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What are the key drivers of CO_2 emissions in Denmark from 1980 to 2012? A decomposition analysis using the LMDI approach.

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Abstract

By using a decomposition method of LMDI, this paper identifies the drivers behind the changes of the CO_2 emissions level in Denmark between 1980 and 2012. By looking at four driving factors such as activity effect, structural change, technological change and CO_2 emissions intensity, enables the study to find what drives and impact the changes in CO_2 emissions in each sector and thereby also in the total level. Along with implementation of new reforms and regulations that implies promoting renewable energy and a greener economy, has an improvement within energy- and fuel switch efficiency taken place. These two driving components has also proven to be the two most important components as contributes to the decreasing level of CO_2 emissions over the time period, which is a result that corresponds to previous studies within the energy and environmental field.

Key words: CO_2 emissions, technological change, structural change, CO_2 intensity, energy policy

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1. Introduction

Over the recent years the concerns over the global climate increased and since global warming is a phenomenon that affects the whole world, the need for mitigating and controlling the CO_2 emissions has increased. Decreasing the level of global warming is a long time challenge, but also a challenge which requires crucial action and since the climate change has no borders, is this a challenge that includes the whole world (IPCC, 2013). Member states of the European Union (EU) have agreed to a framework whose ambition is to create a more sustainable climate by 2030. The agreement includes three important targets until 2030 which are to reduce the green-house gases (GHG) with 40 % in relation to the level in 1990, increase the share of renewable energy consumption with 27% and reduce the energy consumption with 27 % (European Commission, 2016). The agreement does also direct to national targets where Denmark is one of the countries with a target to reduce its GHG with 40 % until 2030 in relation to 1990. One of the most central contributor to GHG in Denmark is the CO_2 emissions, whose share to the GHG in 2014 was almost with 73 % (Denmark National Inventory 2016, 2016). This means that a reduction of CO_2 emissions is one of the most important intervention, in order for Denmark to reach its target of reducing GHG with 40 % in 2030. Denmark has already massively decreased its total fossil fuel related CO_2 emissions, with almost 41 % between 1980 and 2012 where the majority of the decreasing level was achieved after the 1996 and forward, figure 1, 6 and 9. Decreasing its CO_2 emissions level with 41 % over a 36 year period and still managing to not compromising with the long-run economic growth, is considered a successful decoupling. However, the decreasing level of CO_2 emissions as arises in connection with produced output, differs from sector to sector where some sectors shows a steeper decreasing trend than other sectors, while others actually show an increasing trend. Therefore it is important to receive knowledge of the drivers behind the changes in CO_2 emissions, to be able to mitigate and control CO_2 emissions within each sector and thereby the total level. A reduction of CO_2 emissions can only be possible if the decreasing level surpass the positive effects of population and growth in GDP and can only be reached through three ways such as technological change, structural change or change to fuels that have a lower carbon content.

In order to examine the driving forces behind the changes in CO_2 emissions in Denmark over the time period 1980 to 2012, the Logarithmic Mean Divisia Decomposition (LMDI) method is used. The LMDI method enables to decompose total changes in CO_2 emissions into four components: activity, energy intensity changes, structural changes and CO_2 emissions intensity (CO_2/GJ). The LMDI is also able to quantify the contribution of the various sectors for the total change in emissions. Data that has been used in the LMDI method is from 1980 to 2012 within five sectors which are the service, transport, industry, agriculture and household sector, to observe the annual changes of CO_2 emissions of Danish production within the time period. Using this method enables to investigate and analyse whether the change depends on switch of fuel, technological change, structural change or changes in activity in the sector.

The level of CO_2 emissions within a country depend on many different aspects which can be all from external effects such as crisis, wars, economic stability of neighbour countries or simply weather changes, to internal effects such as economic growth, policy changes or technological development etc. Looking at each sector from a production based perspective enables to draw conclusions of the drivers of CO_2 emissions, but also to discover weaknesses of past and present energy policies. It is also important to look at each sector in order to create an awareness of that even if a country shows a reducing level of CO_2 emissions in total, there might still be sectors within the domestic production which have an increasing trend. The different aspects of what influences the level of CO_2 emissions have led forward to the research question:

"What are the key drivers behind the changes of CO_2 emissions in Denmark from 1980 to 2012?"

1.1 Purpose

The purpose of the thesis is to determine the drivers behind the changes of total CO_2 emissions in Denmark between the time periods from 1980 to 2012. The changes of CO_2 emissions in each sector and per driving factor are measured between 1980 and 2012, due to the fact of that a consistent time series is available for this time period. To be able to perform the analysis have a decomposition method of LMDI been used, where the changes in each sector and driving factor has been investigated.

1.2 Disposition

The study is divided in the following way. Section 2 starts with a background description of the Danish trend of emissions within the energy sector. The study then continues with a presentation of the Danish energy model and the development of the Danish energy policy plan. Section 3 presents the concept of Environmental Kuznets Curve (EKC) as theoretical background of this thesis which follows by the section of previous literature as includes decomposition studies, other studies of Denmark and other useful studies which concerns the environmental- and energy field. The next section presents the method which includes the decomposition method of LMDI and thereafter are the variables being explained, which have been used in the decomposition analysis. Thereafter are the results presented which is combined with a discussion and the last section ends the thesis with a conclusion part.

2. Background

2.1 Danish trend of emissions within the energy sector

The energy sector has historically, been the major contributor to the Danish trend of green-house gas (GHG) emissions in order to supply households, businesses and heat- and electricity production. In 1990, emissions coming from businesses, households and heat-and electricity production were contributed with more than half to the total GHG emissions in Denmark and is a pattern that have continued since then. The reason behind the large consumption of the energy sector and the emissions it causes, depends mostly on the production of district heating and electricity but also from the individual use of fossil fuel in terms of heating buildings and industrial processes. Of all of the emissions that have arose within the energy transformation sector, around 70 % of them can be explained by the EU emissions trade scheme (ETS) and the remaining 30 % have not been any subject to the ETS, but can mainly be explained by the use of district heating and oil from household and businesses along with the individual use of gas (The Danish Government, 2013).

2.2 The Danish Energy Model

Danish energy system had until the oil crisis in the 1970’s completely relied on the imported oil (Pedersen, 1996), but the oil crisis created the starting point of a rethinking within the Danish energy system (DEA, 2015a). Denmark has after the oil crisis in the 1970’s and during the following 46 years put together an energy supply that is domestically sourced, with the aim of widen the use of renewables and construct the whole system to be more energy effective (DEA, 2015a).

The Danish energy model is a system that has been developed in the purpose of structures involving all energy sectors and at the meantime emphasising the supply and demand. This in order to create renewable energy, system development/integration as involves electrification and energy efficiency. The model contains a very active and continuously energy policy which have proved that by having targets such as supporting industrial development, technological innovations, renewable energy targets and improve energy effectiveness, enables the possibility to have a high standard of living and still sustain economic growth and at the meantime reduce the reliance of fossil fuel and thereby mitigate climate changes (Bæk, 2015).

The model has its largest focus on the interaction between the sectors, which have a purpose to focus on the individual concepts and components. The created support and interaction has open up the ability to balance the use of renewable energy such as wind, with traditional sources as guarantees the supply. This has in turn generated a more efficient energy system, which have enabled to meet the demand on energy with renewables which would otherwise cost a lot (DEA, 2015a).

However, even if Denmark is one of the most successful countries that have been able to introduce renewable energy into the energy system (Greenpeace, 2014), the energy system does still rely in a large extent on oil and coal (DEA, 2015b).

2.3 The Danish energy

The oil crisis in the beginning of the 1970's was a wakeup call for many industrialised and developing countries, that the dependency of the oil source was not sustainable in the long run. The preparation for the intervention started in 1974 and the first energy policy plan was introduced in 1976 (Jensen, 1976). After the first energy plan, three more energy plans were introduced during the time period until 1996, where the second energy plan was introduced in 1981 and was an extension of the first energy plan from 1976. The aim of the second energy plan was to give further added weight to the environmental and socioeconomic considerations, which enables to continuing the process of reducing the dependency of the imported fuels (Energiplan 81, 1981). The third energy plan was implemented in 1990, also known as Energi 2000 (House of Green, 2015) and is recognised as the plan of action since it did an introduction of creating a more sustainable development of the energy sector. One of the targets was to reduce the CO_2 emissions with 20 % in 2005 in relation to the levels in 1988, but the plan was also an endeavour of increasing the use of more desirable fuels such as solar energy, natural gas, biomass and wind. To reach the different targets until 2005, a variety of mitigations was taken in place such as subsidies construction, taxation on CO_2 emissions and operations on district heating systems (Danish Energy Policy, 2015). The fourth energy plan was implemented in 1996, where the aim was to achieve a further reduction of fossil energy sources and in emissions caused by production and consumption of energy. The plan did also contain supplement of the target within the third plan which was to achieve a reduction with 50 % of CO_2 emissions in 2030 in relation to the CO_2 emissions level in 1998 (Danish Energy Policy, 2015).

3. Theory

3.1 Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve is an invert U-shaped curve as shows a hypothetical connection between income per capita and different indicators of environmental degradation. The hypothetical relationship is named after Simon Kuznets, who also invented the hypothesis of that income inequality will rise at first, in order to fall along with the development of economic growth.

The curve is divided into three parts that shows the economic degradation, where the energy consumption and thereby pollution level differs depending on which part the economy belongs to. The three parts are the pre-industrial economics, industrial economies and post-industrial economies which refers to service economies. In an economy’s early stage of the curve, placed in the pre-industrial and most of the industrial part, the pollution level will continuing to increase along with an increasing income per capita. At the later stages of industrialization, environmental degradation reaches a peak and starts to decline with increased income per capita (Stern, 2004).

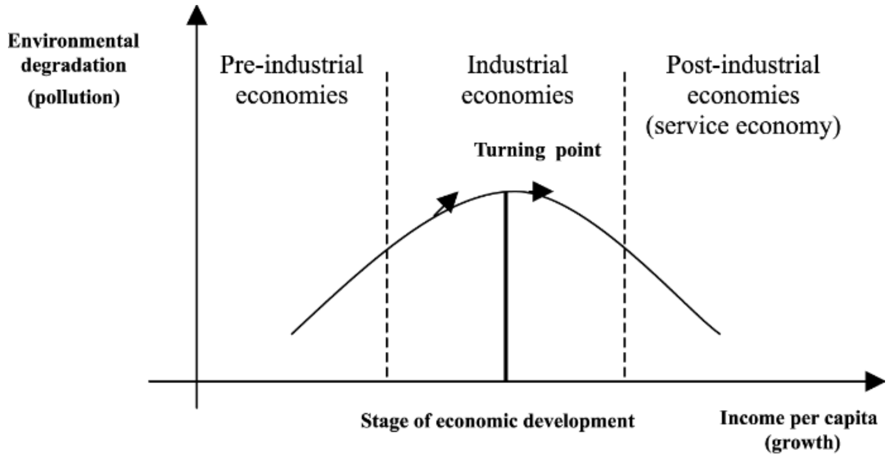
The explanation of the raising pollution level in the early stage of the curve depends on that when an economy is at its lowest level of development, the intensity and quantity of the environmental degradation is restricted due to the fact of the influence of the subsistence economic activity on the resource base, but also for the reason of limited amounts of biodegradable wastes. The economic development is then increasing along with that the intensity is increasing within the extraction of resources and agriculture and along with the set off of the industrialization. The consequence leads to that the rates of resource regeneration begins to fall below the rate of resource depletion, which in turn leads to that the amount of waste generation begins to increase and thereby the toxicity. When an economy has reached the higher levels at the EKC and thereby higher developments, reduces the pollution level due to the transition to a service economy. At this level are services combined with an increased environmental awareness such as fuel switching in order to produce more environmentally friendly products, but also a structural change against information-intensive industries and a technological improvement. This leads in turn to a stepwise reduction and equalized environmental degradation (Panayotou, 1993). Panayotou indicates (1993) that the transition to a service economy is one of the biggest reasons of how the economic growth has reduced the environmental impact, where he simply means that in the beginning of an economy's industrialization are more machines and energy used and along with that the economy de-industrializes the less energy is used (Henriques and Kander, 2010).

Panayotou refers also to that the level on the EKC can be connected to trade, which have an important impact on the pollution since trade liberalization can exclude inefficient industries as might cause major levels of pollutions, but also open up the ability to import less environmentally friendly produced product from countries which have more strict regulations. If liberalization policies such as environmental protection regulations, leads to a reduction or an increase of industrial pollution depends a lot of what stage of development the country has on the EK-curve. Panayotou (1993) argues that the level at the EKC mirrors the demand for environmental amenities since people can afford to buy/consume more environmentally friendly produced products, along with an increased income. The increased income might also raise the demand for services and goods that are less material- or machine- intensive, but an income increase can also increase the demand of enhance the environmentally quality, which leads to more restrictive environmental regulations and thereby achieve a lower level of pollutant produced products (Panayotou, 2003).

The concept of EKC have emerged in the beginning of 1990 in the study by Kruger and Grossman, which investigated the impacts of NAFTA and in the 1992 World Bank Development Report. However, the hypothesis have also experienced some criticisms concerning that it is only applicable to some certain pollution types and excluding others. Criticisms have also emerged regarding to use the hypothesis with econometric test, since the hypothesis is only applicable to panel-data. This means that use the hypothesis on other estimations than countries and time in fixed effect, turn out to be problematic (Stern, 2004).

Even if EKC has been criticized several of times, the Danish economy is amongst the 25 richest counties per capita in the world (WRC, 2016) and seems to hint to fit the picture of that when an income increase, raises also the demand of improve the environmentally quality and for goods and services that are less machine- or material intensive.

Figure: Environmental Kuznets Curve.



Source: Panayotou (1993).

4. Previous research

Over the last decades there has been done a lot of research that relates to economic growth, energy and CO_2 emissions and their impact on the environment and contribution to the climate change. Many of these studies that are related to emissions, represents the main components to be either structural change or energy intensity, technological development/efficiency, decomposition structure and have also included emission factors and energy types. The main results from this study, which differ from previous decomposition studies and from studies on Denmark, are that both the technological development within energy intensity and CO_2 emissions intensity are the strongest drivers behind the changes, especially in the household sector. Structural changes also have an important impact when it comes to the growth of the transport sector, but this to a negative trend since it has the opposite effect on reducing the level of CO_2 emissions.

Focusing on the drivers behind the changes in CO_2 emissions, enables a reinforcement of the efficiency of the already existing set of mitigation measures in force (Pablo-Romero & Sánchez-Braza, 2015). The study by Pablo-Romero & Sánchez-Braza (2015) uses an aggregate translog production function for a panel of 38 countries over a twelve years period in order to examine what role energy have in economic growth. This study contributes with knowledge and support to the fact that economic growth is possible and still decrease the carbon emissions level, but does not neglect the relation between growth and energy consumption. The study does also point out that economic growth contributes to higher physical capital, which support the connection that an increasing energy efficiency and can be linked to the down sloping Environmental Kuznets Curve (EKC) (De Graaf, 2011), showing the relationship between an increased income per capita and environmental pollution. The study by Kander et al (2013b) can also be related to the EKC, where the study showed strong evidence of that consumers in the high-income countries such as Netherlands and Sweden, consumed more energy-light products. In the field of environmental studies of CO_2 emissions and energy have a lot of different methods been used. Decomposition method is one of the most common and effective method to use when investigating the changes of CO_2 emissions, since it enables to look into each component as might influence the changes of both CO_2 emissions and energy (Ang & Zhang, 2000). Many different decomposition methods have been used in the environmental field such as structural decomposition analysis (SDA) (Casino, Roman and Ordones, 2015) or index decomposition analysis (IDA) (Papagiannaki and Diakoulaki, 2009).

The earlier study by Papagiannaki and Diakoulaki (2009), investigates how the total trend of CO_2 emission is affected by the CO_2 emissions that emerges from passenger cars from 1990 to 2005 within inter alia Denmark. According to the study, the share of road transport in Denmark has done a rapid growth over the recent decades and thereby also the CO_2 emissions from road transport. This has in turn had a negative influence on the total decrease of CO_2 emissions in Denmark, where strong evidence have been found that the increasing trend of CO2 emissions in road transport owes a great deal to the emissions that have been caused by passenger cars. In order to investigate the changes, the study uses a decomposition method of LMDI I as belongs to the IDA family, where the study looks into the drives behind the changes in CO_2 emissions from passenger cars. The decomposition method enables the study to find two significant reasons of why passenger cars increase their contribution to CO_2 emissions. The first one is that the ownership of cars have increased and second the reason is that it have become more common to use more bigger and powerful cars, which in turn have increased the energy consumption and thereby the CO_2 emissions. However, the study also emphasizes that the CO_2 emissions from passenger cars have decreased over the time period due to the fact of an improvement of fuel efficiency, but also because of technological development. Technological development have also been pointed out in other studies such as Kopidou, Tsakanikas and Diakoulaki (2015), Kander et al (2013b) and Henriques and Kander (2010), to be one of the main reasons behind the reduction of CO_2 emission in all sectors, where the later study emphasized that the major driver that contributes to a decrease in energy intensity exists within the industry sector.

The study by Kopidou, Tsakanikas and Diakoulaki (2015), also emphasizes the role of CO_2 emission intensity at the CO_2 emissions level, which decreased in connection with a reducing level in CO_2 emission intensity. Energy intensity and CO_2 emissions intensity have a noticeable impact on reducing the CO_2 emission levels, which Kyunam and Yeonbae (2011) also accentuates. What the study by Kyunam and Yeonbae (2011) also brings up is what contributes to the growth in CO_2 emissions, which the study refers to be dominated by the change in economic activity as then can be seen as an inhibition factor in the process of decreasing the CO_2 emissions level.

Others studies that also used the decomposition method of LMDI such as the study by Henriques and Kander (2010) and Kander et al (2013b), have found modest result showing that structural change have any impact on the change of energy intensity. By this, the studies concludes that the transition to a service economy has little effect on decreasing the energy intensity, where technological change have a much larger impact, which the later study refers to mostly depend on the ICT revolution. However, according to the study by Xiao, Niu and Guo (2016), structural change still matters even if its reducing ability takes longer time compared to technological change. The study means that shifting from being a heavy energy intensity producer to a service economy, have an influence of using less energy in the production and thereby decrease the level of CO_2 emissions. The same can be supported in the Danish study by Wier et al (2005), where evidence have been found that the service sector is the sector who contributes least to environmental effects types. The study have also found evidence of that middle income families living in houses in Denmark are consuming the least environmental friendly basket and since the middle income families contributes to a large share of families in Denmark, can this be connected to the household sector's share of contribution to total CO_2 emissions in Denmark, see fig 1.

In the field of environmental studies have there been done a number of studies of the Danish CO_2 emissions, where different types of decomposition methods have been used. Some of them have already been mentioned in this section such as Papagiannaki and Diakoulaki (2009) and Wier et al (2005). Another Danish decomposition study by Jacobsen (2000), observes the energy consumption within the Danish manufacturing industry by using a decomposition input-output method, which shows that structural change has a minor impact within emissions and energy. However, the study by Jacobsen (2000) shows also that the explanation of why the energy consumption increases, depends on that the production within the industry has risen with more than what the domestic demand requires, due to the fact of an increased production in order to an increased exportation which depend on an increase energy demand.

By referring to the previous studies above, there are lot of previous literature within the environmental and energy field that uses decomposition methods such as LDMI, in order to investigate drivers behind changes in energy consumption and energy intensity. Many of the studies mentioned above are commonly just focusing on the structural or technological change or both for the analysis. The same concerns the Danish studies as relates to CO_2 emissions, where many studies uses around four to five decomposition factors but delimits the study to a specific sector or time period such as the studies by Papagiannaki and Diakoulaki (2009), Wier et al (2005) and Jacobsen (2000). However, to be able to achieve a broader perspective of what affects the changes in CO_2 emissions, this study uses also a decomposition method of LMDI but in contrast to other previous studies uses the study a longer time frame of 32 years, which enables to catch important fluctuations. The study takes also the whole economy into consideration by including all five sectors which enables to compare the sectors against each other, but also together with the decomposition factors and thereby achieve a better knowledge of the drivers behind change in the level of CO_2 emissions.

5. Method

5.1 Decomposition Analysis

In order to analyse the change of CO_2 emissions over time in different sectors, a decomposition method is a valid and useful tool. This due to the fact that decomposition methods enable to measure the contributions to CO_2 emissions from the different pre-defined factors, explain the reason of change in CO_2 emissions, but the methods also enables to compute the effectiveness of technology and energy policies. Decomposition methods which are energy-linked have during the past decades becoming more widely used, where two different decomposition techniques have become more commonly used which are structural decomposition analysis (SDA) and index decomposition analysis (IDA) (Wang et al, 2014). Structural decomposition analysis uses input-output tables, where IDA uses aggregated sectoral data (Hoekstra and van den Berg, 2003 in Wang et al, 2014). While SDA can capture more complex effects than IDA, its application is conditioned by the availability of input-output tables. IDA has the advantage of using data that is more easily available and which covers a wider time frame. For these reasons, IDA is the method chosen on this thesis.

5.2 LMDI

Under the umbrella of IDA have there been developed many techniques and methods (Mahony et al, 2012) such as Logarithmic Mean Divisia index I and II (LMDI), Laspeyres method, Paasche index and Fischer Ideal inter alia (Wang et al, 2014) and of these methods is LMDI I the most favoured one which also is the method that has been used in this thesis. This for the reason of that the method is easy to understand, it is possible to add subsectors and the method allows for a perfect decomposition since it do not leave any residual etc. and the method can be both expressed in additive or multiplicative terms. However, there are also some negative aspects within the LMDI method that are important to consider. One of these aspects is that the LMDI method is not defined for negative numbers in data or for zeros, but since the data that have been used in this paper have neither been negative or zero, is this an aspect that have not been an issue in order to carry on with the analysis (Heinen, 2013).

5.3 Mode of procedure of the LMDI approach

To be able to understand how one can use the LMDI method to study the change in CO_2 emissions, one have to go through the formula process. To begin, one can look at the index decomposition analysis formula below, where *V* stands for energy related aggregate. In the formula is the assumption taken that there are $_n$ different factors which are conducing to changes in V over time and each of this n factors are related to a quantified variable, where there also exists n variables such as, x_1,x_2, x_3,…., x_n.

Index decomposition analysis (IDA) is identified as:

Equation 1

$$V = \sum_i V_i = \sum_i x_{1,i}\, x_{2,i} \,\ldots.\, x_{n,i}$$

The aggregate changes from V_0 in period 0 to V_t in period *T*.

Equation 2

$$V^0 = \sum_i x_{1,i}^0\, x_{2,i}^0 \ldots x_{n,i}^0$$

Equation 3

$$V^T = \sum_i x_{1,i}^T\, x_{2,i}^T \ldots x_{n,i}^T$$

In the additive decomposition is it the difference that is decomposed and gives the formula:

$$\Delta V_{tot}=V^T-V^0=\Delta V_{x1}+\Delta V_{x2}+\ldots+\Delta V_{xn}.$$

The IDA identity can then be used in order to calculate the changes in CO_2 emissions. The changes in CO_2 emissions in each industrial sector can be analysed by calculating the changes in four underlying driving factors. The four factors are the overall industrial activity (activity effect), industry activity mix (structure effect), sectoral energy intensity (energy intensity effect) and CO_2-emission intensity factors (emission-factor effect), where CO_2 emissions is the product of all these four factors. These four different factors will be investigated in the transport sector, agriculture sector, transport sector, service sector and in the household sector to quantify the CO_2 emission. By using the formula of Equation 1, the IDA identity can be rewritten to:

Equation 4.

$$C = \sum_i C_i = \sum_i Q \frac{Q_i}{Q}\frac{E_i}{Q_i}\frac{C_i}{E_i}\sum_i Q\, S_i I_i U_i$$

In the formula above stands C for the total CO_2 emissions and C_i is the CO_2 emissions created in industrial sector *i*. Variable Q stand for the total industrial activity level, Si is the activity or output share given by Qi/Q. Ii is given by Ei/Qi and stands for the energy intensity of sector i and the last variable Ui is the CO_2 emission factor of sector i given by Ci/Ei. The LMDI formula for additive decomposition with the LMDI technique is:

Equation 5.

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{emf}$$

Where changes in total CO_2 emissions from year 0 to year T can be decomposed into various effects: activity effects (ΔC_{act}) , structural effects (ΔC_{str}), intensity effects (ΔC_{int}) and CO_2 intensity effects (ΔC_{emf}). (ΔC_{act}) measure the changes in total CO_2 emissions that occur due to changes in the overall activity level (or GDP), ΔC_{str} will show the CO_2 emissions caused by structural change in sector i and will be shown through measuring the impact changes in the share of output from different sectors. ΔC_{int} measures the contribution of changes in sectoral energy intensity to changes in total CO_2 emissions. Sectoral energy intensity shows the technological change in sector i, in other words the higher energy intensity in sector i the less technological change within sector i. Finally, the last ΔC_{emf} shows the contribution of changes in the CO_2 intensity of the energy basket to changes in total CO_2 emissions. Each of the drivers is then calculated with the formulas shown in Equation 6.

Equation 6.

$$\Delta C_{act} = \sum_i \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} \ln(\frac{Q^T}{Q^0})$$

$$\Delta C_{str} = \sum_i \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} \ln(\frac{S_i^T}{S_i^0})$$

$$\Delta C_{int} = \sum_i \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} \ln(\frac{I_i^T}{I_i^0})$$

$$\Delta C_{emf} = \sum_i \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} \ln(\frac{U_i^T}{U_i^0})$$

(Ang, 2005).

5.4 Explanation of the decomposition components

This sector of the paper are explaining the components that have been used in the decomposition method of LMDI, these are activity, fuel switch/CO_2 emissions intensity, structural- and technological change.

5.4.1 Activity effect (output effect)

The activity effect is used in the decomposition method analysis in order to investigate how the changes in the demand for economic activity or produced output have influenced the changes of CO_2 emissions level in relative terms, both in each sector and at the total level and is value-added for all sectors (Heinen, 2013). Limiting the economic activity is one way to be able to reduce the level of CO_2 emissions, but since this would imply a major burden on the economic growth in a country, is it very rare that this type of intervention would be applied. Instead, a large attention have been put on implementing technological improvements (Kyunam and Yeonbae, 2011). However, the demand is price elastic which means that if the demand for a certain produced product will decline, the produced output for the product will fall (IEA, 2012).

5.4.2 Structural change

Structural is one of the two components that drives the changes in energy intensity, where energy intensity stands for the energy that is required in order to produce one $ worth of GDP. Structural change refers to the change between sectors, which means to quantify the influence of the changes in the share of output from different sectors such as a transformation from an industrial economy to a service economy (UNIDO, 2011).

5.4.3 Technological change

Technological change is the second component that drives the changes in energy intensity and refers to the changes within a sector. Change within a sector can be reached either by replace old technology with new one, innovation, switch to more efficient fuels or increased efficiency. This means in other words that the output is the same but less energy is used, or that the energy use is the same but generates larger output. When the level of energy intensity decreases, the less intensive and the more efficient. However, technological change can also depend on changes in energy consumption of the informal economy and household sector (UNIDO, 2011).

5.4.4 Fuel switch (CO_2 emissions intensity)

Effects from the component fuel switching or CO_2 emissions intensity, refers to the changes as occur from changes in the energy basket to fuels with a different CO_2 emissions content per TJ. One example of a fuel switching effect that would reduce the level of CO_2 emissions would be to replace coal with natural gas in the electricity system and a fuel switching effect that would raise the level of CO_2 emissions would be the opposite. The same as in technological change, a reducing in the level of CO_2 emissions intensity refers also to an improvement in the efficiency (Salovaara, 2011).

6. Data

6.1 Data used in the LMDI analysis

The data used in this thesis is times-series data from 1980 to 2011 for the decomposition method of LMDI in each sector. The data that has been collected from the Danish Energy Agency (DEA, 2013a), United Nations Statistics (UN Statistics, 2015) and from the Odyssee database (Odyssee, 2016). The Odyssee database was used to calculate the new shares for the transport sector and household sector.

In the decomposition analysis within each sector the time period for the data is from 1980 to 2011, where the value added data is in constant 2005 prices per sector and has been used from the UN Statistics database (UN Statistic, 2015). The data for energy consumption (TJ) for all sectors is collected from the Danish Energy Agency, where the data for CO_2 emissions per sector also has been collected. The data from the Danish Energy Agency is observed data and not adjusted, due to the fact that the adjusted data takes climate variations into account and the observed data shows the registered amount in every year (DEA, 2013b). The data of energy consumption and CO_2 emission for the transport- and household sector, the energy consumption and CO_2 emission for passenger cars is extracted from the transport sector to the household sector. In order to receive the share of energy consumption for passenger cars, all energy was summed up for all the different type of fuels which was consumed by passenger cars. The share of energy consumption in TJ was then multiplied with the conversion factor of CO_2 emissions, to receive the share of CO_2 emissions that passenger cars have caused. The data that was used to calculate the share of energy consumption and CO_2 emission from passenger cars was collected from the Odyssee database. The data from the passenger cars was then combined with the data from the Danish Energy Agency, in order to get the total value of energy consumption and CO_2 emissions for the transport- and household sector.

In the LMDI decomposition analysis calculations of the annual change in four drivers per sector was done: the overall activity, structure, energy intensity and CO_2 emission intensity effects. Data on value added, energy consumption and CO_2 emissions are needed in order to calculate these four factors and measure the annual change of total CO_2 emissions in each sector. Value added data takes each sector’s share of total GDP into account and thereby also each sector’s economic growth pattern, which is necessary in order to calculate the effect in total CO_2 emissions from each sector per year.

6. 2 Restriction of data

Within the data that concerns the CO_2 emissions for each sector was collected from the Danish Energy Agency, the transformation sector was not included into the values of CO_2 emissions. In the transformation sector, electricity, district heating and gas works gas are included. All of the sectors are more or less consuming electricity, district heating, except for the transport sector and gas with the exception for the transport- and agriculture sector. The consumption of electricity, district heating and gas causes CO_2 emissions, and is therefore important to allocate the amount of CO_2 emissions caused from the transformation sector to the different sectors, due to the fact of getting the right amount of CO_2 emission in each sector (DEA, 2013a). The allocation of each sector and each category within the transformation sector was done by dividing the CO_2 emission caused from the production of category j in year t, with the total consumption of category j, year t and then multiply the quota with consumption of category j in sector i, year t. An example within the electricity category and sector i is illustrated below to get a better understanding of the allocation.

Equation 7.

$$\text{Alloc. of } j \text{ to } i, \text{year } t = \frac{CO2_j^t}{consumption_j^t} * cons_{ij}^t$$

$$\text{Alloc. of } elecricity \text{ to } houshold, \text{year } 1980 = \frac{CO2_{electricity}^{1980}}{consumption_{electricity}^{1980}} * cons_{household,electricity}^{1980}$$

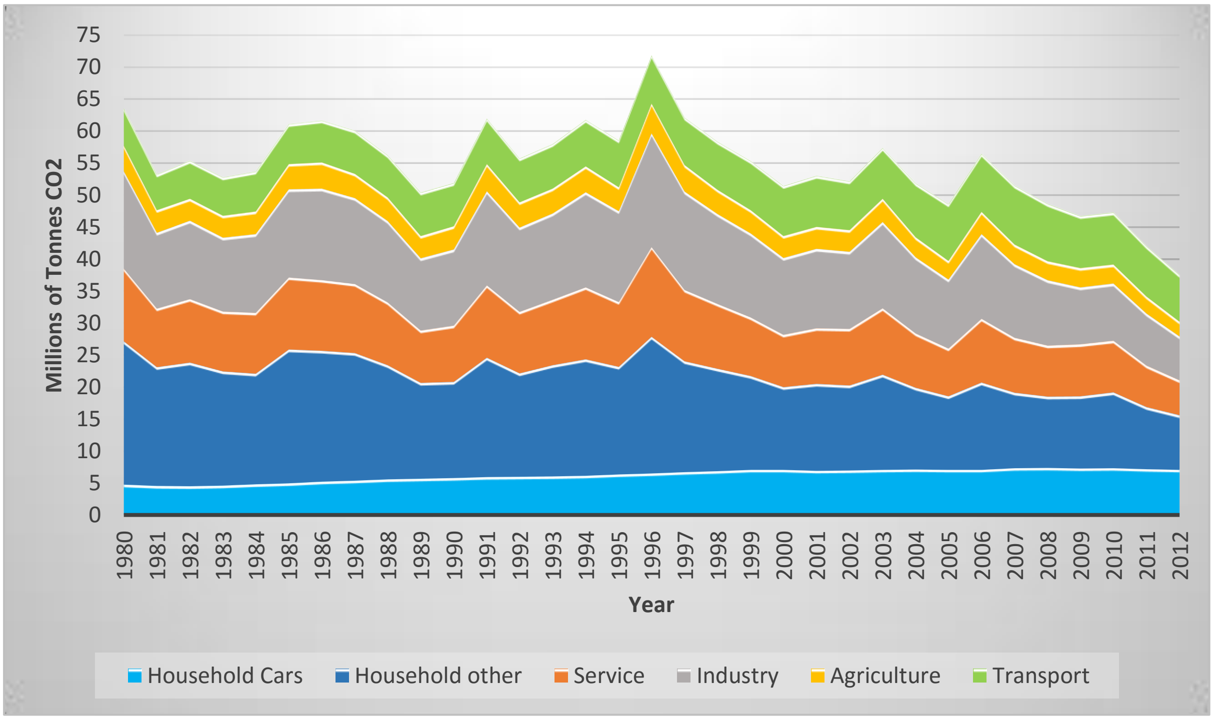
A further restriction was also made within the household and transport sector. From the data collected from the Danish Energy Agency, the transport by passenger cars is included within the transport sector (DEA, 2013a). However, since the transportation by passenger cars belongs to the household sector, calculations were done in order to extract the share of passenger cars from the transport sector to be included within the household sector. The reason of the restriction depends on the basis that the personal transportation does not create any value.

6.3 Data description

In the following part is a data description, which presents a background graph of the total CO_2 emissions between 1980 and 2012 in section 6.3.1 and background graphs of the factors that influence the level of CO_2 emissions in section 6.3.2, such as technology and structural change which is shown in the graph that presents the changes in energy intensity, GDP growth which shows the economic growth and CO_2 emissions' intensity that shows the change of energy mix.

6.3.1 CO_2 emissions

Figure 1. Total CO_2 emissions in Millions of tonnes, annual change from 1980-2012. Source:



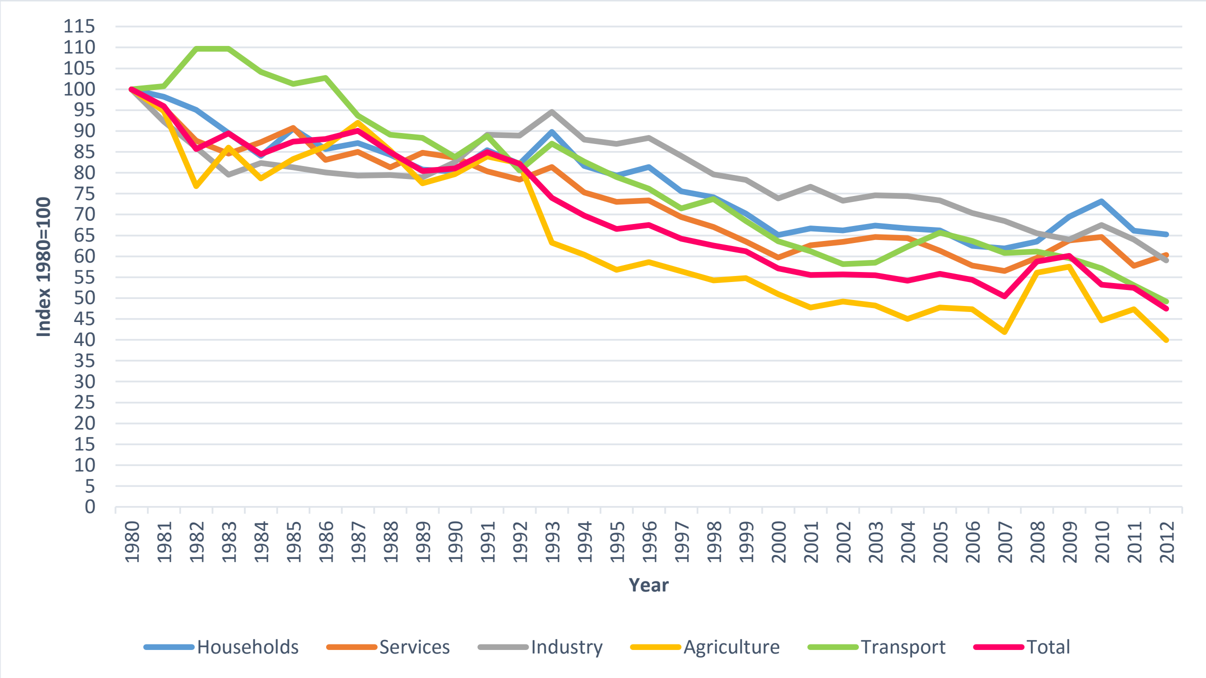
Source: DEA (2013a) and Odyssee (2016).

Figure 1 shows how the CO_2 emissions in Denmark has changed since 1980 to 2012 in total but also in each sector, where the CO_2 emissions within the service-, industry-, agriculture-, and the household sector has decreased over the time period with around 52 %, 55%, 42 % and 62 % respectively, in relation to 1980. However, if one divides the household sector into two shares that contains household cars and household other, it can be seen that even if the total household sector has decreased its CO_2 emissions, the CO_2 emissions from household cars has actually increased over the time period with around 49 % in relation to 1980. As will be shown later in the result section, the rise of the CO_2 emissions level within household cars is partly due to the fact that the ownership of cars has risen and the same concerns driving more powerful and bigger cars that require more energy, which can be supported by Papagiannaki and Diakoulaki's study (2009).

Another sector that also has increased its level of CO_2 emissions over the time period is the transport sector, whose level has increased with almost 26 %, see figure 1. The transport sector includes CO_2 emissions which comes from road transport, rail transport, domestic sea transport, international- and domestic aviation and military transport. One hypothesis that might explain the increase of the level of CO_2 emissions within the transport sector, and is supported in the study by Jensen and Olsen (2003), is that the level of road transport has risen, which causes higher levels of CO_2 emissions since it increases the consumption of propellant fuel. However, the study by Jensen and Olsen (2003) does also point out that the increasing CO_2 emissions levels also depends on the increase of aviation- and sea transport, but not as much in comparison with road transport. Nevertheless, even if the transport sector and household cars within the household sector have increased their CO_2 emissions level over the time period, the total level of CO_2 emissions still show a decreasing trend where the level of CO_2 emissions has decreased from 63,5 million tonnes year 1980 to 37,5 million tonnes in 2012, which is a decrease of almost 26 million tonnes or 41 % over the time period.

6.3.2 Factors that influence the level of CO_2 emissions.

Figure 2. Development of total energy intensity, index 1980=100

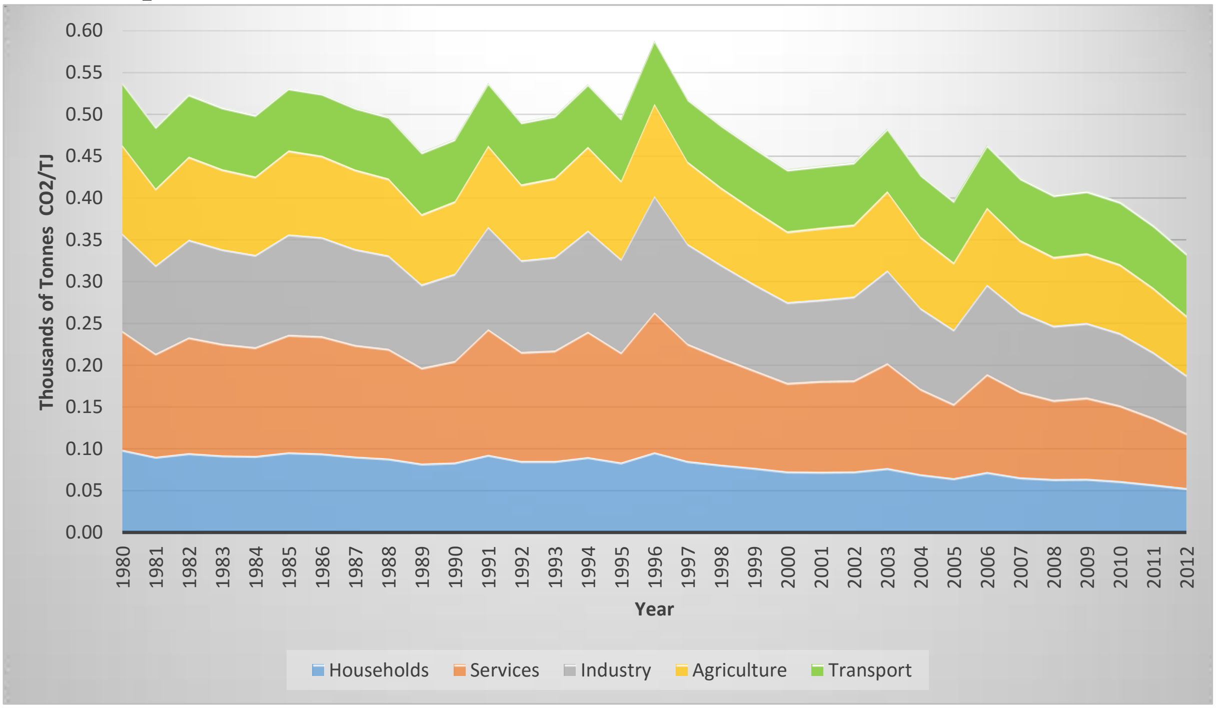


Source: UN Statistics (2015), DEA (2013a) and Odyssee (2016).

Figure 2 is an index graph where 1980 has the base value 100. The figure illustrates the changes in total energy intensity from 1980 to 2012, which have decreased on average with almost 53%; which means that the amount of relative energy intensity within the production has become lower in relation to 1980. Figure 2 also shows the change of energy intensity in each sector, where all sectors show an average decreasing trend. A small time period that stands out more than the others are the years between 1990 to 1993, where almost all sectors more or less did an increase followed by a steep decrease to 1996 and then a further steeper decrease which has kept the same decreasing pattern more or less over the rest of the time period. According to section 5.4.2, one can conclude that the technological development within each sector has done a large improvement over the time period, since all of the sectors are showing a decreasing trend of energy intensity.

The two sectors that have decreased their energy intensity the most are the agriculture sector and transport sector, which have decreased with around 60 % and 51 % respectively. In respect to figure 1 the transport sector's decrease seems odd, since the transport sector is the only sector which has increased its level of CO_2 emissions over the time period, see figure 1. However, the transport sector may have done some technological improvements, but there might be other factors that affect the total level of CO_2 emissions, which is further investigated in later sections.

Figure 3. CO_2 emissions intensity in thousands of Tonnes/TJ (Tera joule), Annual change.

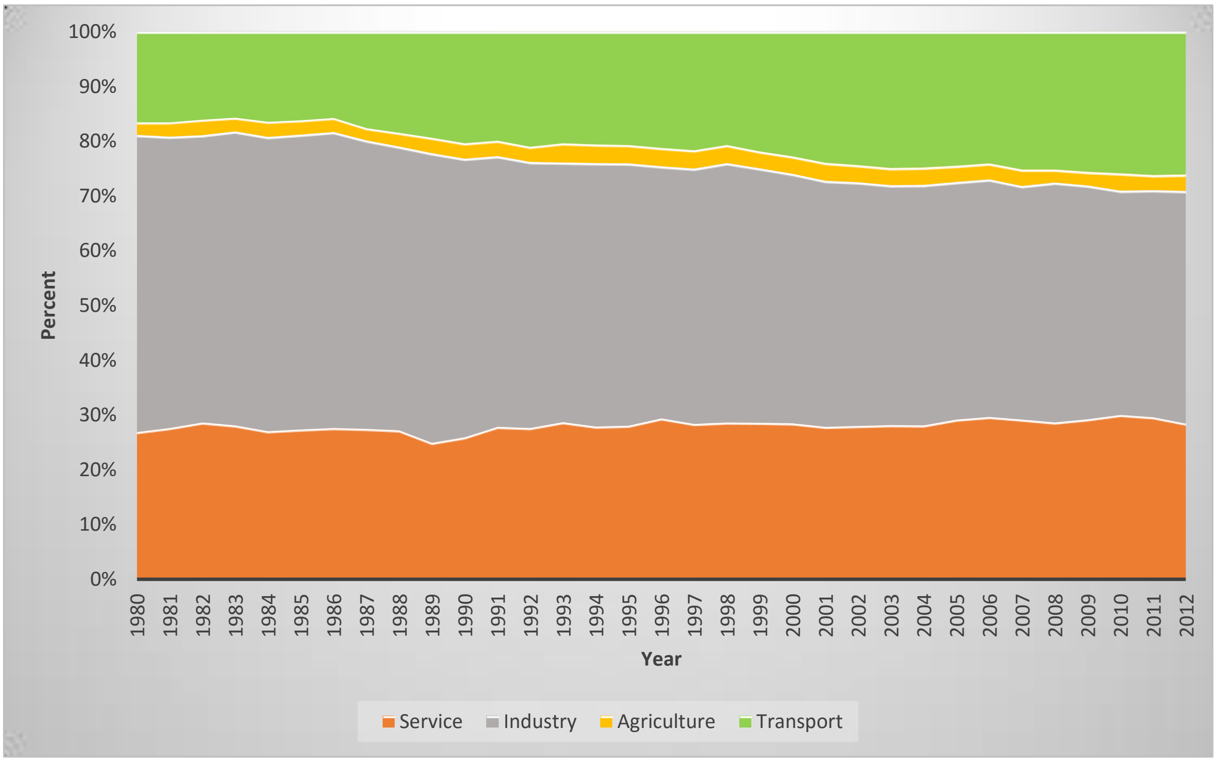


Source: DEA (2013a) and Odyssee (2016).

Figure 3 presents the changes of CO_2 emissions intensity in each sector and the total change in CO_2 emission intensity by summing them all sectors. One can conclude from figure 3 that the CO_2 emission's intensity has decreased in each sector, due to the increased efficiency in the fuel switch and thereby also the total level. From 1980 to 2012 the total level of CO_2 emissions intensity decreased with almost 38 %. The sectors that have decreased their CO_2 emissions intensity the most in relation to 1980 are the service-, household-, industry- and agriculture sectors, which have decreased with 54%, 45%, 40% and 33% respectively. The transport sector has also decreased its level of CO_2 emissions intensity over the time period, this with 0, 4 % which is a very modest decline in contrast to the other sectors. As will be shown later in the result- and discussion section, the reason to why the transport sector is showing an almost constant trend of its CO_2 emissions intensity over the time period, might be explained by the lack of substitutes to fossil fuel.

The level of CO_2 emissions intensity has decreased over the years, but the decreasing trend has not always been steady over the whole period. All of the sectors except for the transport sector have had some fluctuations over the time period, especially during the years between 1990 to 1997 and 2002 to 2008/2009.

Figure 4. Value added GDP, each sector's percentage share of total GDP (excluding the household sector).

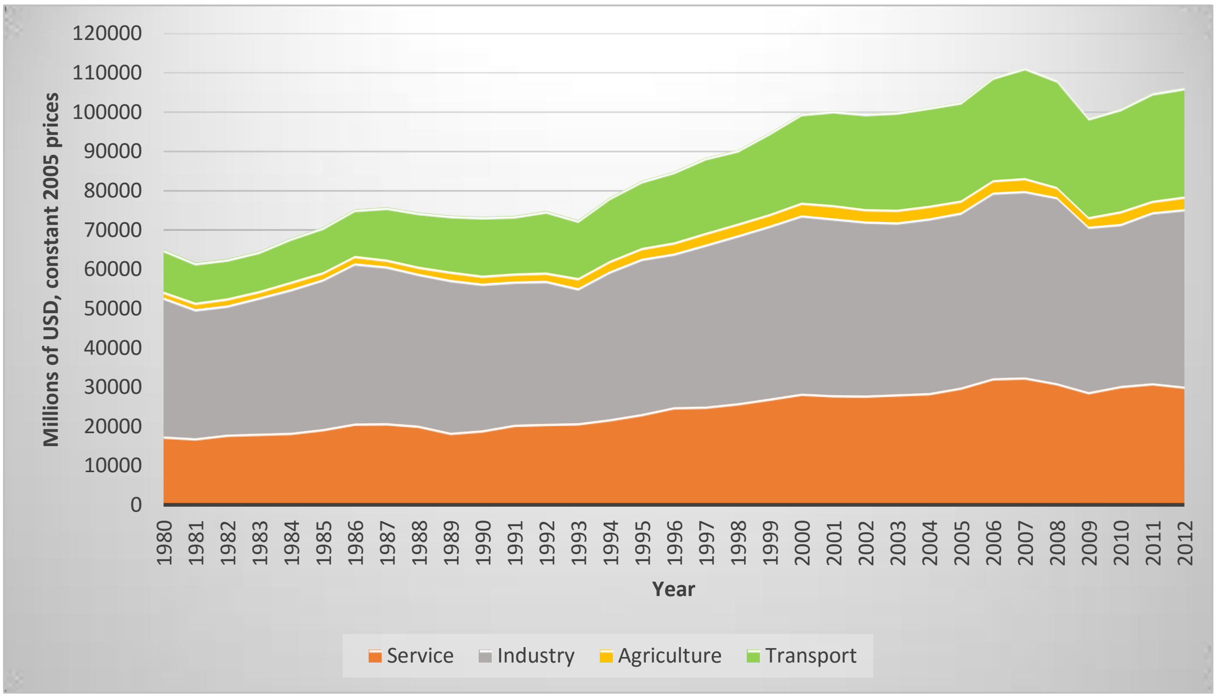


Source: UN Statistics (2015).

Figure 4 shows the value added shares of GDP in Denmark per year. It can be concluded from the figure that the sectors that have increased their shares of total GDP the most are, the service-, transport-, and agriculture sector, where the service sector has increased with around 6 % and the transport sector with around 57 % since 1980. The agriculture sector's share of total GDP has also undergone an increase over the time period, from 2,3 % year 1980 to 3 % year 2012 which is an increase of around 30 %. This means that if the sector increases its share of total GDP with one percent it is a huge increase within the sector, but for the total GDP the increase will still be relatively small.

The industry sector has in contrast to the other sectors decreased its share of total GDP with around 21 % over the time period, even if the GDP within the sector has increased over the time period, see figure 4. The change of each sector's share of total GDP is an important aspect to take into consideration when one analysing the changes of CO_2 emissions, since a decrease/increase of one sector's share might be the explanation of why that sector's CO_2 emissions has decreased/increased.

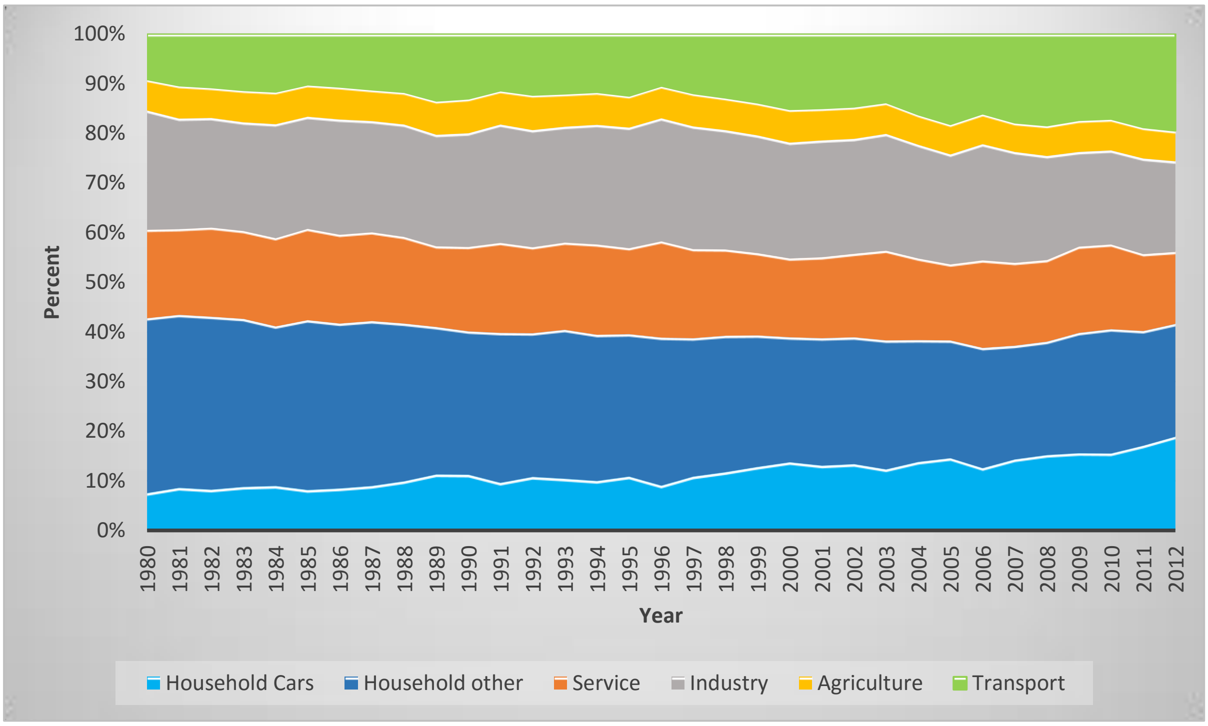
Figure 5. Total GDP of Denmark, millions of USD in 2005 prices, annual change between 1980 and 2012



Source: UN Statistics (2015).

Figure 5 shows the annual growth of the GDP in Denmark, which has increased with more than 63 % in year 2012 since 1980, which is an average rise with around 37 %. Figure 5 also shows interesting fluctuations over the time period, where the total GDP was declining in the beginning of the 1990s which was followed by a steady increase until 2007. Figure 5 also enables to see each sectors share of the total GDP, except for the household sector. However, to see the percentage change of the value added share in each sector of total GDP per year figure 4 is a better choice to look at.

Figure 6. Contribution to total CO_2 emissions from each sector, annual change 1980-2012, not value added



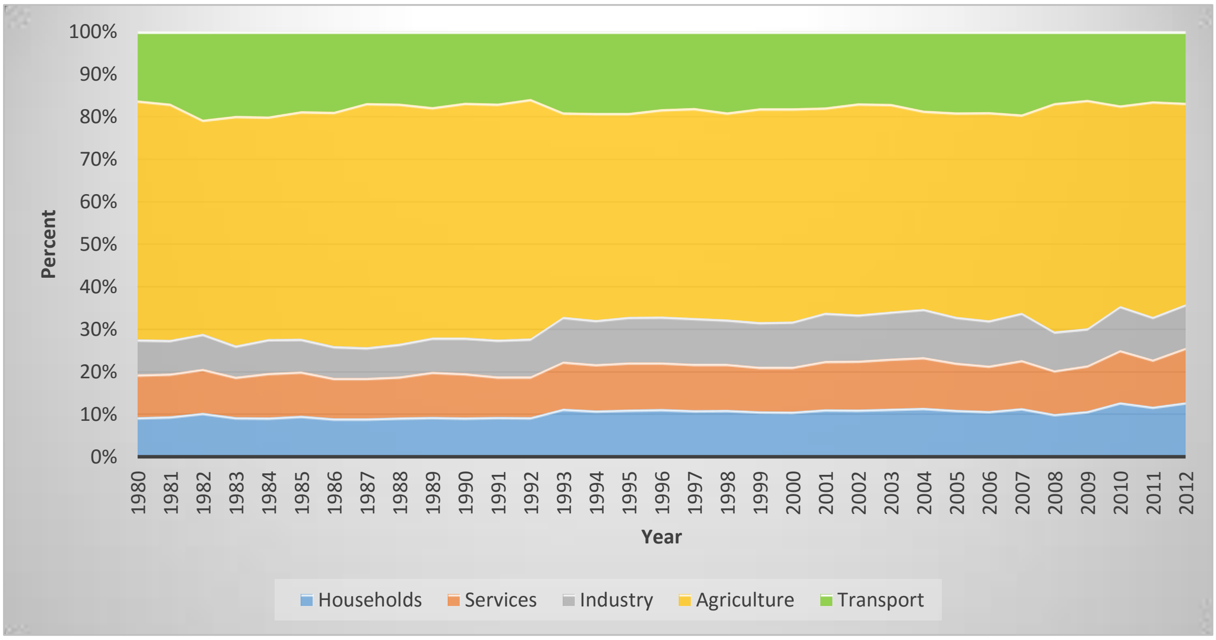
Source: DEA (2013a) and Odyssee (2016).

Similar results as in figure 3 are also shown in figure 6, however figure 6 also illustrates each sector's share of contribution to the total CO_2 emissions. Figure 6 shows inter alia that the industry sector is one of the sectors that contributes the most to the CO_2 emissions, but what also can be concluded is that the sector's share has declined over the time period, which corresponds to the results from figure 3 where the sector shows a downward slope. However, what differs between figure 3 and 6 is that figure 6 shows that even if the household sector is decreasing its level of CO_2 emissions and CO_2 emissions intensity, it is still the sector which actually contributes the most to the total CO_2 emissions in Denmark and has barely changed over the time period. This might be explained by the share of household cars, whose share of contribution to the level of CO_2 emissions also can be seen in figure 6.

The household sector's large contribution to the total CO_2 emissions level in Denmark is illustrated in figure 6. In the figure the household sector has been divided into two shares and shows the division of household cars and household others. What can be concluded from figure 6 is that the household other's share of contribution to the total CO_2 emissions has fallen over the time period with around 36 %. However, if one looks at the household cars, one can actually see that the share of contribution to CO_2 emissions is showing a steadily increasing trend since the beginning of 1980, where an increasing trend has more than doubled year 2012 in relation to the 1980s' level. The household sector has decreased its CO_2 emissions with around 42 % over the time period, but at the same time the household cars has actually increased its CO_2 emissions with around 48 %, see figure 1. One hypothesis of why household cars shows an increasing level of CO_2 emissions, which will be further discussed in the result and discussion section, can be due to the increased amount of owners of passenger cars, which is also emphasised in the study by Papagiannaki and Diakoulaki (2009), but also for the reason of that the fuel of passenger cars has very few substitutes.

The fact that the household cars has and is still increasing its CO_2 emission, might explain why the household sector has not decreased its CO_2 emissions more than what it has done, see figure 1.

Figure 7. Contribution to total energy intensity, annual change between 1980-2012, not value added



Source: DEA (2013a) and UN Statistics (2015).

Figure 7 shows the change within each sector's share of contribution to the total level of energy intensity over the period between 1980 and 2012. According to the figure, one can conclude that the agriculture sector contributes the most to the total level of all the sectors, where the agriculture sector was almost 40 % larger than the transport sector in 1980, which is the sector which has the second largest share of contribution to energy intensity. However, in contrast to the other sectors the agriculture sector has reduced its share of contribution over the time period with around 16 % year 2012 in relation to 1980. The household-, services- and industry sectors are the ones that have increased their share of contribution the most, with around 37 %, 27 % and 24 % respectively year 2012 in relation to 1980. The transport sector has also increased its share, but only with ca 4 % which is a modest change compared with the other sectors.

7. Results and discussion.

In this part of the thesis the results from the decomposition method of LMDI presented for the changes in the level of total CO_2 emissions in all sectors and in all the decomposition factors that are the drivers behind the changes in the level of CO_2 emissions over the time period. The decomposition method of LDMI is a time-series decomposition over the time period between 1980 and 2012.

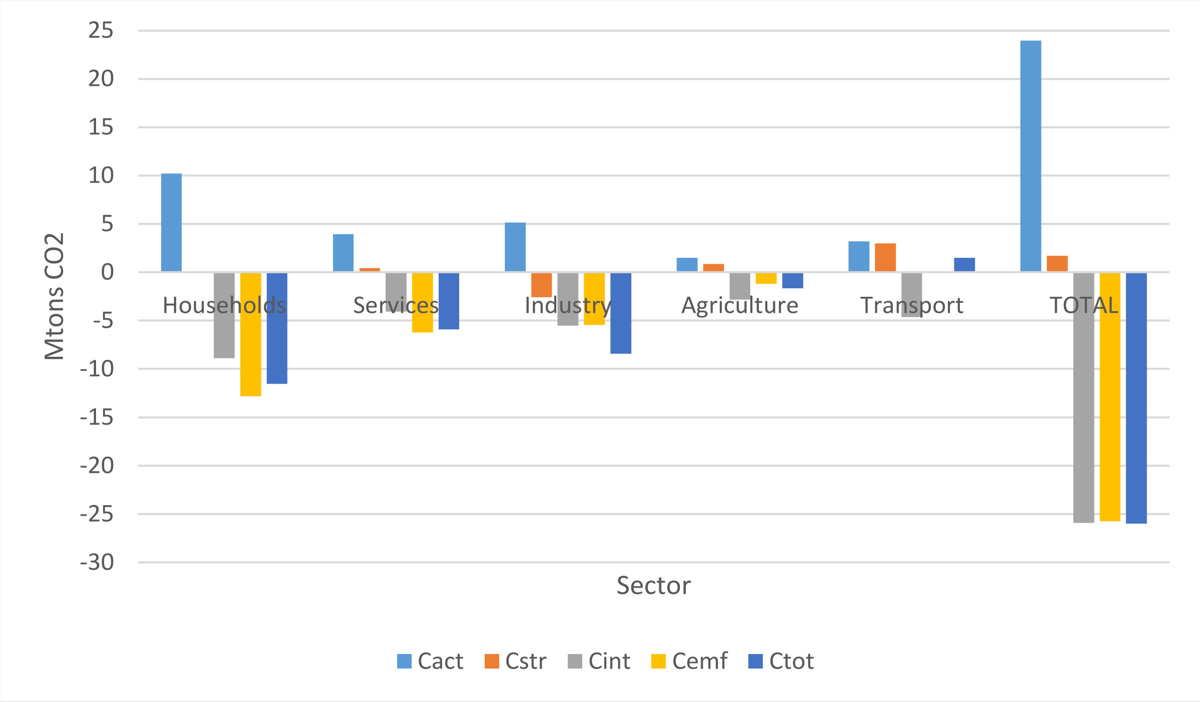
7.1 Result from the production based decomposition analysis of LMDI

Figure 8. Total CO_2 emission per sector, annual change, value added GDP is included

Source: DEA (2013a), Odyssee (2016) and UN Statistics (2015).

The annual change of total CO_2 emissions between 1980 and 2012 can be seen in figure 8, which also shows the annual change of the CO_2 emissions level in each sector. Over the time period the total level of CO_2 emissions fluctuated a lot, which mainly depends on the household-, service-, and industry sector, see figure 8. These three sectors are the ones who stands out the most and affect the total level of CO_2 emissions, especially the household sector. As mentioned in section 2.1.1, the biggest contributor to the total level of CO_2 emissions in Denmark is the energy consumption within the household and businesses, which can explain why the household sector stands out. In contrast to these three sectors, the transport- and agriculture sectors annual change holding a steady level of CO_2 emissions over the time period. However, despite the fluctuations and smaller impact from the transport- and agriculture sector, the total level of CO_2 emissions is still showing a decreased trend of the level of CO_2 emissions, which can be seen in figure 9.

Figure 9. CO$_2$ emissions in each sector and decomposition component, 1980 to 2012, value added GDP is



Source: DEA (2013a), Odyssee (2016) and UN Statistics (2015).

Figure 9 shows the change of total CO_2 emissions in Denmark between 1980 and 2012, but in contrast to the figure 8, figure 9 shows a period wise decomposition between 1980 and 2012. Figure 9 also shows the total changing amount in CO2 emissions in each sector and how the different drivers has impacted the total level of CO_2 emissions.

It can also be concluded from figure 9 that both energy intensity and CO_2 emissions intensity are the two components that have been the largest contributor of reducing the CO_2 emissions level in each sector and in the total level. The opposite has been the case for the activity effect component, which have had an increasing impact on the CO_2 emissions level in each sector and thereby also on the total level. The level of CO_2 emissions declined with almost 26 million tonnes year 2012 in relation to 1980, where the most important driver of reducing the level was the energy efficiency and fuel switching efficiency which declined the level of CO_2 emissions with 25,9 million tonnes and 25,7 million tonnes, respectively. These effects were enough to surpass the positive effects of activity and structural change which increased the level of CO_2 emissions with 23,9 and 1,7 million tonnes respectively.

It can also be concluded from figure 9 that the structural changes have decreased within the industry sector over the time period and increased in the services-, agriculture- and transport sector. By referring to the study by Xiao, Niu and Guo (2016), the effect of the structural change might also be one of the reasons why the total CO_2 emissions level have fallen in the industry sector, since industry produced products are commonly generating a higher pollution level. However, the reducing level of CO_2 emissions caused by structural change within the industry sector does not exceed the rising level of CO_2 emissions caused by the increased level of structural change within the service-, agriculture- and transport sector, and contributes therefore to the rising level of total CO_2 emissions, see figure 9.

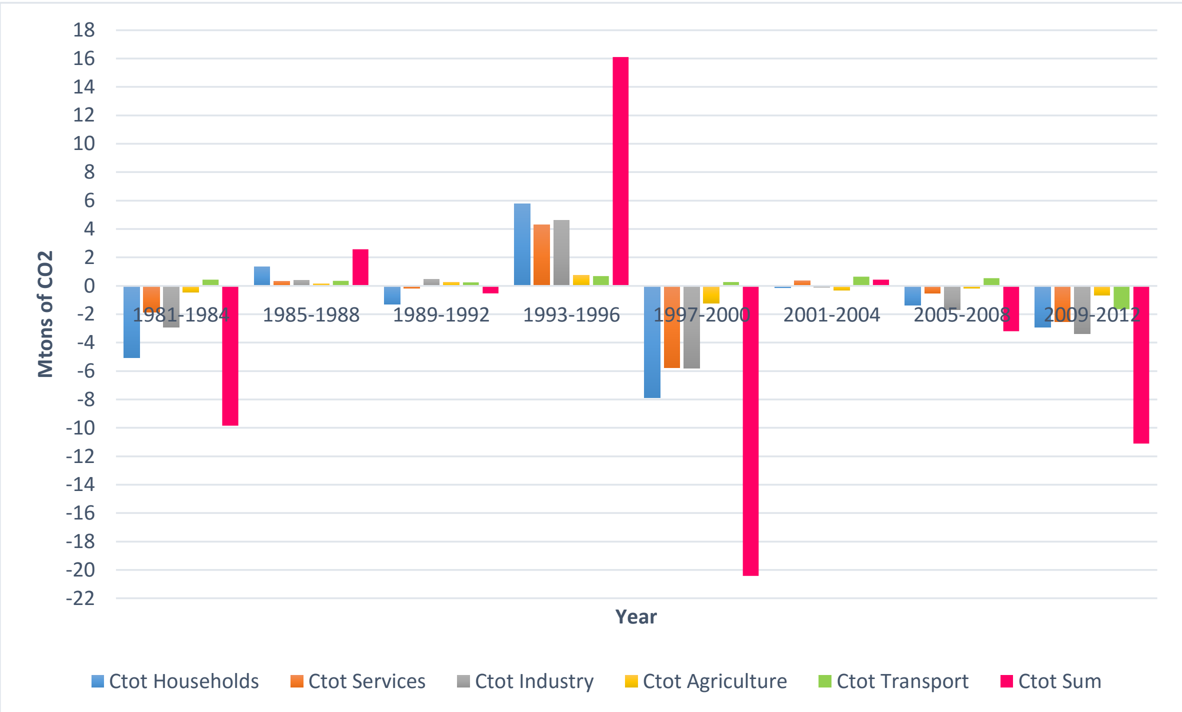
What figure 9 also shows is that the household sector is the sector that has the highest decreasing level of CO_2 emissions over the time period and thereby contributes the most to the total decreasing level of CO_2 emissions and thereafter the industry- and services sector, which more or less corresponds to the results from figure 6 in paragraph 6.3.2.

However, figure 9 also shows that the only sector that actually has increased its level of CO_2 emissions is the transport sector. According to the figure this depends mostly on the activity affect, but also on the structural change where both driving components have risen the level of CO_2 emissions over the time period within the sector, which indicates that the produced output within the sector has increased over the time period. The energy efficiency is the component that has the largest impact to reduce the CO_2 emissions level within the transport sector. The same concerns the fuel switch efficiency which also has a reducing effect, but in contrast to the energy efficiency component is the effect from fuel switching modest with only 26,4 thousand tonnes compared to energy efficiency's impact on 4,6 million tonnes. The activity effect has increased the level of CO_2 emissions within the transport sector with 3,2 million tonnes and structural change has increased the level of CO_2 emissions with 2,9 million tonnes.

All in all, by comparing the effects between the driving components, one can see that the effects from activity and structural change exceeds the effects from technological change and the CO_2 emissions intensity, which is why the sector has increased its level of CO_2 emissions. One hypothesis that explains this is by referring to the study by Papagiannaki and Diakoulaki (2009), which is the amount of car owners increasing in Denmark over the last years, but also the use of bigger and more powerful cars. This can support why the level of CO_2 emission within the transport sectors has increased, which then depends on a larger activity effect caused by an increased demand for cars etc. which increases the produced output, but also due to that the fuel for road transport has a few substitutes that can be as powerful and price competitive as fossil fuel (Kopp, 2006). This results in that the fuel switch component has a very small impact on the transport sector's level of CO_2 emissions. Denmark has introduced new policies that encourages the use of more desirable fuels such as natural gas, see section 2.1.4, which is one hypothesis of why the fuel switch efficiency has a modest but still positive impact on reducing the CO_2 emissions level. However, a larger impact from fuel switch on the CO_2 emissions level requires either more or better substitutes to fuels, or a change in the consumption pattern which can be to either travel more with public transport or travel less with airplanes etc.

However, to receive a better understanding of the changes during the time period one can look at figure 10 and 11, where the change of the total CO_2 emissions per sector is shown in figure 10 and the change of total CO_2 emissions per decomposition factor is shown in figure 11. Both figures show a time-series chaining decomposition, where the whole time period is divided into eight four-year periods.

Figure 10. Time-series chaining decomposition of total CO2 emission per sector. 4 year period between 1980 and 2012, value added GDP is included.



Source: DEA (2013a), Odyssee (2016) and UN Statistics (2015).

Figure 10 enables a better understanding of how the changes of CO_2 emissions behaves over the years, since the time period from 1980 to 2012 is divided into 8 intervals in a four-year period. The arguments divide the time period into eight four-year period and using a time-series decomposition are that the annual variations is taken into account. A further argument was to not lose important fluctuations that have happened over the time period, where changes may be dampened if one take a too long time span, since a period's upward trend can damp another ones downward trend and thereby not give fully correct results. This also explains why this section contains the two figures such as 10 and 11, which is to be able to illustrate how the level of CO_2 emissions have changed sporadic in each sector and by each driving factors over the whole time period.

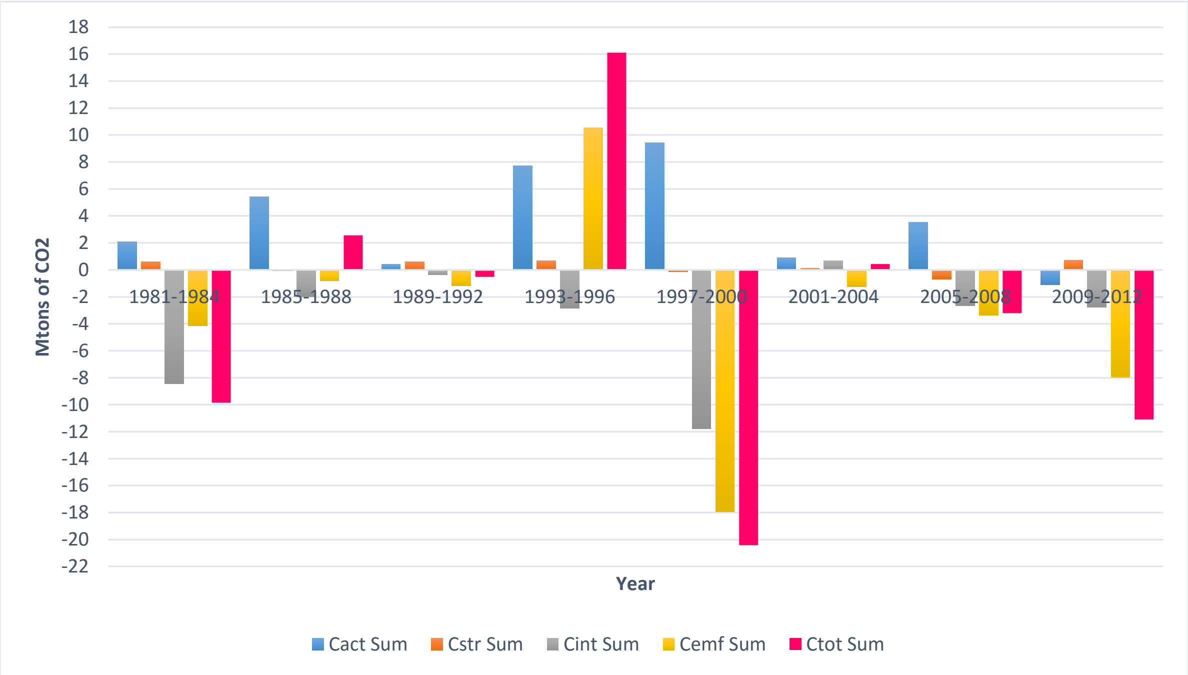
As in previous figures such as figure 8 and 9, figure 10 also shows that there are three sectors that stand out more by having a larger impact on the total level of CO_2 emissions in each time interval. These sectors are the household-, industry- and services sector, especially the household sector which again can be explained by the large consumption of energy within the sector, see section 2.1.1. It can be noted from figure 10 that some fluctuations in the total level of CO_2 emission have taken place during the years, where the time-periods 1993 to 1996 and 1997 to 2000 stands out the most. This might be explained due to the new environmental policy that was introduced and implemented during these years, such as the third and fourth energy plan which are mentioned in paragraph 2.1.4. The third energy plan was introduced 1990 with the purpose of using more environmentally friendly fuels such as natural gas, solar energy, biomass and wind. This can explain the decrease of the total level of CO_2 emissions between 1989 and 1992, due to the effects from using more environmentally friendly fuels as resulted in a positive effect within the fuel switching factors which reduction together with energy efficiency surpassed the increased level of CO_2 emissions caused by activity and structural change.

In 1993 a new regulation was implemented which was a requirement that all power stations need to use at least 1,4 million tonnes of biomass (House of Green, 2015). This regulation together with the introduction of the fourth energy plan in 1996 with the aim of a further reduction of fossil fuel which mean to reduce the import of fossil fuel and become more self-supplied, might explain the large increase of the CO_2 emissions level between 1993 and 1996. This is due to when such reforms are implemented, the CO_2 emission intensity increases in the beginning until the fuel switch effect has become efficient. This can explain the large increase of the CO_2 emissions level between 1993 and 1996, but also the reduction between 1997 and 2000 due to that the fuel switch had become more efficient along with the Danish transformation to a service economy and due to the agreements from the Kyoto Protocol in 1997, which implied reductions of 8 % year 2012 in relation to 1998's CO_2 emissions level (Danish Energy Policy, 2015).

Another aspect that might explain the reduction of CO_2 emissions in 1997, was that the fourth energy plan did also include targets of that renewables should cover 12-14 % of the energy consumption by 2005, where the most significant renewable energy was biomass that went from contributed with 61 PJ to 85 PJ, between 1996 and 2005 (Danish Energy Policy, 2015). This might also support the decrease of the CO_2 emissions level within the household sector that started in 1997, since the household sector owes a great deal to the large share of energy consumption, see paragraph 2.1.1.

Another sector that is interesting to look at is the transport sector. The transport sector has until 2008 always had a negative impact on the decreasing level of CO_2 emissions, see figure 10. One reason why the transport sector started to decrease its level of CO_2 emission at this time was due to the economic crisis in 2007/2008, which reduced the economic growth in transportation, but also due to an increasing amount of initiatives to decrease the CO_2 emissions driven per km (The Danish Government, 2013). The initiatives that were taken in act included reforms such as a minimum requests of biofuels, taxation of cars in purpose to benefit those who drove more energy-efficient and environmentally friendly cars, but also technological development of cars in order to follow the new CO_2 regulations from EU (The Danish Government, 2013). The new reform in 2008 gave results on the energy efficiency and fuel switch efficiency, which can be seen in figure 11, where the effects from these two components are the largest contributor to the decreasing level in CO_2 emissions.

Figure 11. Time-series chaining decomposition of total CO_2 emission per decomposition component. 4 year period between 1980 and 2012, value added GDP is included.



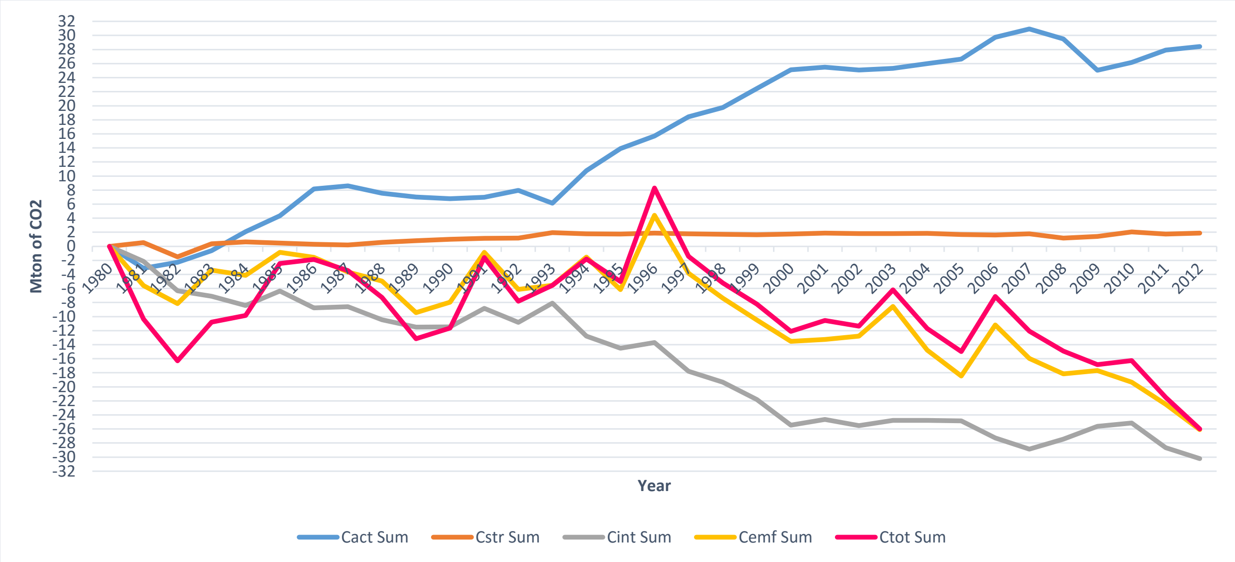
Source: DEA (2013a), Odyssee (2016) and UN Statistics (2015).

Figure 11 shows the change in total CO_2 emission in each component, which impacts the total level of CO_2 emissions. The time period is from 1980 to 2012 and is divided into 8 intervals in a four-year period. From the figure it can be concluded that there are four four-year periods that stands out which are 1981-1984, 1993-1996, 1997-2000 and 2009-2012. Between 1981-1984 the second energy plan that was introduced, that partly meant that the government implemented new regulations in terms to improve the energy efficiency (House of Green, 2015), which also can be seen in figure 11 to be the main driver of reducing the CO_2 emissions level. The rise between 1993 and 1996 can be connected to the new policy regulation in 1993 and the fourth energy plan which was implemented in 1990, see paragraph 2.1.4. As mentioned above, the new regulations and the fourth energy plan between 1993 and 1996 might have resulted in the decline of fuel switch efficiency. This can also be supported in figure 11, where the CO_2 emission's intensity are the components that have the largest impact of the increasing CO_2 emission levels between these years. Furthermore the impact from the CO_2 emissions intensity seems to have the same large impact on the level of CO_2 emission in the period between 1997 and 2000, but in this case a reducing impact. The impact from the CO_2 emissions intensity can also be connected to what mentioned above, that by this time has the fuel switch and energy intensity has become more efficient, but also due to the new reforms as appeared along with the agreements from the Kyoto Protocol in 1997.

The large reduction between 2009 and 2012 can also be connected to the new initiatives that was taken in act in 2008, that included reforms such as a minimum requests of biofuels, taxation of cars in purpose to benefit those who drove more energy-efficient and environmentally friendly cars, but also technological development of cars in order to follow the new CO_2 regulations from EU. As a result from these initiatives, one can see in figure 11 that the reduction of the CO_2 emissions level depend on the improvement within energy and fuel switch efficiency, but also on a reduction of the activity effect which can be due to the economic crisis in 2007/2008 (The Danish Government, 2013).

What also can be concluded from the figure is that the components which differ the most of impacting the total level of CO_2 emission in each four-year period are the activity, energy intensity and CO_2 emissions intensity, especially the later. The structural change is the component who has changed the least compared to the others, but is actually contribution to a negatively to the decreasing level of the CO_2 emissions since it has increased the level with 1,8Mtons over the time period, see figure 9 and 12.

Figure 12. Cumulative changes in total CO_2 emissions by driving factor, 1980-2012



Source: DEA (2013a), Odyssee (2016) and UN Statistics (2015).

Figure 12 shows the cumulative changes in the level of total CO_2 emissions and each driving factor's impacts the level. Even if the annual change of the CO_2 emissions level has fluctuated a lot over the time period, see figure 8, and the total level has decreased with almost 26 % in 2012 since 1980. As many other studies emphasises such as Kopidou, Tsakanikas and Diakoulaki, (2015), Kander et al (2013b) and Henriques and Kander (2010), technological change and CO_2 emissions intensity has a major impact on reducing the level of CO_2 emissions. The results from figure 12 also supports this assumption, since figure 12 shows that the two driving factors that have the largest impact on reducing the total level of CO_2 emissions are the technological changes and CO_2 emission's intensity. One can see in the figure that these two driving components have decreased over the time period, which means that they have become more efficient, paragraph 5.4.3, 5.4.4.

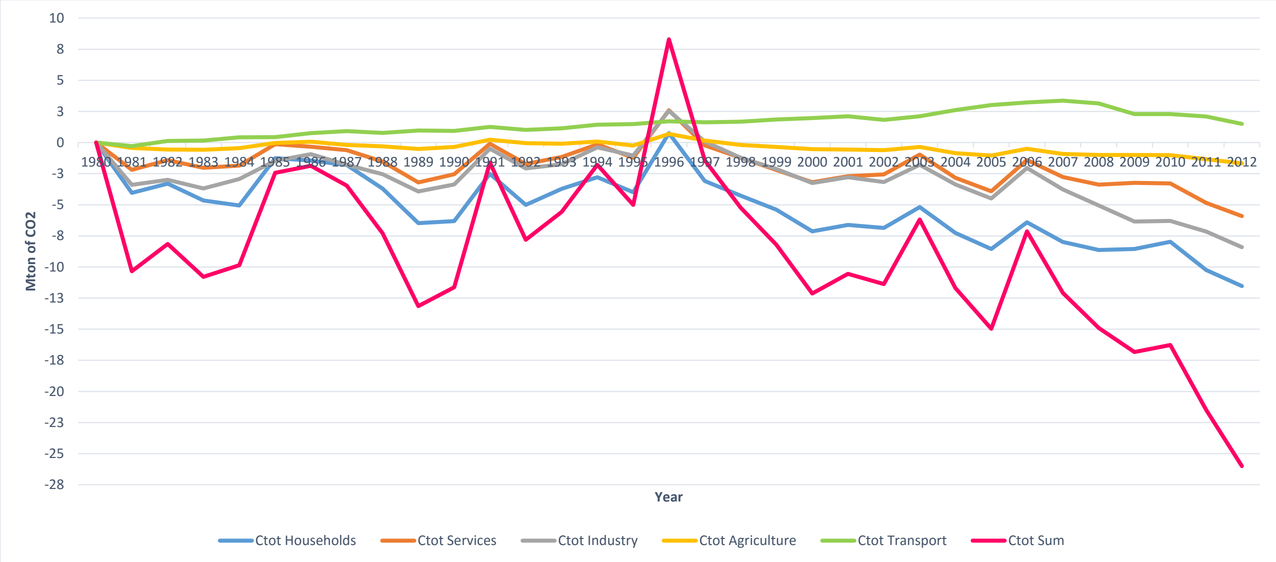
One hypothesis of the driving factor's impact on the total CO_2 emissions level might be supported from the changes after the oil crisis in the beginning of 1970s. As mentioned before in paragraph 2.1.2, Denmark has since the oil crisis in the beginning of the 1970s put together an energy supply which comes from domestic sources, in purpose of being more energy efficient but also to increase the use of renewables. According to figure 12, the contribution to the level of CO_2 emissions from technological change has decreased over the time period, which implies a technological improvement. This might be connected to what is mentioned above, that Denmark has become more energy efficient after the oil crisis in the 1970s. The same concerns the fuel switch efficiency, which has decreased its contributions to the CO_2 emissions level over the time period.

The other two driving factors such as activity effect and structural change, have had a negative impact on reducing the total level of CO_2 emissions over the time period, especially the activity effect as can be supported by the study of Kyunam and Yeonbae (2011) to have a major impact on increasing the level of CO_2 emissions. The same conclusion can be drawn from figure 12, where the activity effect has since 1984 shown an increasing trend of its CO_2 emissions level, where the trend has had some dips at year 1993 and around 2007/2008. One possible explanation of why the component activity effect has increased its CO_2 emissions level, might be due to the transport sector's growing share of total GDP and rise of produced output. This can be seen by looking at figure 9 where structural change has increased the most within the transport sector compared to the other sectors, which also can be supported with the study by Papagiannaki and Diakoulaki (2009). However, the industry sector might also have impacted the activity effect's contribution to the CO_2 emissions level where the study by Jacobsen (2000) supports that energy consumption has increased along with the production within the industry sector where a large share is for exportation.

The two driving components such as energy efficiency and fuel switch efficiency have over the whole time period surpassed the two other driving components, activity effect and structural change, except for around 1996 and 1997. One possible hypothesis can explain this is that the reform of a further reduction of oil, see paragraph 2.1.4 but also that Denmark became self-sufficient in energy with its own production of natural gas and oil etc. This means that all the CO_2 emissions that have occurred from the production of the imported oil to Denmark, has not be seen in the Danish level of CO_2 emissions. However, being self-sufficient implies that the CO_2 emissions that have emerged from the production of oil and natural gas is visible within the Danish level of CO_2 emissions, which can explain the increased levels of CO_2 emissions seen in figure 12. (House of Green, 2015). The reason why the CO_2 emissions level then went down might be explain by that an improvement within fuel switch efficiency, due to the changed reforms and an encourage interaction between the sectors, see paragraph 2.1.2.

The driving component that has the same pattern as the total level of CO_2 emissions is the fuel switch efficiency, which supports that the type of fuel that is used as a major influence on the total level, but also has the sectors where the cumulative changes in the CO_2 emissions level can be seen in figure 13.

Figure 13. Cumulative changes in total CO_2 emissions per sector, 1980-2012.



Source: DEA (2013a), Odyssee (2016) and UN Statistics (2015).

Figure 13 shows the cumulative changes in level of total CO_2 emission between 1980 and 2012 in each sector, but also the total level. In terms of cumulative changes over the time period are the household-, industry-, services- and agriculture sectors. The sectors that have decreased its CO_2 emissions level the most, with 11,5 million tonnes, 8,4 million tonnes, 5,9 million tonnes and 1,6 million tonnes, respectively. Of all these sectors the household sector has the largest reducing level. One hypothesis of why the household sector contributes positive to the decreasing level of CO_2 emissions might be supported by the theory of EKC, as can be seen in paragraph 3.1. The concept means that an increased income along with that the economy becomes more de-industrialized, will be reflected on the consumption pattern which implies to consume more environmentally friendly produced products which are less machine- and material intensive. Even if the concept of EKC has met a lot of criticism, it fits the concept pretty well with the Danish economy. This, for the reason that Denmark is one of the top 25 richest countries in the world, measured in GDP/capita (WRC, 2016), and since the concept emphasizes the impact from an increase income on the environment, might support why the household sector has decreased its level of CO_2 emissions with the explanation that the consumption pattern has changed since the consumers actually can afford to consume more environmentally friendly produced products.

The industry sector also shows a decreasing trend of its level of CO_2 emissions over the time period, which might be due to the impact from the driving factor structural change that has decreased within the industry sector and increased within the services sector, see figure 9. However, according to previous studies such as Jacobsen (2000) and Xiao, Niu and Guo

(2016), structural change has an impact but it is very modest and might not be the only explanation of the industry- and services sector's reducing level of CO_2 emissions. One hypothesis that are related to the argument that are mentioned in the paragraph above, is that both the domestic and international demand of more environmentally friendly products has increased, which related to the theory of EKC. According to figure 9, the industry sector shows an increase of the level of CO_2 emissions caused by the component activity effect, which might be due to an increase exportation as the study by Jacobsen (2000) is meaning. However, the effects from energy efficiency, fuel switch efficiency and structural change surpasses the level of CO_2 emissions caused by the activity effect. This might imply that the production within the industry sector has become more environmentally friendly, which can be due to an increased income and thereby a changed consumption pattern, but also to more restrictive environmental regulations within trade as have been mentioned in paragraph 3.1, which in the end can lead to reduction of the level of CO_2 emissions.

The agriculture sector has also reduced its CO_2 emissions in terms of cumulative changes, where the reduction also has been steady since 1996, refer to figure 13. The energy intensity and CO_2 emissions intensity are the two driving components that have had a reducing impact on the level of CO_2 emissions within the agriculture sector, especially in the energy intensity. The reducing impact on the CO_2 emissions level from an improvement in energy efficiency and fuel switch efficiency are on a level of around 2,8 and 1,2 million tonnes respectively, which together surpasses the increasing impact from the activity effect and structural change which has a level on 1,5 and 0,86 millions of tonnes, respectively. One hypothesis that can explain the reduction of the level of CO_2 emissions is due to the large improvement in energy efficiency, see figure 9, but also due to that Denmark implemented mitigation plans between the periods of 1990 to 2010 which can explain the increased efficiency within the fuel switch component within the sector (The Danish Government, 2013).

The same as mentioned can be seen in figure 12, year 1996 stands out compared to the other years by that the large increase of the level of CO_2 emissions. What can be concluded from figure 13 is that this is the only moment at the time period as the household-, industry and services sector contributes to increase the total level of CO_2 emissions. One hypothesis as can explain this and is also mentioned before, is that Denmark implemented a new reform to stop all importation of fossil fuel and become self-sufficient in 1996. This might have risen the CO_2 emissions level, due to that the CO_2 emissions caused by the production of oil and coal was by this year visible within the Danish level of CO_2 emissions and not in the country where oil and coal has been imported from. The energy consumption is largest within the household sector, where the sector accounted for half of the Danish emissions in 1990, which is a pattern that have continued ever since. This is mostly due to the individual use of fossil fuel in order to heat up buildings and industrial processing (The Danish Government, 2013). A further explanation of the household sector's reduction is that the share of passenger cars is included within the household sector and since the Danish government implemented a new taxation of cars in 1996, to benefit those who drove energy-efficient and environmentally friendly cars, might this have gave an effect of increasing the share of environmentally friendly cars on the roads (The Danish Government, 2013).

The only sector that shows an increasing trend of its level of CO_2 emissions is the transport sector, see figure 13. As mentioned many time before, this increase might be due to an increased amount of owners of passenger cars and more bigger and powerful cars and since there exists a few substitutes to fuel, has this resulted in an increased level of CO_2 emissions. When the climate policy plan where written in 2013 (The Danish Government, 2013), the transport sector stood for around 1/3 of the total energy consumption in Denmark, which is almost based on fossil fuel and can directly be related to the level of CO_2 emissions that comes from the transport sector.

8. Conclusion

The GDP of the Danish economy has done a large increase over the last 32 years, but still has the country enables to display a decreasing trend of its level of CO_2 emissions over this time period. This paper has investigated the change of the level of CO_2 emissions from a production perspective by using a decomposition method of LMDI, which is one of the most common tool to use in the field of environmentally studies. Investigating the changes in the level of CO_2 emissions implied that focus has been on the sectors such as household, industry, services, agriculture and transport, but also on the drivers behind the changes in the CO_2 emissions level by using four components such as activity effect, technological change, structural change and CO_2 emissions efficiency.

Of all the sectors the household sector proved to be the sector which has decreased its CO_2 emissions level the most, even if a large share of the sector contains the CO_2 emissions caused by passenger cars. This depends mostly on the different regulations and reform that has been introduced over the time period, but some hypothesises can also support that the decreases depends on an increased income which changes the demand of products that has been more environmentally friendly produced. The sector that stands out and actually shows an increasing trend of its CO_2 emissions level is the transport sector, which can be supported to mostly depend on that there only exists a few substitutes to oil as a fuel along with an increasing output.

The impact from driving components on the level of CO_2 emissions has differs during the time period, but the driving components that as shown to have largest impact on reducing the level of CO_2 emissions are the technological change as implies an improvement in energy efficiency, but also an improvement within the fuel switch efficiency. Both activity effect and structural change has more or less always had a negative impact on reducing the total level of CO_2 emissions, except for the last period between 2009 and 2012 where the activity effect contributed to reducing the CO_2 emissions level where the economic crisis in 2007/2008 had some impacts.

Along with economic growth and new policy changes such as new reforms or other regulations due to different climate policy agreements or with the EU, has led to an improvement within the technology and thereby also in the energy and fuel switch efficiency. However, an economic growth and an increased income can also have an important impact on the level of CO_2 emissions. In the early stages of industrialization increases many countries its level of CO_2 emissions such as Denmark's when it became self-sufficient of oil and coal production in 1996. However, along with an improvement in energy efficiency the larger reduction in the level of CO_2 emissions. The same concerns the improvement in fuel switch efficiency which rises due to a change consumption pattern of more environmentally friendly produced products along with an increased income.

All in all, this paper has found support of that the driving factors as contributors the most to increase the level of CO_2 emissions over the time period between 1980 and 2012, are the activity effect and structural change. The driving factors that contributes the most to lowering the levels of CO_2 emissions are the technological change and fuel switch, which has enables to be improved due to new reforms and an policy changes to a greener economy. However, this paper suggest that in order to reduce the levels of CO_2 emissions even more, a lot of effort should be put on changing the consumption pattern or improve the efficiency of fuel switch which can lower the CO_2 emissions coming from road transport and passenger cars.

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Appendix

Cumulative changes in total CO_2 emissions per sector and per driver factor 1980-2012.

	1980	1981	1982	1983	1984	1985	1986	1987
CO2Tot Households	0	-4037.36	-3303.08	-4660.72	-5055.8	-1253.37	-1445.4	-1806.17
CO2Tot Services	0	-2184.83	-1422.45	-2025.36	-1854.12	-124.516	-331.699	-604.965
CO2Tot Industry	0	-3395.8	-2992.31	-3681.11	-2923.09	-1462.25	-934.433	-1781.48
CO2Tot Agriculture	0	-435.698	-568.155	-577.727	-452.625	-35.6037	69.79111	-192.8
CO2Tot Transport	0	-293.925	134.2798	161.6642	429.9595	439.1319	768.3341	921.848
CO2Tot Sum	**0**	**-10347.6**	**-8151.71**	**-10783.3**	**-9855.68**	**-2436.6**	**-1873.4**	**-3463.56**
CO2act Sum	0	-3121.66	-2269.65	-619.539	2093.503	4350.415	8171.586	8605.243
CO2str Sum	0	509.321	-1488.4	347.6617	622.1495	457.0273	304.2702	172.5238
CO2int Sum	0	-2158.69	-6328.21	-7117.57	-8437.39	-6383.17	-8768.48	-8593.9
CO2emf Sum	0	-5576.58	-8151.71	-3393.81	-4133.94	-860.88	-1580.78	-3647.43
CO2tot Sum	**0**	**-10347.6**	**-16303.4**	**-10783.3**	**-9855.68**	**-2436.6**	**-1873.4**	**-3463.56**

Year	1988	1989	1990	1991	1992	1993	1994	1995	1996
CO2Tot Households	-3699.42	-6470.55	-6318.4	-2515.16	-5001.84	-3711.08	-2790.47	-3986.16	756.9911
CO2Tot Services	-1533.24	-3198.56	-2541.71	-94.2278	-1718.01	-1160.43	-138.974	-1228.63	2602.033
CO2Tot Industry	-2536.08	-3923.72	-3357.76	-500.299	-2078.62	-1736.24	-379.731	-1039.02	2541.358
CO2Tot Agriculture	-301.647	-519.672	-349.122	236.7397	-40.2009	-99.6684	88.6663	-239.729	692.4017
CO2Tot Transport	780.3642	966.7755	935.8613	1263.464	1024.406	1139.515	1429.325	1486.693	1702.924
CO2Tot Sum	**-7290.02**	**-13145.7**	**-11631.1**	**-1609.48**	**-7814.27**	**-5567.9**	**-1791.18**	**-5006.85**	**8295.708**
CO2act Sum	7536.266	6996.969	6776.468	6972.876	7955.972	6145.963	10745.29	13906.74	15697.15
CO2str Sum	549.8966	799.2296	1007.223	1123.96	1172.709	1933.975	1759.155	1753.415	1861.865
CO2int Sum	-10437.6	-11496.5	-11464.2	-8846.41	-10818.9	-8077.98	-12768.4	-14512.7	-13682.5
CO2emf Sum	-4938.6	-9445.38	-7950.67	-859.907	-6124.05	-5569.86	-1527.23	-6154.28	4419.148
CO2tot Sum	**-7290.02**	**-13145.7**	**-11631.1**	**-1609.48**	**-7814.27**	**-5567.9**	**-1791.18**	**-5006.85**	**8295.708**

Year	1997	1998	1999	2000	2001	2002	2003	2004
CO2Tot Households	-3083.97	-4264.69	-5395.82	-7134.27	-6620.65	-6852.08	-5190.85	-7259.47
CO2Tot Services	-217.625	-1228.29	-2199.37	-3180.01	-2697.97	-2564.02	-970.472	-2831.09
CO2Tot Industry	90.63079	-1217.06	-2117.89	-3252.86	-2790.89	-3165.58	-1778.4	-3371.47
CO2Tot Agriculture	160.3953	-191.29	-347.569	-523.745	-555.977	-610.593	-348.791	-844.825
CO2Tot Transport	1626.224	1676.062	1849.409	1968.827	2120.195	1820.254	2107.062	2611.82
CO2Tot Sum	**-1424.34**	**-5225.27**	**-8211.23**	**-12122.1**	**-10545.3**	**-11372**	**-6181.45**	**-11695**
CO2act Sum	18423.3	19752.15	22437.84	25125.1	25473.16	25097.19	25326.03	26009.91
CO2str Sum	1758.089	1714.547	1623.614	1736.593	1888.566	1807.499	1825.075	1849.135
CO2int Sum	-17772.3	-19322.5	-21788.8	-25463.5	-24654.1	-25503.9	-24785.3	-24785.7
CO2emf Sum	-3833.43	-7369.42	-10483.9	-13520.2	-13252.9	-12772.8	-8547.28	-14768.3
CO2tot Sum	**-1424.34**	**-5225.27**	**-8211.23**	**-12122.1**	**-10545.3**	**-11372**	**-6181.45**	**-11695**

Source: DEA (2013a), Odyssee (2016) and UN Statistics (2015).

Cumulative changes in total CO_2 emissions per sector and per driver factor 1980-2012.

	2005	2006	2007	2008	2009	2010	2011	2012
Ctot Households	-8545.44	-6401.27	-7988.63	-8626.02	-8548.64	-7964.47	-10250.8	-11525
Ctot Services	-3917.55	-1400.92	-2766.09	-3373.71	-3234.29	-3285.17	-4849.82	-5907.32
Ctot Industry	-4489.54	-2046.1	-3770.13	-5048.8	-6351.26	-6297.54	-7154.77	-8409
Ctot Agriculture	-1038.42	-497.363	-922.268	-998.642	-994.237	-1003.92	-1330.13	-1666.74
Ctot Transport	3021.514	3218.553	3364.774	3145.209	2292.553	2286.338	2090.731	1509.159
Ctot Sum	**-14969.4**	**-7127.1**	**-12082.3**	**-14902**	**-16835.9**	**-16264.8**	**-21494.8**	**-25998.9**
Cact Sum	26653.9	29755.23	30943.32	29520.45	25055.19	26175.49	27921.77	28421.62
Cstr Sum	1668.999	1599.375	1777.963	1166.813	1392.518	2041.517	1732.913	1879.631
Cint Sum	-24843.5	-27268.6	-28857.7	-27446.2	-25611.7	-25149.8	-28664.2	-30216.2
Cemf Sum	-18448.8	-11213.1	-15945.9	-18143.1	-17671.9	-19331.9	-22485.3	-26084
Ctot Sum	**-14969.4**	**-7127.1**	**-12082.3**	**-14902**	**-16835.9**	**-16264.8**	**-21494.8**	**-25998.9**

Source: DEA (2013a), Odyssee (2016) and UN Statistics (2015).