT

The effect from hydro energy was almost insignificant (see also Table 5). The reduced share of hydro energy in the total electricity mix is responsible for a slight increase of +7.15 kt CO_2. For the Netherlands the hydropower potential at the rivers seems to have reached its limit, as it was also never mentioned in energy and climate policies.

SOLAR/WIND ENERGY EFFECT

The effect due to the increased production of electricity from solar and wind installations was responsible for reductions of -1.48 Mt. This effect at electricity supply can for 98% be assigned to the production of electricity from wind turbines (CBS, 2016b), which was also the main focus of the instruments here. A clear correlation is present with the increased intensity of instruments focusing on renewable energy penetration, which clearly accordingly increased with each interval for the solar/wind category (see also Figure 11). However, also here not the full effect can be assigned to the instruments as a part of the newly installed capacity would also have been invested in without policy intervention.

BIOMASS ENERGY EFFECT

Biomass is used at both electricity and heat production, also linked through its use at CHP plants. The share of biomass in heat production has however decreased towards 2012, unable to weigh out the large fossil based CHP capacity increase (see also Figure 16), causing an increase of +0.50 CO_2. The effect from the increased use of biomass at electricity production on the other hand amounted to -1.69 Mt. With that the net effect of -1.20 Mt was the result of overall increased biomass use at electricity and heat production over 2008-2012 (Figure 85). The incineration of biomass at electricity plants was also a focus of the instruments, though the production of heat is also linked to electricity production through CHP. Especially after 2000 the intensity of instruments promoting biomass at electricity production increased, in line with an increased effect towards the end of the research period (see also Figure 11).

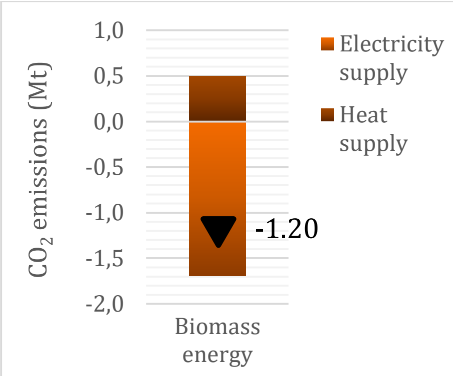

Figure 85 – The biomass energy effect achieved by Kyoto 2008-2012 at electricity & heat supply

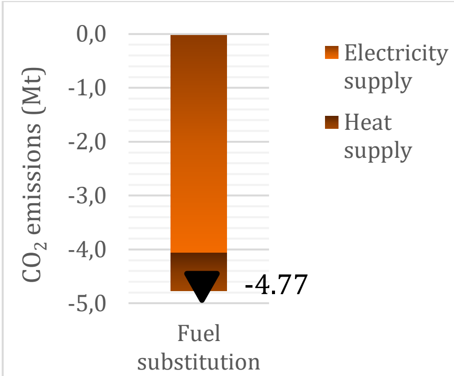

Figure 86 – The fuel substitution effect achieved by Kyoto 2008-2012 at electricity & heat supply

FUEL SUBSTITUTION EFFECT (AT ENERGY PLANTS)

Fuel substitution at electricity and heat supply was responsible for a relatively large effect of -4.77 Mt (Figure 86). At both electricity and heat supply the main shift was the substitution of coal by gas. After 2002 there was a slight shift back to coal at both subsectors (see also Figure 19). The fact that similar trends were observed is partly because of the strong link between sectors through CHP. To achieve fuel substitution effects at electricity and heat production was never clearly expressed in energy and climate policy, but it was indirectly influenced by the promotion of CHP (which involves cleaner gas). Also the EU ETS may have indirectly promoted fuel substitution. The fuel prices (low coal price) were however probably more influential, overruling the development as observed at the final intervals.

ENERGY EFFICIENCY EFFECT

The energy efficiency effect was the largest effect that took place at electricity and heat supply, responsible for -11.51 Mt CO_2 reductions (Figure 87). The efficiency effects at these two subsectors went through similar pathways, again largely due to their strong link through CHP production. The energy efficiency improvements achieved over 2008-2012 were also clearly dominated by the improvements occurring up to 1998. Here large energy efficiency effects were achieved due to the increased CHP use, improving the overall energy efficiency. After 1998 this development stagnated again and the slightly worsening electric and thermal efficiencies caused small CO_2 increases (see also Figure 19). To improve the efficiency through CHP was also the main policy strategy at electricity and heat supply in the nineties. Improving electric and thermal efficiencies was to a much smaller extent represented in energy and climate policy, explaining the disappointing results here. The liberalization of the electricity market and autonomous improvements were also identified as factors to have influenced the energy efficiency effect.

CARBON FACTOR EFFECT (OF WASTE)

At electricity and heat supply the overall worsening carbon factor of waste caused an effect of +0.31 Mt on emissions over 2008-2012. Waste was used at both types of energy production (and at CHP), giving comparable effects (Figure 88). Especially after 2002 the carbon factor effect was large (see also Figure 19), due to the change of the submix that the non-biomass fraction of waste consists of. None of the energy and climate policies aimed to affect the emission factor of waste. In fact, it might have been the case that the worsening waste mix is the indirect effect of better waste recycling.

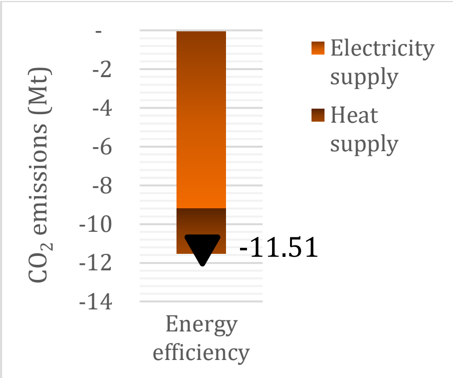

Figure 87 – The energy efficiency effect achieved by Kyoto 2008-2012 at electricity & heat supply

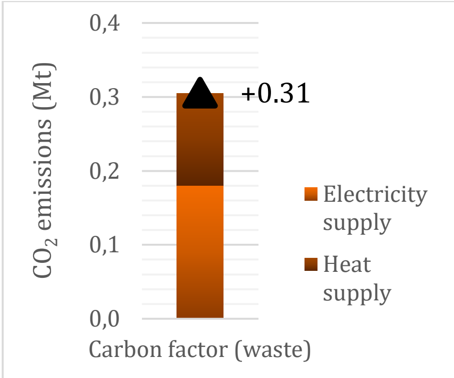

Figure 88 – The carbon factor effect (waste) achieved by Kyoto 2008-2012 at electricity & heat supply

OTHER EFFECTS ENERGY SECTOR

Historically the emissions due to the other energy use at the energy sector (inputs into transformation processes and own energy use) have increased by +2.79 Mt (Figure 89 and also Figure 79). The improved carbon factors of electricity and heat were responsible for respectively -1.00 and -0.92 Mt, which means that the other effects which could not be included in a decomposition analysis (effects for example from activity increase or fuel substitution) have caused an increase of +4.71 Mt (Figure 89 and also Figure 80). Some of the energy and climate instruments may have influenced emissions from this other energy use at the energy sector, but these effects could not be further quantified.

EFFECTS AT OTHER DEMAND SECTORS

The changes occurring at the other demand sectors were not large, but altogether responsible for -0.55 Mt CO_2 reductions (Figure 90). The non-specified sector decreased with -0.48 Mt as only heat and some coal use was reported up to 1994. For fishery energy use (oil) was only reported in the final years, therefore giving an increase of +0.26 Mt. Data of these sectors is therefore considered fairly unreliable. Data available for domestic aviation and navigation was on the other hand more consistent, with aviation showing a decrease of -0.35 and navigation an increase of +0.02 over 2008-2012 compared to 1990. No effects from the changing carbon factors of electricity or heat use needed to be distinguished here. Which underlying effects drove the changes that took place at these 'other demand sectors' was not further examined as the sectors could not be included in the decomposition analysis.

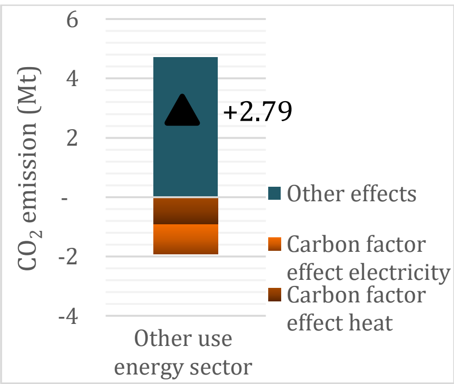

Figure 89 – The effects achieved by Kyoto 2008-2012 at own use of the energy sector

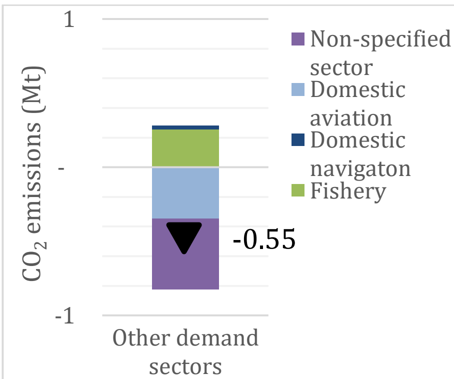

Figure 90 – The effects achieved by Kyoto 2008-2012 at the other demand sectors

12. CONCLUSION

In 1997 the Netherlands signed the Kyoto Protocol, with that committing to reduce average greenhouse gas emissions over 2008-2012 with 6% compared to 1990 levels. The Netherlands was able to reach this target, thanks to the large reductions achieved at the non-CO_2 GHGs and the acquirement of carbon credits to compensate for the excess emissions. Energy-related CO_2 on the other hand have shown a large increase between 1990 and 2012. According to the sectoral construction method used here, energy-related emissions increased by 11.8%, from 148.58 to 166.14 Mt (+17.56) over 2008-2012. In order to better curb these emissions in the future the following research question was defined:

What were the driving factors of energy-related carbon emissions from combustion during the first Kyoto period (1990-2012) in the Netherlands and how can they be attributed to energy and climate policies?

LMDI decomposition analyses on the sectors revealed that three main drivers can be distinguished which together explain 82.5% of the total change in energy-related CO_2 emissions. By far the largest driver was the activity growth, responsible for an increase of +42.73 Mt in the target period. A large part is the result of an ethic of continued economic growth, slightly offset (-1.29 Mt) by the economic structure effect shifting towards the tertiary sector. The economic growth was also related to the activity growth at transport. At the residential sector the underlying trend was a stable population growth from a birth surplus mostly. None of these activity developments were targeted by energy and climate policies as a strategy to reduce energy-related emissions. The development that did substantially influence activity levels was the global financial crisis; the second identified main driver during Kyoto. In case activity growth would have continued as it had between 1990 and 2008, the activity effect would have reached up to +56.74 Mt by 2012. Evidently the recession was an important factor contributing to the Kyoto target, as the activity effect over 2008-2012 was +42.73 Mt instead.

The third main driver of emissions considers efficiency improvements; historically the main decarbonization strategy in the Netherlands. At the demand sectors this influenced the energy intensity effect, in total quantified as -16.74 Mt over 2008-2012. A clear correlation was indicated with the energy and climate policy – essentially different at each sector – as the effect grew with the regular introduction of new efficiency instruments until the turn of the century, thereafter both staying stable. Only at transport the energy intensity did not improve despite the policy efforts, presumably the result of the observed modal-split developments. Also at the other sectors other hidden effects were found to have influenced the energy intensity effect specifically. At electricity and heat supply – where indirect emissions of electricity and heat use occur – efficiency improvements came forward as an energy efficiency effect of -11.51 Mt CO_2 compared to 1990. These improvements can mainly be ascribed to the increased use of CHP, inducing large reducing effects up to 1998 in line with the main policy strategy focusing on CHP in the nineties. Here as well the achieved effect is not equal to the savings effect, as it was also influenced by other effects which would also have occurred without these policy instruments.

In short, the continued (economic) growth, the recession and the efficiency improvements were the main drivers of the energy-related CO_2 emissions during the first Kyoto period. Only the latter can partly be attributed to energy and climate policies, which took place as measures for energy conservation of final use at the demand sectors and secondly CHP encouragement addressing indirect primary energy inputs occurring at electricity and heat supply.

13. DISCUSSION

POSSIBLE PRESENCE OF HIDDEN FACTORS

Any decomposition analysis stands or falls with the choice for meaningful equations (with its factors) and the chosen indicators to express the factors. The choices made here as justified in the method section were mostly led by data availability and general time constraints, but also needed to take into account the comparability of the sectors and the aggregated nature of the level of analysis. The choice of activity indicators induced some implications, as these were not straight-forward like the energy-related indicators. They were chosen carefully, also deriving from decomposition literature, as they need to be good determinants of energy use. At the economy sectors the issue of the choice of activity indicator (GVA) is most exemplary. Other indicators like physical product output for manufacturers may better explain a sector's energy use. The GVA was however *available* for all economy sectors and additionally allowed to *compare* the economy sectors with an economy effect. The ratio of GVA to physical output is therefore a hidden factor that plays a role in determining the energy use. Without any *time constraints* certain hidden factors could be further researched and quantified into effects. However, to keep the different analyses manageable and also *comparable* to the other (non-economy) sectors, the amount of effects was limited. Another issue is that on this *aggregated nature of analysis* multiple kinds of energy use are under consideration. For example, a doubling of GVA may mean twice as much electricity use to run the machines, but not necessarily a doubling of heat demand of the factory (a hidden structure effect). The activity indicator GVA was especially complex, but similar issues came up at transport using the sum of pkm & tkm and at the residential sector using number of households, as were discussed in more detail at the end of each chapter. The implication therefore involves that hidden factors were sometimes still present in between the activity and the energy intensity effect. Depending on the sector, effects that were subsequently still incorporated in the energy intensity have led to an overestimation or an underestimation of the genuine savings effect from efficiency efforts. Future research with a more sectoral focus using more detailed data could continue on the quantification of these hidden effects due to the activity indicators used here, like: different complex effects from GVA, the modal-split occurring at transport and possible structure effects like people per household affecting different kinds of energy use at the residential sector.

INTERACTION BETWEEN FUEL SUBSTITUTION AND ENERGY INTENSITY

Another important implication of this research arises from the interaction between fuel substitution and the energy intensity effects at the demand sectors. The total fuel substitution effect was (substantially) upwards (+7.25 Mt), which is remarkable when the general trend was a substitution of own heat production by purchasing (CHP) heat, which should overall lower CO_2 emissions. However, due to the higher carbon factor of heat, the substitution of own production to heat purchase induces an upwards CO_2 effect. At the same time a downwards energy intensity effect occurs, as final heat requires less energy units than the former (own) inputs for the same heat production. The problem is that the function demand (warmth) is not included, which is why the fuel substitution in this case should be cancelled out by an energy intensity effect. At the analysis of electricity and heat supply the fuel substitution effect did describe genuine substitution, because the produced electricity or heat (function demand) by a certain fuel was included in the equation. This also allowed to show the efficiency effect from the ratio between inputs to function (conversion). Another issue of the fuel substitution effect on the level of the demand sectors is that when different functions are involved (warmth, electric power and sometimes even transport) the substitution effect may rather describe a substitution of functions, as came forward for example at the service sector. Both implications of the fuel substitution effect and the energy intensity effect could not be avoided here, because on this level of analysis the function fulfilled by each energy source is unknown. It is therefore important to keep in mind at the demand sectors that the energy intensity also improves from a result of the use of more efficient energy carriers and that fuel substitution is affected counterintuitively by this same development. Only a lower level of analysis incorporating the fulfilled functions could provide insight into the genuine fuel substitution effects, energy intensity effects and even energy efficiency effects. At this research the fuel substitution effects were mostly overestimated (and cancelled out by energy intensity effects) as a result of the CHP heat developments, or due to a shift in functions (more use of electric appliances).

IEA DATABASE IMPLICATIONS

Another explanation for the relatively high fuel substitution effects from (CHP) heat and in fact all effects as a result of heat use – and relatively low effects from electricity use – are due to the allocation of inputs using the energy content. Allocating to exergy when CHP is considered is proven a better method, but as within the used IEA database the own use from decentral CHP heat production was already allocated using energy content, mixing two methods would give inconsistent results. Only a more detailed database would be able to reveal better CO_2 amounts from heat and electricity consumption. At the electricity and heat sector the effects were therefore viewed in parallel, but at the demand sectors this implied a general overestimation of effects of heat and an underestimation of effects from electricity use. Another possible solution may be to execute a decomposition of energy use and leave the conversion to CO_2 emissions as a final step, to improve transparency from the interrelationship between demand and supply. The question remains whether this would be an improved method; the charm of the method that was chosen here is precisely to be able to include indirect emissions more evidently. It was also hinted that also the other indirect emissions occurring at the energy sector (especially from oil refineries) may give an even fairer picture of CO_2 effects from energy use of the demand sectors. These CO_2 emissions comprise a large share of total energy-related emissions and increases were a substantial +4.71 Mt by 2008-2012.

Besides the implication of the energy allocation at the IEA database, more drawbacks were found due to the use of the IEA dataset (see Appendix C for an extensive list). A very important drawback originates from the fact that the data before 1995 is unreliable. CBS itself – which was nevertheless the basis for the IEA data – does not publish this data at the moment because of a lack of basic data during that period. When examining the full Kyoto period this data weakness can however not be avoided. As it is unclear which data was missing exactly before 1995, it is difficult to estimate how this has affected the results in the first two intervals. The results seem to indicate that especially the heat data was influenced. At the time of writing, the CBS has however revised its statistical data for 1990 to 1994, as published on October 12th (CBS, 2016l). The most recent national energy exploration report by ECN using this updated data, shows that this adjusted data result in larger achieved emission reductions, differing by four percent points (Schoots et al., 2016). Another main disadvantage of this database is its simplified character, which hindered the possibility to uncover interesting other effects. Especially the aggregated character of transport disallowed to show the already mentioned modal-split effect, but also to allocate freight transport to the responsible economy sector. This second shortcoming led to an overall underestimation of the energy intensity of the economy sector, as their energy use for transport also contributes to their economic activity. The economy structure effect is therefore accordingly overestimated. The simplification of the IEA database also disallowed to reveal the possible effects from different types of oil and coal use. Especially the submix of oil varied substantially between sectors and in time, inducing a changing carbon factor which may especially have substantially impacted the transport sector. Including more subfuels may also be able to explain the difference in constructed CO_2 emissions compared to the official CRF inventories and result in better decomposition effects. At last the incorrect certification of CHP plants that was found at the IEA database, in combination with the allocation of inputs to own use, disallowed to uncover the possible effect from a shift towards CHP production and decentral production. Both types of shift developments have influenced the overall energy efficiency; its quantification into an effect may be valuable especially to better estimate policy effects. Only more detailed (and better) databases are able to resolve the above issues. For the scope of this research these implications were surmountable. An important advantage of using the IEA database is the possibility to compare effects with other countries, without the risk of having different underlying assumptions between countries' databases, offering an interesting potential for future research.

POLICY IMPLICATIONS

Two final points may be able to significantly improve the results especially valuable for policy implications, being 1) an additional analysis which takes out the effects from autonomous improvement and 2) a sensitivity analysis – especially taking into account the effects from using certain time intervals – to provide confidence intervals of the achieved effects. Nevertheless, the research was able to indicate the main drivers of emissions up to the 2012 Kyoto target and their link with energy and climate policies in the Netherlands; already of significant value for the implications of future energy and climate policy. The largest driver was the effect from activity as a result of continued growth at all sectors, slightly offset by the economy structure shift towards services. Limiting this growth has historically not been a part of the decarbonization strategy, as the concept of 'sustainable development' is rather viewed as the goal to keep ongoing development possible, without having a similar growth in environmental impact (i.e. CO_2 emissions). This subject is to some extent a taboo in policy, for economic reasons mostly, but also because reducing activity has a lot to do with our lifestyles. Interfering here by somehow limiting economic growth, travelled distance or the number of households is undesirable (and maybe even unethical) from a political point of view. However, this growth does not (yet) occur sustainable as it is not decoupled from energy-related emissions. The impending undesirable climate change as a result of these CO_2 effects therefore justifies limiting activity as the ethically right thing to do. The global crisis also showed the CO_2 impact of reduced activity, indicated as the second large driver contributing to reaching the 2012 Kyoto target. According to Peters et al. (2012) the effects of the latest 2007/2008 crisis are however already rebounding. Of course provoking a new crisis is undesirable, but creative solutions should be sought to start abating the large activity effects, starting from a politics of happiness instead.

The effects from efficiency improvements influencing both the energy intensity of the demand sectors and the efficiency of electricity and heat supply were found as the third important driver of emissions until Kyoto 2012. A correlation was shown here with deployed energy and climate instruments, indicating that these can be considered responsible for a considerable part of the CO_2 reductions there. This does not necessarily imply that policies should continue to focus on efficiency improvements; at some point the theoretical potential of energy efficiency will be reached. The major advances for example made in the nineties with CHP may indicate that in this area more room for improvement may be marginal, let alone relatively costly. Decomposition analysis using future scenarios could give insights into potential future effects. In this light the potential for renewable energy effects may therefore be more promising. Historically the renewable energy effect is not considered a large driver in reaching the Kyoto target (-3.63 Mt), as it increased its share from only 1.2 to 4.7% in final energy use. If the 2020 target of 14% will be reached the renewable energy effect will certainly be much larger. Which types of renewables still offer potential does not come forward from this research, but the deployed instruments did show a clear correlation with demonstrated renewable energy effects, indicating the possible effectiveness of future instruments promoting renewable energy sources.

Considering future national CO_2 targets, the decomposition results showed that net electricity import and nuclear energy could also potentially help achieving substantial reductions. However, this would certainly be condemnable, taking into account other environmental impacts. Fuel substitution also offers potential, especially at electricity and heat production where -4.77 Mt CO_2 reductions were achieved as coal reduced its share from 38.2 to 20.8% of energy production. The further or even complete substitution of coal by gas will certainly induce even larger emission reductions. At final demand the potential of fuel substitution is more difficult to oversee, due to the above discussed complexity of this decomposition factor. A strategy of fuel substitution at all sectors has been too unspecified in the past, which signifies that there is a need for more explicit policy instruments to promote the shift to cleaner fuels. Again decomposition analysis using scenarios could quantify the potentials of different decarbonization strategies. Taking into account these listed recommendations which followed from the historical developments during 1990-2012 as elaborated in this research may help reaching the increasingly challenging climate targets, in order to combat climate change more effectively in the future.

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APPENDIX A - TIME PERIODS FOLLOWING THE POLITICAL AND THE ECONOMIC SITUATION

The chosen intervals (1990-1994-1998-2002-2008-2012) for the LMDI decomposition analyses were executed followed the political (Table A1) and the economic situation (Figure A1) of the Netherlands.

The first three periods perfectly follow the political periods of Lubbers III, Kok I and Kok II. The Gross Domestic Product (GDP) in constant 2010 prices grew in all three periods, with 8.6% until 1994, 16.5% until 1998 and 12.0% until 2002. The GDP per capita shows a similar trend. Between 2002 and 2008 the country's GDP increased with another 14.1% to a maximum value of 647.2 billion Euros. The political environment on the other hand was turbulent, with three cabinets led by prime minister Balkenende collapsing, but with a constant centre-right orientation. The last research interval (2008-2012) is characterized by the financial crisis followed by the European debt crisis, accompanied with a 1.8% decrease in Dutch GDP. The political situation was mixed: centre-left in the first half until 2010 and centre-right second half of the interval.

Table A1 – Cabinets in the Netherlands between 1990 and 2012 (Rijksoverheid, 2015)

Period	Cabinet	Political ideology	Orientation
1989-1994	Lubbers III	Christian democratic (CDA) Social democratic (PvdA)	Centre-left
1994-1998	Kok I	Social democratic (PvdA) Economic liberalism (VVD) Social liberalism (D66)	Purple
1998-2002	Kok II	Social democratic (PvdA) Economic liberalism (VVD) Social liberalism (D66)	Purple
2002-2003	Balkenende I	Christian democratic (CDA) Right wing populism (LPF) Economic liberalism (VVD)	Centre-right
2003-2006	Balkenende II	Christian democratic (CDA) Economic liberalism (VVD) Social liberalism (D66)	Centre-right
2006-2007	Balkenende III	Christian democratic (CDA) Economic liberalism (VVD)	Centre-right
2007-2010	Balkenende IV	Christian democratic (CDA) Social democratic (PvdA) Christian democratic (CU)	Centre-left
2010-2012	Rutte I	Economic liberalism (VVD) Christian democratic (CDA)	Centre-right

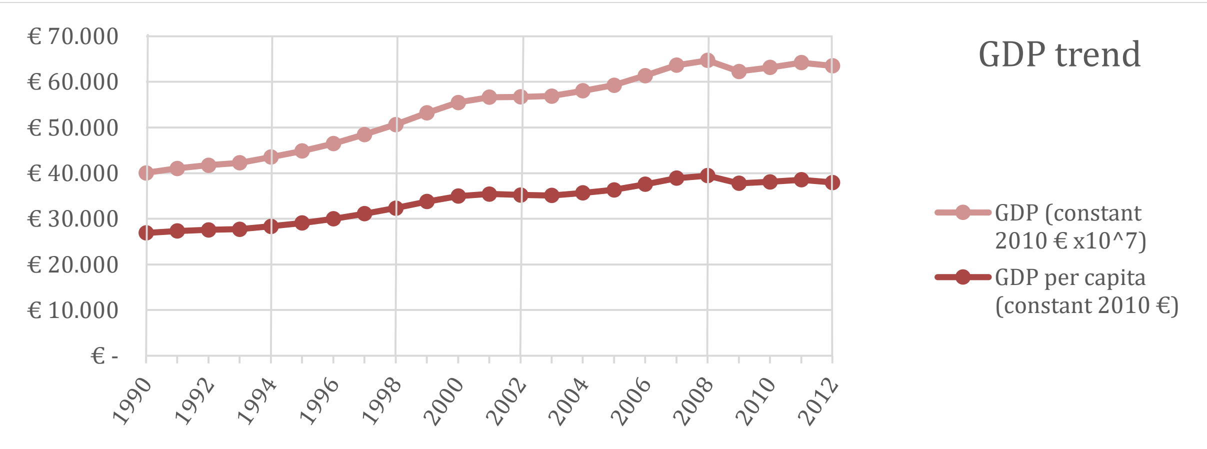


Figure A1 – The economic situation in Gross Domestic Product (GDP) in constant 2010 Euros and GDP/cap in the Netherlands between 1990 and 2012 (CBS, 2015b; World Bank, 2015)

APPENDIX B - BOUNDARIES OF THE MAIN DEMAND SECTOR CATEGORIES

Below follows an explanation on which subsectors are covered in the main demand sectors. The subdivision follows the balance definitions of IEA (2016a) applicable for the used energy dataset (IEA, 2014), which in their turn abide by the ISIC (International Standard Industrial Classification).

INDUSTRY

The industry is subdivided into twelve different subsectors of industry. (1) The basic metal industry comprises the manufacture of basic metals (iron, steel and non-ferrous metals) and the casting of metals. (2) The chemical and petrochemical industry includes chemicals, chemical products and pharmaceutical products and pharmaceutical preparations. (3) The subsector of non-metallic minerals covers products such as glass, ceramic and cement. (4) Transport equipment is about motor vehicles and the related manufacture of trailers, parts and other accessories. (5) Machinery includes fabricated metal products, electronics, machinery and equipment. (6) The category 'mining and quarrying' only excludes the recovery of fuels. (7) The subsector 'food and tobacco' also includes beverages. (8) Paper, pulp and print covers the manufacture of paper & paper products and printing & reproduction of recorded media. (9) The industry of wood and wood products includes also articles of cork, straw and plaiting materials, but excepts furniture. (10) Construction is about the construction of buildings, civil engineering and specialized construction activities. (11) Textile and leather also includes the manufacture of other apparel. (12) Lastly the manufacture of rubber and plastic products, furniture, and other goods (such as: jewellery, toys and umbrellas) comprise the so-called non-specified industry.

SERVICES

The service sector includes all commercial and public services. A number of different types of subsectors can be distinguished which all together make up the service sector:

- Repair and installation of machinery and equipment
- Water supply (including sewerage, waste management and remediation activities)
- Wholesale and retail trade (including repair of motor vehicles and motorcycles)
- Warehousing and support activities for transportation
- Postal and courier activities
- Accommodation and food service activities
- Information and communication
- Financial and insurance activities
- Real estate activities
- Professional, scientific and technical activities
- Administrative and supportive service activities
- Public administration and defence (including compulsory social security)
- Education
- Human health and social work activities
- Arts, entertainment and recreation
- Other service activities
- Activities of extraterritorial organizations and bodies

AGRICULTURE

The main demand sector called agriculture comprises the activities in agriculture itself (crop and animal production, hunting and related activities), but also includes forestry and logging. The related energy use in this subsector occurs at traction (excluding agricultural highway use) and with the agricultural and domestic use of power and heating. Fishery is excluded from this sector due to a lack of data.

TRANSPORT

The transport sector covers all transport activities of people and load over rail, road, water and through the air, regardless of the economic sector that it may belong to. Excluded is only the use of vehicles on the company site (like agricultural machinery). The subsectors covered in the whole transport sector are:

- Domestic aviation[1]
- Road
- Rail
- Pipeline transport[2]
- Domestic navigation[1]
- Non-specified transport[2]

[1] For the decomposition analysis domestic aviation and navigation were excluded because of the absence of relevant activity indicators.
[2] In the Netherlands the energy use of the subsectors pipeline transport and 'non-specified' transport have historically been zero between 1990 and 2012.

RESIDENTIAL SECTOR

The residential sector concerns the non-commercial daily living of people in dwellings. This excludes the institutional housing of people from the residential sector, which are part of services. Energy use for transport of household members is covered in the transport sector.

APPENDIX C - DRAWBACKS OF THE IEA DATABASE

In this research the IEA database was the source for all energy-related data, as opposed to the more obvious Dutch CBS StatLine database. The main reason for this choice is that the IEA database also covers data before 1995, which the CBS does not publish anymore because important basic energy data was missing for these years (CBS, 2005). The source of the IEA data is still the (old) CBS datasets which implies that data up to 1994 is biased. Furthermore, the tables as published by the IEA are in some aspects simplified, which means that some important trends could not be further researched as the microdata was not available. Also other striking features were found in the data. Below follows a list containing the drawbacks and its implications that came forward during this research:

- The IEA database did not distinguish for different subtypes of fossil fuel categories. This implied that average carbon factors for the categories needed to be used. Between sectors the submix of fossil fuels could however vary significantly.
- Variations of carbon factors over time could also not be taken into account for the overarching fuel categories. Especially for transport for example the sub-substitution between different oil types (gasoline and diesel) may have significantly influenced the carbon factor of the oil category. Only for the fuel category 'waste' the changing carbon factor could be taken into account, deriving from CRF inventories, which was legitimized because the waste data was compatible.
- The construction of energy-related carbon dioxide emissions with average carbon factors for the overall fuel types (except for waste) led to an overall overestimation of emissions (+1.5% on average). Also the fact that CRF inventories are expected to have used the most up to date data, which is every year adapted on the basis of the newest definitions, may have contributed to the difference in total amounts.
- The combined category of solar/wind is also pitiful as it disallowed to quantify the effects separately for solar or wind energy. This specifically impacted the specifically the analysis of the electricity and heat supply, at the other sectors with reported final solar/wind use (services and the residential sector) it could be deducted that this comprised solar energy only. The individual effects at electricity and heat supply from solar or wind needed to be estimated using more detailed CBS data.
- Within the IEA database, the production of heat that was used by the (auto)producer itself, was accounted for as final consumption of the primary inputs, using an allocation method on the basis of energy content. To avoid the use of two different methods, the allocation on the basis of energy content was therefore adopted to allocate inputs for heat and electricity from multiple output (CHP) plants. This method is however criticized for its relatively large allocation of inputs to heat, which is better represented by its exergy content. This has large implications for the effects demonstrated in this research from changes in the use of heat, due to its relatively large carbon factor.
- The allocation of inputs for own heat use also prohibited the possibility to quantify the effects due to a possible shift to decentral (in general more efficient) producers, because the efficiency could not be taken out from the data anymore as only inputs were left visible, blurred with the other final energy use.
- The transformation data available for energy plants (from inputs to secondary energy carriers) does not always seem as reliable. Especially when small numbers are considered the apparent

efficiency fluctuated a lot, which is remarkable. For waste on the other hand these statistical data (inputs) are clearly constructed, as they were assumed to have a 100% efficiency.

- The analysis of plant inputs and outputs and their apparent efficiencies also exposed that some plants were wrongly classified as CHP plants until 1998. This explains why the drop of CHP plants seemed to occur, while the overall efficiency of production still improved. This hindered the possibility to quantify the reduction effect due to the shift towards more efficient CHP production.
- Some striking single standing values were also found in the database, of which the one at the residential sector for biomass in 1998 was most remarkable. In terms of impact on results, the unclarified dip led to two very large renewable energy effects in the decomposition analysis (from 1994-1998 and 1998-2002), which basically cancelled each other out again but obstructed to show what really happened in 1998. Implications were small because the renewable energy use (and its effect) was still very small in comparison. Moreover, it did not impact the synthesized analysis using average data over 2008-2012.
- The IEA grouped together not only energy sources, but also (sub)sectors. Especially for transport the disaggregated energy data would have been valuable to be able to reveal the structure effect due to a shift towards certain transport modes. The summation of freight and passenger transport was done in the database, but also no distinction between different types of road transport was made which can differ a lot in energy intensiveness for each pkm.
- The data before 1995 is considered less reliable, as basic data was missing for these years, therefore not published by CBS itself while this research was conducted. This explains some of the remarkable differences in data before and after 1995, shortly listed below. Besides the revisions and changing definitions with time, also many developments (especially CHP) had taken place around 1995, which may also partly explain the discontinuities.
  - At industry no heat was reported before 1995. A large increase as of 1995 is not unexpected due to the introduction of CHP heat instead of own heat production, but a reported heat consumption of zero is suspicious and may have been part of the missing basic data.
  - Before 1995 there was much more oil use at services than after 1995. Again however the increased use of CHP heat (instead of own heat production from oil) may also have caused this trend. It must however also be noted that the service sector is a residual item on the balance, which strengthens the argument that the discontinuity is caused by the lack of basic data before 1995.
  - CBS reports that before 1995 heat was covered under the category of biomass, which may explain the zero values for heat at the industry. However, heat use was reported for other sectors, but it is unclear to which sectors this definition applied, or whether the IEA was able to work around this issue in their database already or not. If not, then the heat use has been underestimated, while the biomass use was overestimated.

APPENDIX D - LIST OF DEPLOYED ENERGY AND CLIMATE INSTRUMENTS

Below one finds a list with the most important energy and climate policy instruments that were deployed between 1990 and 2012. The main sources were the national communications (NC1 up to NC6 in the reference list) and the IEA policy database (2016b). The list is in alphabetical order.

ACEA (ASSOCIATION OF EUROPEAN AUTOMOBILE CONSTRUCTORS) COVENANT

The ACEA covenant was made with car manufacturers (including Japanese and Korean manufacturers), to limit the CO_2 emissions of passenger cars that are sold in Europe. The agreement involved a target set on 140 grams of CO_2/km in 2008 (NC4, 2005).

AGRICOVENANT: CLEAN AND EFFICIENT

In 2008 the agricultural sectors concluded a covenant containing multiple goals for 2020. Total CO_2 emissions should be reduced with 3.5 to 4.5 Mt compared to 1990. Considering the energy efficiency specifically, this should improve with 2% per year over 2011-2020. Renewable energy use must amount to 212 PJ in 2020, of which 12 PJ wind energy (NC5, 2009).

BENCHMARK COVENANT

The benchmark covenant was signed in 1999 between national and provincial governments and representatives of industry (including energy plant owners). With this voluntary agreement the energy intensive companies (annual energy use ≥0.5 PJ) agreed to become among the most energy-efficient in their business type, no later than 2012. The covenant was superseded in 2009 by the Long-term Agreement Energy Efficiency (LEE) to further promote energy efficiency improvements of ETS enterprises (NC5, 2009).

BLOW COVENANT: INTERGOVERNMENTAL WIND ENERGY AGREEMENT

The BLOW covenant was signed in 2001 between the central government, the provinces and the municipalities. The agreement was to realize 1500 MW of onshore wind capacity in 2010. By 2007 this target was already reached, so new future goals were set (NC5, 2009).

BSET/NEWS: SUBSIDY SCHEMES FOR ENERGY CONSERVATION AND/OR CHP

BSET and NEWS were two overarching subsidy schemes in place from 1995 until 1997 which encouraged the use of CHP by lowering the investment costs through subsidies (NC4, 2005).

CLIMATE-NEUTRAL GOVERNMENT

The government strived for CO_2-neutral buildings and operations by 2012. This was done by means of the procurement of green electricity, clean gas and efficiency improvements. For complete neutrality CO_2 compensation was used (NC5, 2009).

CO_2 DIFFERENTIATION FOR BPM (MOTOR VEHICLE TAX)

Since 2006 the purchase tax for passenger cars and motorcycles is linked to its fuel efficiency, to promote the purchase of more fuel efficient vehicles (NC4, 2005).

Coal covenant

The coal covenant is a negotiated agreement signed in 2002 by the governments and owners of coal-fired power plants. Involved companies committed to increase the amount of biomass used in their plants (NC4, 2005).

Ecodesign

In 2009 the EU Ecodesign directive was introduced to improve the energy efficiency of appliances by setting minimum efficiency requirements for certain (energy using) product groups (NC6, 2013).

Efficient leasing

As of 2008 the income tax scheme system was designed in such a way, that driving more energy efficient business cars were fiscally encouraged (NC6, 2013).

EIA: Energy Investment Tax Deduction

The EIA is a fiscal incentive to encourage the investment in relatively innovative energy-efficient technologies or renewable energy options, as a part of the investment may be deducted from the company's profit tax. The tax relief programme was introduced in 1997 (NC3, 2001).

EINP: Energy investment tax deduction for non-profit organizations

Until 2002 the EIA had a similar variant applicable for non-profit organizations: the EINP. This tax deduction programme was specifically important for the retrofitting of existing buildings (NC4, 2005).

Energy labelling of household appliances

Following the 1992 EU Directive, as of 1996 energy labels were made obligatory for household appliances like refrigerators, freezers, washing machines, tumble dryers and dishwashers. Other categories followed, like dish washers and lighting. MAP and EPR financially facilitated the purchase of A-label appliances (NC2, 1997).

Energy labelling of vehicles

Since 2001, following the EU 1999 Directive, energy labels were introduced for new passenger cars taking into account their fuel consumption and CO_2 emissions. Beyond the directive the Dutch car labels also included comparisons to other car types (NC4, 2005).

Energy tax

The Energy tax (until 2004 REB: regulatory energy tax) is a tax on natural gas and electricity introduced in 1996, to green the Dutch tax system. For CHP exemptions were in place. Until 2003 the tax also had special provisions for renewable energy, but these were replaced by the MEP. Tax rates have been raised several times since its introduction (NC4, 2005).

Environmental permits

Since 1993 environmental permits are issued in order to protect the environment. As of 2001 a 14 million Euro budget was reserved to reinforce the role of energy measures at environmental permits. An important aspect is the prevention of free riding by companies which do not comply to LTAs, by obliging these companies (through permits) to invest in energy-saving options with an internal rate of return of at least 15% after taxes (NC3, 2001).

EPA: ENERGY PERFORMANCE ADVICE

From 2000 until 2004 the government partially subsidized the (voluntary) EPA. This is an advice on the possible energy-saving measures that could be taken to improve the energy performance of buildings. If measures are subsequently implemented the EPA pays the bill and adds a bonus to the EPR premium (NC3, 2001).

EPBD: ENERGY PERFORMANCE BUILDING DIRECTIVE

The EPBD is a EU Directive of 2003 considering requirements for energy performances of buildings and had to be implemented into national legislation by 2006. The ultimate goal is zero-energy buildings by 2020. For the Netherlands most of the requirements were already covered in the policies, but some regulations like the EPN required more tightening. Another important requirement of the EPBD was the obligatory energy certificate of buildings in 2008 (NC4, 2005).

EPN: ENERGY PERFORMANCE NORM

As of 1995 the EPN was implemented including tighter regulations related to the energy use of new buildings. Before 1995 the standards on insulation and energy performance were less stringent, incorporated in the legal framework of the Dutch building code. The EPN standard is a coefficient describing the gas use of the building per year. Norms are set for both residential and non-residential buildings; for the latter category different coefficients are applicable for different building types. Every couple of years the standards have been tightened (NC4, 2005).

EPR: ENERGY PREMIUM REBATE

The EPR is a scheme that promotes the investments in energy-efficient appliances (with A-label) including high efficiency boilers and certain kinds of insulation, by providing a partial rebate for consumer's purchase. The scheme has been in place since 2000 until 2005. Since 2001 the scheme also made money available to include renewables such as solar panels and solar boilers (NC3, 2001).

EU ETS: EUROPEAN EMISSION TRADING SYSTEM

A cap and trade system for CO_2 emissions within the EU started in 2005 to promote the cost-effective reduction of CO_2 emissions. Annually a maximum emission cap is set and these allowances are auctioned. Companies within the ETS system have to submit allowances that are equal to their own emissions. Participants can trade allowances or use other Kyoto mechanisms to compensate for their emissions (NC4, 2005).

GDS: GREEN DEALS

As of 2011 the government started the Green Deal programme, supporting companies setting up energy saving or local renewable energy projects – beyond support by financial grants (NC6, 2013).

GEO GUARANTEE

To foster the use of geothermal energy, the government set up a guarantee scheme. To mitigate the risk of exploratory drilling, 85% of the investments are covered in case the drilling fails (IEA, 2016b).

GLAMI COVENANT

As of 1997 the greenhouse horticulture sector agreed with the government to strive to achieve 65% energy efficiency improvement by 2010 compared to 1980. The energy efficiency index is a ratio of primary fuel use to unit of product (NC4, 2005).

GREEN CERTIFICATES TRADING

In 2001 a tradable green certificates programme was established, where certificates would prove the renewable character of the produced electricity. Through the establishment of green certificates, a market for green electricity emerged, promoting the production of green energy (IEA, 2016b).

GREEN INVESTMENT FUNDS

Many renewable energy projects are eligible as green investments. Private persons or companies that invest in certain projects are able to deduct interest and dividend from their income tax since 1995. Commercial banks primarily operate the funds while independent organizations assess the potential green projects (NC3, 2001).

KOEPEL COVENANT

Since 2008 the second generation of LTAs for residential buildings were formulated to save energy by improving the energy efficiency of the built environment. These were 1) The 'More with less' agreement with different types of organizations involving efficiency improvements at existing buildings, 2) The covenant with social housing organizations to achieve additional savings and 3) The 'Spring agreement' with several builders' associations to improve the efficiency of new buildings. As of 2012 these covenants are pooled together into the so-called 'Koepel' covenant (NC6, 2013).

KZRZ/THE NEW DRIVING FORCE/ECODRIVING

In 1996 the KZRZ (Buy fuel efficient! Drive fuel efficient!) programme started, involving a number of approaches to influence the driving behaviour in passenger cars. Especially the driving style was an important part of the programme, as taught to professional drivers and by driving schools. It also included the stepped up enforcement of speed limits, tax measures to stimulate the use of econometers, onboard computers and cruise control. In 1999 the programme was succeeded by 'The new driving force' and since 2006 it carries the name 'Ecodriving' (NC4, 2005).

LEAN AND GREEN

The lean and green subsidized programme allows transport companies to earn an award for reducing emissions with 20% in five years (NC6, 2013).

LTAS: LONG-TERM AGREEMENTS (AGRICULTURE)

Since 1993 the government established an LTA with horticulture, which subsector covers about 85% of the energy use in agriculture. The first set target was 23%, with a target value of 30% improvement in 2000. By 1997 letters of intent had also been received from the mushroom growers and the flower bulb producers (NC2, 1997).

LTAS: LONG-TERM AGREEMENTS (INDUSTRY)

Since the 1990s the government has established LTAs with many different branches of the industry, covering about 90% of the industrial (primary) energy consumption. Companies in the signing branches voluntarily make long-term efficiency plans. The government facilitates the LTAs by broadening facilitation, establishing knowledge networks and providing information and consultancy. In 2001 the second generation LTAs were formulated, followed by the third generation in 2008 (NC6, 2013).

LTAs: Long-Term Agreements (services)

In 1994 the formulation of LTAs in the service sector started, considering energy efficiency improvements. Until 2000 the goal was to reach 30% improvements. About 30% of the energy use was covered with participating institutions, including the institutional health care, education, Schiphol, banks and supermarket chains. Also LTAs with relevant organizations for the rental and maintenance of office buildings were established to improve the energy efficiency of the service sector (NC2, 1997).

LTAs: Long-Term Agreements (social housing sector)

As of 1992 the first generation of long-term agreements were in place at the residential sector. These focused on the social renting sector, involving efficiency targets for their building stock. The LTAs was renewed in 1995 and superseded by the Sustainable Construction agreement requiring improvements until 2001 (NC2; 1997).

MAP: Environmental Action Plan

The MAP was an action plan executed by the energy companies, which provided both information and financial support for energy-saving measures specifically for small firms, non-residential buildings and households, to foster reaching saving targets (i.e. CO_2 reduction) by 2000 (NC1, 1994).

MEP/SDE/SDE+: Environmental Quality of Electricity Production Programme / *Stimulating Renewable Energy Production (+)*

The MEP subsidy programme for renewable energy options was introduced in 2003, replacing the special provisions of the (regulatory) energy tax, to encourage renewable energy. The successors in 2008 (SDE) and 2011 (SDE+) are extensions of the MEP (NC6, 2013)

MPI: Environmental Plan Industry

The MPI is an advice programme by the former Gasunie (now GasTerra) responsible for the domestic supply of natural gas. The programme offers support for companies to improve energy conservation according to their LTA environmental action plans (NC1, 1994).

NL ETS (sector horticulture)

As of 2011 a sectoral emission trading system was set up for the horticulture, a national system similar to the EU ETS. This system is covers the horticultural sector which is not already covered by the EU ETS system for its public electricity production (NC6, 2013).

Orders in Council Greenhouse Horticulture

These Orders in Council for Greenhouse Horticulture defined crop-specific energy norms on the level of individual companies needed to be achieved (NC4, 2005).

PV: subsidy scheme solar panels

As of 2012 a subsidy scheme for PV solar panels was in place for buyers from the private sector. A 50 million Euro budget was available, which ran out in August 2013 (NC6, 2013).

Special gas price CHP

From 1990 until 1998 the use of CHP was encouraged by reducing the operating costs through offering a special gas price for gas used for CHP (NC4, 2005).

SPIRIT/BTS/EOS: TECHNOLOGY FUNDING

SPIRIT, BTS and EOS were three overlapping programmes that provided funding for (new) technologies, to promote their development and diffusion (IEA, 2016b).

SUBSIDIES OTHER FUELS

As of 2006 two complementary subsidy schemes were launched to encourage the increased use of alternative fuels. One specifically focused on innovative biofuels for transport, the other complementarily subsidized the investment in filling stations for multiple alternative fuels, like CNG, bio ethanol and bio diesel (NC5, 2009).

TIEB: TENDERS INDUSTRIAL ENERGY CONSERVATION

The TIEB was a programme providing subsidies for research, demonstration and deployment of new technology projects that could potentially save energy at industrial processes (NC1, 1994).

TRANSPORT AVOIDANCE PROJECT

Between 2000 and 2006 the transport avoidance project encouraged to reduce the transportation of commercial goods by means of communication (informing and knowledge dissemination) and chain mobility (IEA, 2016b).

TRANSPORT BIOFUELS ACT

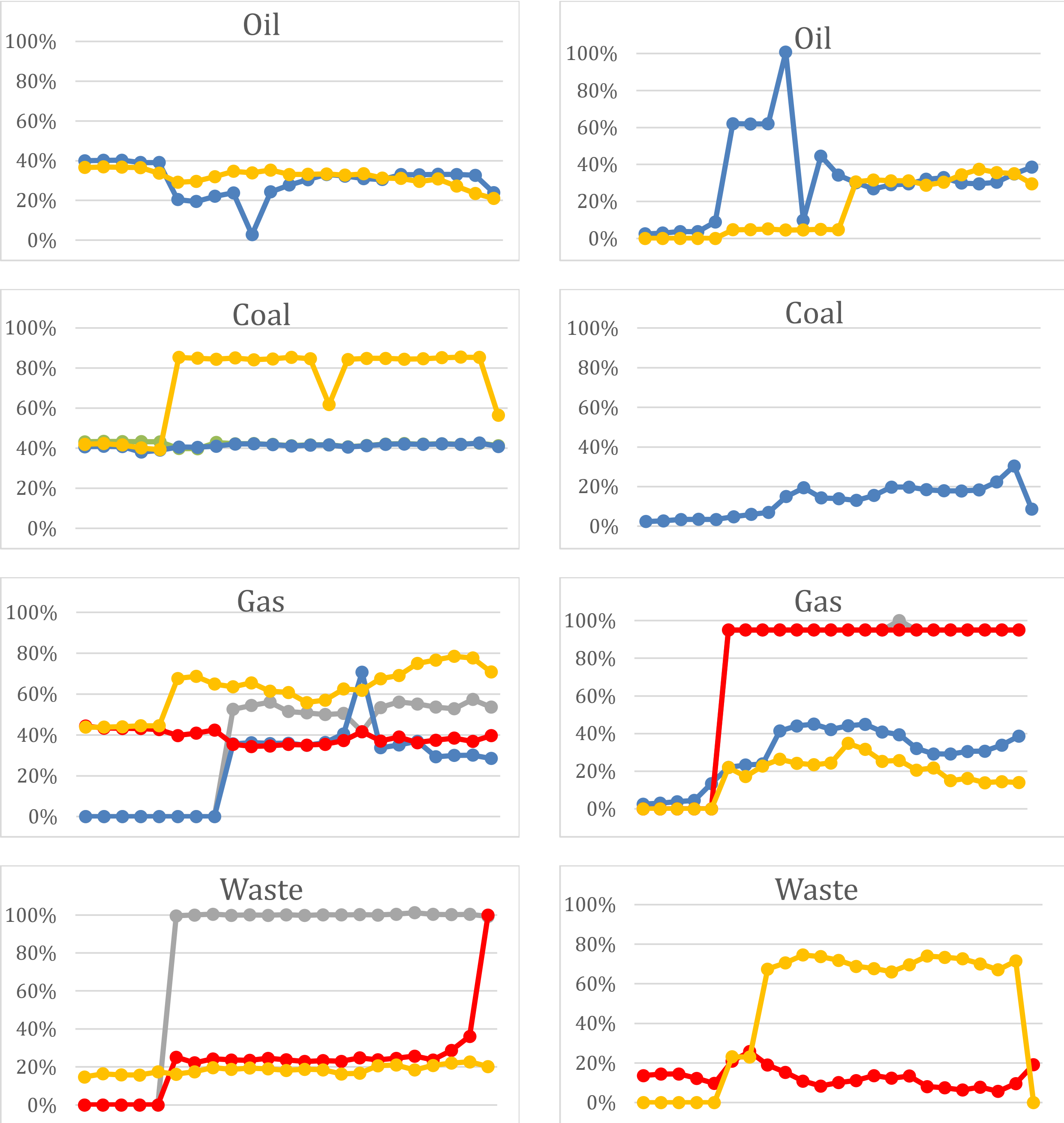
The 2007 'Transport Biofuels Act' was published containing biofuel targets until 2010, as obligatory for petrol and diesel producers and suppliers. This act followed the 2003 EU directive on biofuels, but targets needed to be adapted (lowered) in 2008 (NC5, 2009).

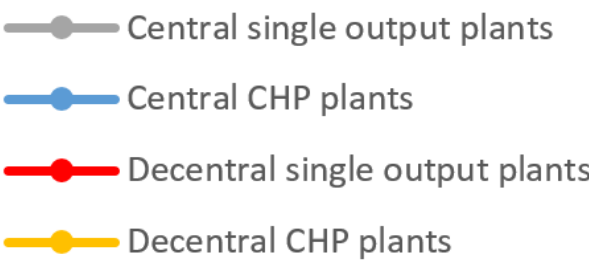
VAMIL: ARBITRARY DEPRECIATION OF ENVIRONMENTAL INVESTMENTS

The VAMIL allowed accelerated depreciation for investments in innovative environmental technologies since 1995. The tax incentive is similar to the EIA, but the VAMIL list is much broader (NC3, 2001).

APPENDIX E - PLANT EFFICIENCY DEVELOPMENTS BETWEEN 1990 AND 2012

ELECTRIC EFFICIENCIES | THERMAL EFFICIENCIES





1. Relatively high efficiency of decentralized CHP is the result of input allocation to the demand sectors.
2. Apart from the decentralized CHP, the inputs to CHPs are not further allocated to electricity or heat, so they represent electric or thermal efficiencies.
3. When efficiencies are 0%, there was no activity.
4. The 100% efficiency of waste must be a result of assumptions of the IEA data collection.
5. Outliers (especially the case for oil) are the result of small quantities of energy inputs and outputs