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Master thesis

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By means of the LMDI I decomposition analysis, which driving factors can be found in the evolution of CO_2 emissions for China, the United States, the European Union, and India in the time period from 1990 to 2012? Furthermore, what impact had existing policies on these driving factors, and hence on CO_2 emission evolution?

Supervised by:
Dr. Robert Harmsen (Utrecht University)
Assistant Professor Energy & Resources
Copernicus Institute of Sustainable Development
Faculty of Geoscience
Willem C. van Unnikgebouw
3584 Utrecht
r.harmsen@uu.nl

Pieter van Breevoort (Ecofys Netherlands B.V.)
Consultant
Kanaalweg 15G
3503RK Utrecht
p.vanBreevoort@ecofys.com

Written by:
Saskia Thies
Jan Pieterszoon Coenstraat 66
3531EX Utrecht
saskia.thies@gmail.com
Student number: 4295315

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Saskia Thies

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Abstract

Global CO_2 emissions have been continuously increasing between 1990 and 2012, especially with China and India as emerging countries. Together with the United States (US) and the European Union (EU) they contributed to 59% of total global CO_2 emissions in 2012. Energy related emissions contributed to 69% of total global GHG emissions of which 90% can be attributed to CO_2 emissions. The continuously increasing awareness of climate change led to the question what factors drove CO_2 emission change behaviour. In order to be able to determine these factors, a decomposition analysis was conducted. The Log Mean Divisia Index I was applied to decompose CO_2 emissions for the four above mentioned countries on a macro level and electricity sector as well as on a more in depth sector level for the EU (for transport, industry, and residential buildings). It was further looked into what policies had an impact on these driving factors and which indicators are suitable to monitor CO_2 emission changes. The results differed from country to country but in general it can be said that improvements in energy intensity/efficiency prevented CO_2 emissions to increase even more due to a growth in economic productivity. Only the EU achieved to reduce CO_2 emissions between 1990 and 2012, which resulted from both effective climate change policies and economic events as the fall of the Soviet Union and the financial crisis. All sectors in the EU that were subject of the decomposition analysis but the transport sector contributed to CO_2 emission mitigations. Most of the climate change policies were triggered rather by energy security concerns or taking economic opportunities than by climate change concerns.

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Glossary

A	Physical Activity
CAT	Climate Action Tracker
CCS	Carbon Capture and Storage
CG	per capita GDP
CHP	Combined Heat and Power
CO2	Carbon Dioxide
COP	Conference of the Parties
EC	Electricity Consumption
ECCP	European Climate Change Programme
EE	Electric Efficiency
EF	Emission Factor
EI	Energy Intensity
EM	Energy Mix
ETS	Emission Trading Scheme
EU	European Union
GDP	Gross Domestic Product
GHGs	Greenhouse gases
GVA	Gross Value Added
H	number of Households
HD	Household Density
IEA	International Energy Agency
INDCs	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
LMDI I	Log Mean Divisia Index I
MST	Mean Surface Temperature
NAPCC	National Action Plan on Climate Change (in India)
POP	Population
PPP	Purchasing Power Parity
RCPs	Representative Concentration Pathways
RES	Renewable Energy Sources
S	Surface Area
SI	Surface Intensity
TPES	Total Primary Energy Supply
US	United States
VAT	Value-Added Tax
WBCSD	World Business Council for Sustainable Development

1 Introduction

There is a broad consensus among scientists that global emissions need to be reduced in order to limit the mean surface temperature (MST) to an extent that avoids irreversible effects on the earth. In the outcome of the 16th session of the Conference of the Parties (COP) in Cancun, countries recognised that emissions need to be reduced so that the MST does not increase more than 2°C, in a first step. On a long term, this temperature rise should be limited to 1.5°C compared to preindustrial levels (UNFCCC 2011). As a consequence, the parties of the 19th COP in Warsaw agreed on submitting Intended Nationally Determined Contributions (INDCs) to the 21st COP in Paris in order to "adopt a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties" (UNFCCC 2013, p.4), and hence fulfil the 2°C target. In the report of the 21st COP in Paris it was noted that the INDCs did not achieve the targeted reductions and that emissions should be reduced to 1.5°C compared to preindustrial levels (UNFCCC 2015).

Greenhouse gases (GHGs) remain a certain time in the atmosphere, consequently the MST will only decrease after centuries even if GHG emissions are stopped immediately. Hence, effective measures to reduce emissions are very important and of high concern (IPCC 2013). In this context, the Intergovernmental Panel on Climate Change (IPCC) developed so called Representative Concentration Pathways (RCPs) that model the GHG concentration under different shares of human-induced climate change. The only RCP that is not likely to exceed the 2°C but likely to achieve the long-term 1.5°C target is the RCP2.6 and requires aggressive mitigation measures (IPCC 2013). According to the International Energy Agency (IEA), this requires a reduction of both carbon and energy intensity of about 60% by 2050. Today's annual reduction rate lies around 1.1% but needs to be increased to 2.6% in order to meet the above mentioned target (IEA 2015). In this line of thinking, it is crucial to know how various drivers as energy and the emission factor have evolved over the past to analyse what triggers are needed to achieve the above mentioned targets. This can be evaluated by means of decomposing Carbon Dioxide (CO_2) emission evolutions into factors that drove emission changes.

2 Theoretical background

In the mid-1980s, scientists started to analyse energy-related gaseous emissions by means of a decomposition approach that was further developed from energy demand studies (Ang & Zhang 2000). The energy and gaseous decomposition approaches seek to isolate various factors influencing the energy demand and emission variations respectively. This emphasises the ever-growing attention to the human causes of climate change. In the theoretical background, relevant decomposition analyses are looked into, the research question is presented, and the theory behind decomposition methods is elaborated on.

2.1 Knowledge gap (literature review)

There are several carbon emission decomposition studies carried out for the four largest CO_2 emitting countries or regions – the European Union, China, the United States, and India. A study conducted for the EU found that the European power sector reduced emissions by means of a shift towards higher quality energies, structural changes, and the use of more efficient techniques. The positive effect was lowered by increasing CO_2 emissions due to population growth and the emission factor (emitted gas per unit of fuel consumed) (Fernández González et al. 2014). The European Environment Agency (2012) found in its decomposition analysis for the EU between 1990 and 2012 that an improved energy intensity, a cleaner fossil fuel mix, higher transformation efficiencies, and a higher share in renewable energies contributed to CO_2 emission mitigations. The population and per capita Gross Domestic Product (GDP) in this study contributed to an increase in CO_2 emissions. Furthermore, there are several studies that focus on specific sectors and countries of the EU as e.g. a study in Greece between 1985 and 1995 found out that in the manufacturing sector a decrease in energy intensity and a general recession contributed to emission reductions whereas the sectoral effect and a fuel shift had a positive effect on CO_2 emissions (Mavrotas et al. 2000). In China, Wang et al. (2005) found out that the driving factor that prevented a larger increase of actual CO_2 emissions in China can be traced back to energy intensity, but also the introduction of renewable energies and the switch of fuel contributed positively to the reductions from 1957 to 2000. Similarly, Wu et al. (2005) concluded that the increase in CO_2 emissions in China were mainly driven by scale effects, whereas energy intensity effects contributed to a mitigation of CO_2 emissions during the time period 1996 to 1999. Chen & Yang (2015) isolated the average labour productivity as dominant positive and energy intensity in the production sector as dominant negative factor that drove CO_2 emissions between 1995 and 2011. A decomposition analysis for the US found that an increased productivity and energy use was almost offset by an improvement in energy intensity between 1973 and 1991. During the same period, CO_2 emissions decreased per GDP as well as the carbon intensity of the energy mix decreased (Golove & Schipper 1997). Another study for the US showed that CO_2 reductions due to energy intensity, CO_2 intensity of energy use, and changes in the energy mix prevented CO_2 emissions to be 7.5 times greater due to the increase in GDP between 1973 and 2013 (Shahiduzzaman & Layton 2015). A study on energy use in India found that between 1980 and 1996 economic growth is the main factor contributing to CO_2 emission increases, while energy intensity mitigated CO_2 emissions (Paul & Bhattacharya 2004). In general, most studies examine different sectors and analyse them by means of various factors. Therefore, it bears some difficulties to compare studies with each other. This thesis will set the starting point to compare various decomposition factors on a macro-level and in the electricity sector for the four largest CO_2 emitting countries as well as on a sectoral-level for the European Union. The sectoral approach can give valuable insights into the contributions of different sectors to CO_2 emission changes as well as it provides a more in-depth analysis on possible drivers. Due to data availability, it was only possible to conduct the sectoral analysis for the EU.

2.2 Research Question

Which main driving factors can be found in the evolution of CO_2 emissions in the time period from 1990 to 2012? From these findings, what impact had existing policies on these driving factors, and hence on CO_2 emission evolution?

1) *By conducting a decomposition analysis at a macro-level for the EU, China, the US, and India as well as at a sectoral-level for the EU, which drivers are responsible for the CO_2 emission changes?*
2) *To what extent contributed climate change policies to CO_2 emission reductions?*

This thesis is embedded in the international climate policies field as it aims at finding factors that drive the change of CO_2 emissions. An approach that helps to understand what factors have an influence on the environment is the IPAT Identity (I = P x A x T), where the Impact equals the product of Population, Affluence, and Technology. This idea can be further adjusted in order to describe CO_2 emission changes by means of factors that potentially have an impact on emission change behaviour. The more such an equation is split into various factors, the more precisely carbon emissions can be disentangled into the factors influencing its evolution, however, this can also lead to a split into factors that are not explainable anymore. Therefore, attention was paid on finding the right degree of detail to disentangle emissions into feasible factors. Among global anthropogenic GHG emissions, energy-related emissions make up the greatest share with 69%. The major gas contributing with 90% to this share is CO_2 (IEA 2014b). Therefore, this thesis focuses on energy-related CO_2 emissions, which are mainly emitted in the electricity, transport, industry, and residential sector (IEA 2014b, cf. Figure 2). The four most CO_2 emitting countries/regions in 2012 were China, the United States (US), the European Union (EU), and India. It should be noted that the European Union will be dealt with as one country in this thesis, even though this is technically not correct. One way to isolate driving factors that influenced emission changes is to conduct a decomposition analysis (cf. chapters 2.4 and 3.1.3).

2.3 Selection of countries and sectors

Figure 1 shows that the four largest CO_2 emitting countries contributed to 56% of global CO_2 emissions in 1990 and to 59% in 2012. Therefore, this the focus of this thesis lies on these countries. While the United States and the European Union decreased their relative contribution to global CO_2 emissions, India doubled and China more than doubled their relative contributions.

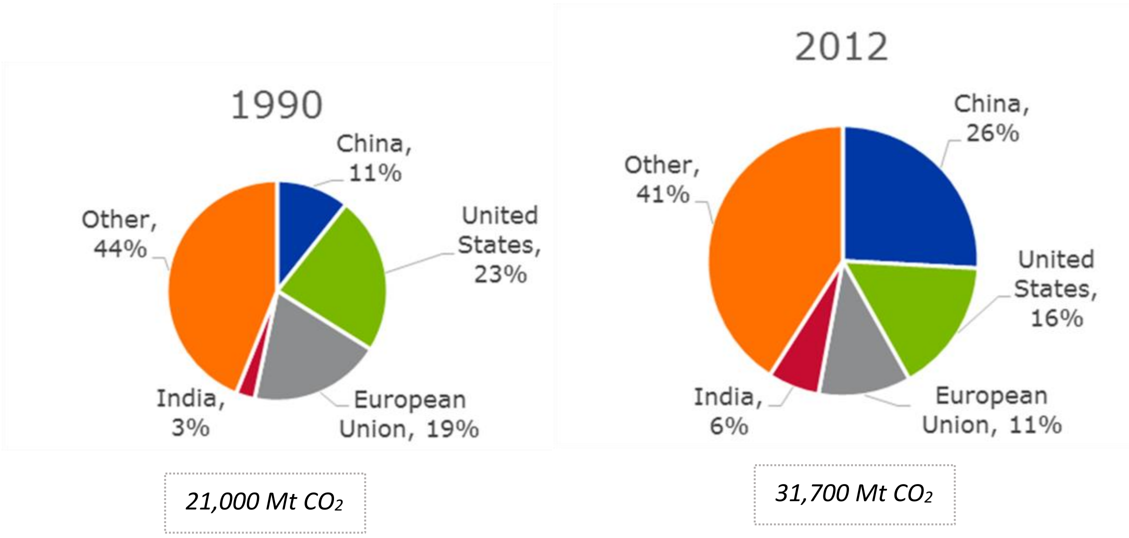


Figure 1: Global CO_2 emissions per country

A detailed decomposition analysis for major energy-related carbon emitting sectors was conducted for the European Union. Data availability was a major obstacle of this thesis and therefore also determined in what detail the sectors of the EU could have been decomposed. The sectors are chosen based on both how much energy-related emission they emit and what data is available. In Figure 2 the sectoral emissions for the EU are visualised. Electricity and heat production make up the largest part followed by industry, transport and residential (IEA 2014b).

Even though four major sectors contributing to energy-related carbon emissions were detected, not all of these emissions could have been decomposed. For the electricity and heat sector, only CO_2 emissions from electricity were decomposed. In the industry sector, CO_2 emissions from iron and steel, cement and chemical and petrochemical (in the suite of the thesis also referred to as chemicals) were decomposed. The three sub-sectors contribute to 57% of industrial CO_2 emissions (cf. Figure 2). Cement is not displayed as a separate sub-sector in statistics but contributes to 70-80% of non-metallic minerals (OECD/IEA 2007). A major obstacle is that about 20% of CO_2 emissions are allocated to "non-specified industry". The sector arises as many countries have difficulties to distribute fuel emissions to specific sub-sectors (IEA 2014a). This should be considered while analysing the results, but is difficult to eliminate. Transport was further split into passenger (cars) and freight transport. As far as

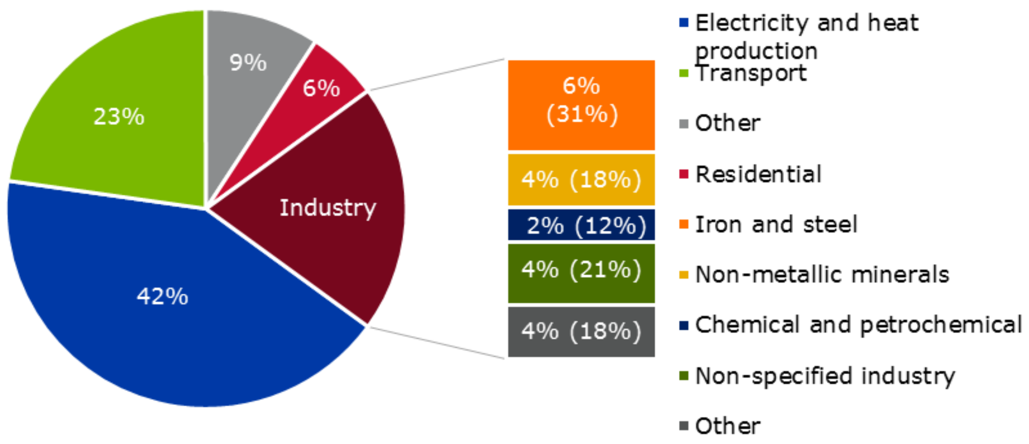


Figure 2: European CO_2 emission shares based on direct emissions on a sector basis, where CO_2 emissions in the industry sector are split into sub-sectors (percentages in brackets are the share of industry)

possible, physical output data was used. However, in the chemical and industrial sector this was not possible as the sectors are too heterogeneous. For the passenger transport, it was only possible to find sufficient data for cars, which is representative as cars made up almost 90% of the passenger road transport in between 1990 and 2012 (International Energy Agency 2015). For the freight transport data on trucks and light vehicles was utilized. Table 1 summarises the areas of the decomposition analysis and the respective countries it was applied to.

Table 1: Sectors and its respective sub-sectors that were decomposed

Sector (i), area	Sub-sector (j)	Applicable to country
Macro-economy	-	EU, China, US, India
Electricity	-	EU, China, US, India
Transport	Passenger transport (cars)	EU
	Freight transport	EU
Industry	Iron and steel	EU
	Cement	EU
	Chemicals and petrochemicals	EU
Residential	-	EU

The decomposition analysis was conducted for the time period 1990 to 2012. The lower boundary of this time period was chosen because international climate politics usually refer to the year 1990 as a base year when talking about emission evolutions. The upper boundary was chosen as the data availability of most data sets is limited to the year 2012. This time period was further split into other time intervals according to interesting policy changes or economic events in order to isolate CO_2 emission changes that otherwise could not have been detected.

2.4 Theoretical background on the Log Mean Divisia Decomposition Analysis

To analyse driving factors that contribute to emissions several decomposition methods have been developed over time. These help to understand what driving factors influenced historic CO_2 emissions (Diakoulaki et al. 2006). The methodology has been established in energy demand studies but was further developed to decompose emissions (Ang 2004). The two major methods are based on the Divisia and the Laspeyres index. Until now, there is no clear consensus among scientists on which of the two approaches is preferable and a decision on which method to use also highly depends on which advantages one values more (Ang 2004). Ang (2004) depicted that the Log Mean Divisia Index I (LMDI I) should be used when applying the Divisia approach or the Shapely/Sun method (also referred to as refined Laspeyres method) when using a Laspeyres approaches. Both of these methods allow for perfect decomposition, where no residues are created. Depending on the aim of the research, one of these two methods is more suitable. The Laspeyres approach is easier to communicate, but also only suitable for a two factor decomposition. Therefore, Ang (2004) recommended to use the LMDI I for general use due to its "theoretical foundation, adaptability, ease of use and result interpretation, and some other desirable properties in the context of decomposition analysis"(Ang 2004, p.1138). It further passes the time-reversal test (Ang 2004). According to the OECD, passing the time-reversal test implies that the same result can be obtained no matter whether it is measured forward or backward in time (OECD 2005). Therefore the logarithmic mean instead of the arithmetic mean weight function is used (Ang 2004). The LMDI I approach can further be divided into a multiplicative and additive decomposition, which stand in relation to each other and mainly differ in the way the results are presented. In this thesis the additive approach is applied (equation (1)) to show absolute CO_2 emission changes. As calculations are based on absolute numbers, the level of CO_2 emissions is distributed over the time span to the respective factors (Ang et al. 2003).

$$\Delta CO2 = CO2^T - CO2^0 = \Delta CO2_{x1} + \Delta CO2_{x2} + (\dots)\, \Delta CO2_{xn} \tag{1}$$

$$where\ 0 = start\ year, t = end\ year, and\ x = factors$$

From this, the formulae to decompose CO_2 emissions into specific factors can be developed. Ang (2005) did so in their practical guide on decomposition analysis. The decomposition factor equations that are found to disentangle carbon emissions can then be used in the decomposition formulae (chapter 3.1).

2.5 Semi-quantitative policy analysis

In the second sub-question of the thesis, it is to be analysed whether or not specific policies led to changes of the level of carbon emissions. In general, environmental policies can be classified into three broad categories, communication, economic and normative instruments. Communication instruments try to increase a population's awareness by means of education, e.g. labelling of products or mass media campaigns. This instrument is usually applied to overcome a lack in knowledge (Khan et al. 2006) and to change people's behaviour. The second broad area are economic instruments that incentivise firms to decrease their environmental impact. Subsidy schemes, taxation, emission standards and cap-and trade systems fall among this category. It works by punishing firms that do not comply to certain standards with financial disadvantages or by diminishing a financial barrier (Bergek & Berggren 2014; Khan et al. 2006). The last category are normative instruments that work with regulations and standards as well as voluntary agreements. Even though regulations and standards can introduce an effective abatement measurement, their main disadvantage is that they are static and usually not easily changeable. Voluntary agreements work on basis of negotiations of environmental standards between the government and public entities (Barde 1994). These instruments can be linked to the outcome of the policy review and the decomposition analysis. The factors that are mainly influenced by policies are the emission factor, energy intensity and the energy mix. The emission factor is determined for example by efficiency standards, voluntary agreements or carbon taxation of power plants as it concerns CO_2 emission and the conventional energy mix. Energy intensity is influenced by energy efficiency policies. The energy mix depends on political decisions as e.g. the European Directive on renewable energies. Other factors are more difficult to be analysed by means of existing policies as various other variables play a role in the evolution of factors as e.g. the per capita GDP or population growth. Even though certain policies could influence the evolution of these factors, it is difficult to determine the exact cause and often the economic situation plays a bigger role in its evolution.

2.6 Societal relevance

This thesis is written at the company Ecofys within the project of the Climate Action Tracker (CAT). Ecofys is a consultancy company focusing on renewable energy, energy and carbon efficiency, energy systems and markets as well as energy and climate policy. The CAT is an independent science-based assessment, which tracks the emission commitments and actions of countries. The thesis does not directly feed into the CAT but is of high value for future work within the CAT. One aspect of the tool is to monitor carbon emission reductions for which already several indicators have been developed. In the discussion, conclusions on carbon mitigation indicators on basis of the outcome of the decomposition analysis are drawn.

3 Method

In the method section, the decomposition analysis approach is further elaborated on as well as data sources and the Excel file are presented.

3.1 Decomposition analysis

In the method for the decomposition analysis the decomposition factor equations are presented on a macro and electricity sector level for all four countries and on a more detailed sector level for the EU. In section 3.1.3 the decomposition factor equations are applied to the LMDI I method. In the macro economy and electricity sector decomposition analysis, conventional energies incorporate nuclear energy and fossil fuels. For the sector analysis of the EU, conventional energies incorporate next to nuclear and fossil fuels also electricity. The corresponding CO_2 emissions from electricity in other sectors are accounted for in the electricity sector (Enerdata 2015b).

3.1.1 Decomposition factor equations on a macro and electricity sector level

In order to decompose the macro-economy or parts of it, one needs to first compile decomposition factor equations that specify into what factors CO_2 emissions are decomposed. For the macro-economy this is shown in equation (2). The changes in population (POP) influence the level of CO_2 emissions. The data sources are specified in chapter 3.2.1 and 3.2.2. The energy intensity (EI) imparts knowledge about how efficient a nation's economy in energy terms is, i.e. how much primary energy is used per GDP. The per capita GDP (CG) shows how much economic turnover is produced per capita. The energy mix (EM) represents the share of renewable energies in the total energy mix as conventional energy over primary energy (E). Renewables are considered to be zero emitters. On a life cycle approach this is not correct, however, compared to fossil fuels the value can be neglected (Varun et al. 2009) as well as it facilitates the calculations significantly. The emission factor (EF) signifies the amount of CO_2 emitted by conventional energies (F), and hence how clean the conventional energy mix is.

$$CO2_i = \sum_i CO2_i = POP * \frac{GDP}{POP} * \frac{E_i}{GDP} * \frac{F_i}{E_i} * \frac{CO2_{,i}}{F_i} \tag{2}$$

$$= POP * CG_i * EI_i * EM_i \; * EF_i$$

For the electricity sector (equation (3), i = electricity sector) the decomposition analysis the electricity consumption (EC) and the electric efficiency (EE) are decomposed next to POP, EM, and EF that were also used in the macro-economy,. The electric efficiency is expressed as 1/efficiency (primary energy over electricity output (EL)) to keep the decomposition factor equation true.

$$CO2_i = \sum_i CO2_i = POP * \frac{El_i}{POP} * \frac{E_i}{El_i} * \frac{F_i}{E_i} * \frac{CO2_i}{F_i}$$

$$= POP * EC_i * EE_i * EM_i \; * EF_i \tag{3}$$

3.1.2 Decomposition factor equations on a sector level

The transport sector (equation (4), i = passenger (car) transport), is also expressed by means of the factors EM, and EF. Additionally, the passenger-km (p – km), the occupancy rate (vehicle-km/passenger-km), and the energy intensity (EI) (E/vehicle-km) are incorporated in the equation.

$$CO2_i \sum_i CO2_i = p - km_i * \frac{v - km_i}{p - km_i} * \frac{E_i}{v - km_i} * \frac{F_i}{E_i} * \frac{CO2_i}{F_i}$$

$$= \; p - km_i * O_i * EI_i * EM_i * EF_i \tag{4}$$

The freight transport is presented in equation (5) (i = freight transport). While the EF and EM stay the same, the energy intensity is expressed as E/tonne-km driven. The activity factor consequently becomes tonne-km.

$$CO2_i \sum_i CO2_i = tonne - km_i * \frac{E_i}{tonne - km_i} * \frac{F_i}{E_i} * \frac{CO2_i}{F_i}$$

$$= \; tonne - km_i * EI_i \; * EM_i * EF_i \tag{5}$$

The decomposition factor equation for the industrial and chemical sector are displayed in equation (6), while iron and steel and cement are displayed in equation (7). The factors EF and EM are equal to those in other sectors. For the industry and chemical sector the energy intensity is expressed as E/GVA as the sectors are too heterogeneous to be expressed by means of physical activity. The use of GVA is not optimal as it restricts from narrowing down real efficiency improvements; instead, structural effects are included in this factor. For the iron and steel as well as for the cement sector it was possible to express the energy intensity as E/A.

$$CO2_i = \sum_i CO2_i = GVA_i * \frac{E_i}{GVA_i} * \frac{F_i}{E_i} * \frac{CO2_i}{F_i} \tag{6}$$

$$= GVA_i * EI_i * EM_i * EF_i,$$

$$where\ i = industry\ and\ chemical\ sector$$

$$CO2_i = \sum_i CO2_i = A_i * \frac{E_i}{A_i} * \frac{F_i}{E_i} * \frac{CO2_i}{F_i} \tag{7}$$

$$= A_i * EI_i * EM_i * EF_i,$$

$$where\ i = iron\ and\ steel\ and\ cement\ sector$$

For the residential buildings (equation (8), i = residential buildings), the variables of total area of buildings (S) and total number of households (H) play an important role. The energy intensity in the residential buildings sector is expressed as E/surface area. The surface intensity (SI) is expressed as area per capita and shows how much space a person inhabits on average. The household density (HD) signifies how many people live in one household.

$$CO2_i = \sum_i CO2_i = H_i * \frac{POP}{H_i} * \frac{S_i}{POP} * \frac{E_i}{S_i} * \frac{F_i}{E_i} * \frac{CO2_i}{F_i} \tag{8}$$

$$= H_i * HD_i * SI_i * EI_i * EM_i * EF_i$$

3.1.3 LMDI I decomposition analysis

As it has been mentioned in the theoretical background section, the change in CO_2 emissions can be decomposed into several factors. The formula for the additive decomposition approach was taken from Ang (2005) and applied to the decomposition factor equations from chapter 3.1.2 (equations (9) to (11)). The subscript i represents the sector, while the variable *x* represents the decomposition factors in which the sector is being decomposed into. Equation (11) expresses the logarithmic average. For a more specific analysis, the time period was changed accordingly.

$$\Delta CO2_{tot} = CO2^{2012} - CO2^{1990} = \Delta CO2_{x1} + \Delta CO2_{x2} + \Delta CO2_{x3} + (\ldots) + \Delta CO2_{Xn} \quad (9)$$

$$\Delta CO2_{tot} = \sum\nolimits_{i,x} L\left(CO2_i^{2012}, CO2_i^{1990}\right) ln\left(\frac{x^{2012}}{x^{1990}}\right) \quad (10)$$

$$where\ L\left(CO2_i^{2012}, CO2_i^{1990}\right) = \frac{CO2_i^{2012} - CO2_i^{1990}}{lnCO2_i^{2012} - lnCO2_i^{1990}} \quad (11)$$

3.2 Data analysis

In the following data sources and assumptions for the macro economy and the electricity sector as well as for the sectoral approach of the EU are elaborated on. Furthermore, how the analysis was conducted in the Excel sheet is explained.

3.2.1 Data sources and assumptions for the macro economy and the electricity sector

For the macro-economic and electricity sector analysis, all data was extracted from the IEA Key World Statistics 2015 database (International Energy Agency 2015). The data for population and GDP in the IEA database originates from the World Development Indicators of the World Bank (The World Bank Group 2016b). Emissions and energy input for Combined Heat and Power (CHP) plants in the electricity sector were taken into account by means of the power loss factor that allocates all CO_2 emissions from CHP plants to electricity, while at the same time artificially increasing the electricity output according to how much heat is produced in the CHP plant ($EL_{outputCHP, new} = EL_{outputCHP} + EL_{Heatoutput} * 0.2$). The share of renewable energies in the electricity sector can either be determined by means of electricity output or by means of energy input. The later one is used in this thesis in order to comply with the decomposition factor equation that gives the CO_2 emission changes according to a change of primary energy input over electricity output (cf. equation (3)). This factor can be re-formulated into (1/η). The efficiency relates to the overall efficiency instead of the thermal efficiency of power plants as total primary energy input is worked with in the data analysis. This signifies that non-thermal energy sources (e.g. wind and hydro energy) contribute to an artificial increase in efficiency as the IEA assumes a conversion efficiency of 100% for these kind of energies (International Energy Agency 2015).

3.2.2 Data sources and assumptions for the sector analysis of the EU

Despite the sovereignty of European member states, and with that different success rates in translating EU directives, the CO_2 emissions of the European Union as a whole are decomposed. This bears the advantage that a higher share of global CO_2 emissions can be looked at but the disadvantage that national differences are not taken into account and generalisations are been made. In 1990 the EU consisted of 12 member states (Italy, France, Germany, Netherlands, Belgium, Luxemburg, Denmark, Ireland, United Kingdom, Greece, Spain, and Portugal), which grew to the EU-28 in 2013 (with Austria, Finland and Sweden in 1995 (together called the EU-15); Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovakia, and Slovenia in 2004; Romania and Bulgaria in 2007, as well as Croatia in 2013) (European Union 2016a). Even though this decomposition analysis is limited to the year 2012, the data for the EU-28 are taken into account as the databases being used already integrated Croatia.

Electricity consumption in the sectoral decomposition analysis of the EU is included in conventional energies, while CO_2 emissions are accounted for in the electricity sector. Therefore, only direct CO_2 emissions are taken into account in the specific sector analysis of the EU. The general emission factors have been calculated from the IEA database (International Energy Agency 2015). If not otherwise stated, data used for the sectoral analysis of the EU is taken from the ODYSSEE database (Enerdata 2015b). The 1990 value of the value added of the chemical industry was taken from PRIMES (European Comission 2010). This was possible as differences between values for other years of the two sources were comparably small. The value added for industry is taken from the World Bank (The World Bank Group 2016b), where, however, the value for 1990 was missing. As no other feasible data for the 1990 value could have been found, it was assumed that the 1990 value equals the 1991 value. CO_2 emissions of cement originates from the World Business Council for Sustainable Development (WBCSD) (WBCSD 2015) and was extrapolated where data was missing (1991-1999 and 2001-2004).

In the passenger transport, only car traffic is considered due to data restrictions. For the industry sector, the share of renewable energies for non-metallic energies is used for the share of renewable energies for cement as no other data could have been found. As cement makes up 80% of the non-metallic energies and the renewable energy share for non-metallic energies lies at about 1%-5%, this can be neglected. The GVA for chemicals is given in M€2005, whereas the GVA for industry and the GDP are given in USD2005. This, however, does not pose a problem as the importance of the decomposition analysis is the difference between two years of one factor, hence the values/units of factors that are not directly compared can be different.

3.2.3. Excel workbook application

The data was inserted in an Excel workbook. It was paid attention that data can easily be changed so the raw data can be updated by copy-pasting new data into the existing workbook. Furthermore, the decomposition analysis was made dynamic, so that the graph for the decomposition analysis can be changed according to three drop-down lists (country, time period, and sector). For the macro-economic analysis every country that is included in the IEA database can automatically be included by inserting the country name in a specified table on the admin-sheet. For the electricity sector this is possible by including additional data from the IEA database in form of new tabs for that specific country and naming it in a pre-defined manner. Sectoral decomposition analysis for other countries can also be included, which, however, takes more of an effort as the data if available at all often has to be collected from different sources. The specifications on how to extend the analysis to other countries is described in detail in the Excel workbook. The values for the different factors for all sectors of the EU as well as for the macro-economy for all countries that were chosen can easily be extracted via a VBA-code.

4 Results

The results part is structured as followed. In chapter 4.1 the European Union is analysed on a macro-economic and sectoral level. First, a policy overview on multi-sectoral as well on specific sectors is given. Secondly, the decomposition analysis is examined as well as lines are drawn from the outcome of this analysis to the before mentioned policies. Lastly, overall concluding remarks on the EU analysis are given. The other three countries that follow the EU analysis are structured similar, however, the analysis is limited to the macro-economy and the electricity sector. A comparison of the macro-economic and electricity sector analysis for the four countries is given in the discussion.

4.1 European Union

Policy overview

While not all decisions on an EU level are obligatory for Member States to convert into national law, there are three binding measures – regulations, directives, and decisions – that are also used in European climate change policies. Regulations are “directly applicable and binding in their entirety” (Borchardt 2010). Directives are also binding, but only by means of the targeted goal; it is not of importance in what way the respective Member States implement the directive (Borchardt 2010). A decisions is “binding on those to whom it is addressed (…) and is directly applicable (European Union n.d.).

Multi-sectoral policies

European policy started to focus on climate change in the late 1990s next to its emphasis on the improvement of energy security (Hubert et al. 2015). The EU-15 agreed in 1998 on reducing 8% of its emissions by 2012 compared to 1990 under the Kyoto protocol (UNFCCC 1998) by distributing different shares of emission targets to each Member State (Hubert et al. 2015). In 2001, the *European Climate Change Programme (ECCP) report* was published initiating an *Action Plan*, which served as a basis for several more concrete and binding legislative texts. In 2007, the EU communicated several non-binding goals for the EU in *‘An Energy Policy for Europe’* (COM(2007)1), where major targets were listed. The energy policy promoted an internal energy market where energy supply is secured and GHG emissions are reduced by at least 20% by 2020 by means of an enhanced energy efficiency of 20% in terms of primary energy use, an increase in renewable energies by 20%, and a share of 10% of biofuels in vehicle fuels (European Union 2007). These targets were then translated into European law that needed to be met by Member States.

The above mentioned efficiency target was underlined in the *Energy Efficiency Directive 2012/27/EU* that repealed both *Directive 2004/8/EC on the Promotion of Cogeneration* and *Directive 2006/32/EC on Energy End-Use Efficiency and Energy Services*. The *Energy Efficiency Directive* required Member States to set national efficiency targets; it applies to many sectors (European Parliament 2012) and specifications can be found in the respective sectoral policies sections. *Directive 2009/125/EC* established a framework for the setting of eco-design requirements for energy-related products that must be met by products that are used and sold within the EU. This is further supported by *directive 2010/30/EU* that deals with the labelling of large energy-consuming products. Both directives aim at a reduced use of electricity, therefore influencing the electricity per capita factor in the electricity sector. In 2012, these directives were also amended by the *Energy Efficiency Directive*.

The renewable energy goal first focused on introducing clean energy in the electricity sector and biofuels or other renewable fuels in the transport sector (*Directive 2001/77/EC* and *Directive 2003/30/EC*). These Directives were repealed by *Directive 2009/28/EC* that set the overall 20% renewable energy in gross final consumption goal for each Member State with specific national targets as well as it specified a 10% renewable energy sources goal for transport fuels (instead of the earlier mentioned 10% biofuel target). The *Council Directive 2003/96/EC (on Restructuring the Community Framework for the Taxation of Energy Products and Electricity)* specifies the taxation on mineral oil products, coal, natural gas and electricity. It further mentions the possibility to exempt electricity produced by renewable energies from taxation (OECD/IEA 2016). Further to these binding targets, other measures passed the EU to promote a higher share of renewables. The *Biomass Action Plan* (2005) aims to increase the use of materials from forestry, agriculture, and waste for the energy production. The use of solar energy is promoted by the *European Photovoltaic Technology Platform* that supports the development of a European PV industry. Similar initiatives/platforms exist for solar thermal, wind energy, and biofuel technologies that all became effective in 2006 (OECD/IEA DATABASE).

The *European Emission Trading Scheme (ETS)* is a key element to reduce GHG emissions in the EU, which started to evolve after the Kyoto protocol in 1998 to reduce emissions accordingly. The *European Emissions Trading Directive 2003/87/EC* came into force in 2003. Following, the *EU ETS* came into effect in 2005 after all member states implemented the directive (Braun 2009). The directive was improved and extended in 2009 by *Directive 2009/29/EC*. The *EU ETS* mostly covers emissions from power plants, industrial plants and airlines, whereas emissions from households and services, transport, waste, and agriculture are not included in the *EU ETS* but make up about 60% of total GHG emissions (European Environment Agency 2012). The *Effort Sharing Decision No.406/2009/EC* defines different reduction targets for each Member State according to its economic activity (European Union 2009). The EU also promotes to reduce emissions by means of carbon capture and storage (CCS) technology. The *Regulation 2009/663/EC* (*European Energy Programme for Recovery*) gives financial support to CCS demonstration plants. The *Directive 2009/31/EC on the Geological Storage of Carbon Dioxide* gives a legal framework for the safe geological storage of CO_2 (OECD/IEA 2016). It should be kept in mind that CCS technologies come with an energy penalty (Bellman et al. 2007).

Electricity

The CO_2 emissions of the electricity sector are largely covered by multi-sectoral policies as the promotion of the integration or renewable energies or the *EU ETS* scheme. Also the CCS policies are applicable to the electricity sector (*Regulation 2009/663/EC, Directive 2009/31/EC*) as well as the *Eco-Design and Energy-Labelling Directives* influence the electricity usage. Further, reductions of other emissions are often of higher concern than the mitigation of CO_2 emissions. *Directive 2001/80/EC* that limits the emissions of certain pollutants into the air from large combustion plants and *Directive 2008/1/EC* that concerns integrated pollution prevention and control were repealed by *Directive 2010/75/EU on Industrial Emissions* (also referred to as *Integrated Pollution Prevention and Control*). The directive specifies emission reduction regulations for SO_2, NOx, CO, and more pollutants other than CO_2, which could lead to increased CO_2 emissions as the reduction technologies usually include an energy penalty. CO_2 emissions are not accounted for in this directive as these are already part of the *EU ETS* (OECD/IEA 2016).

Transport

In 2001, the *White paper COM(2001)370* concerned the promotion of a shift towards an environmentally friendly mode mix and included several measures aimed at reducing energy consumption and CO_2 emissions in the transport sector. These broad guidelines and recommendations followed the *Directive on Biofuels for Transport (2003/30/EC)* that promoted the inclusion of biofuels in the petrol mix and determined indicative targets for member states. It was repealed in 2009 by the *RES Directive (2009/28/EC).* The *EU biofuel Strategy* (2006) further communicated and lined out guidelines on the use and production of biofuels. The *Regulations EURO 5 and 6 (2007/715/EC)* specify targets for new cars and light commercial vehicles as well as *Regulation 2009/443/EC* formulates specific targets to limit CO_2 emissions from new cars (OECD/IEA 2016). Furthermore, different tax regimes on petrol and diesel are established among Member States, where diesel is generally favoured (Groot 2014; SEPA 2000).

Industry

While the *EU ETS* applies to industry, special arrangements are made for the manufacturing industry to prevent carbon leakage. This resulted in free emission allowances depending on the level of efficiency and the degree of carbon leakage risk (European Commission 2014). The *Energy Efficiency Directive 2012/27/EU* also applies to the industrial sector, where specific regulations as energy audits are determined (European Union 2015). Further, the above mentioned policies on limiting emissions of certain pollutants (*Directive 2010/75/EU*) as well as the CCS technology also applies to industrial combustion plants.

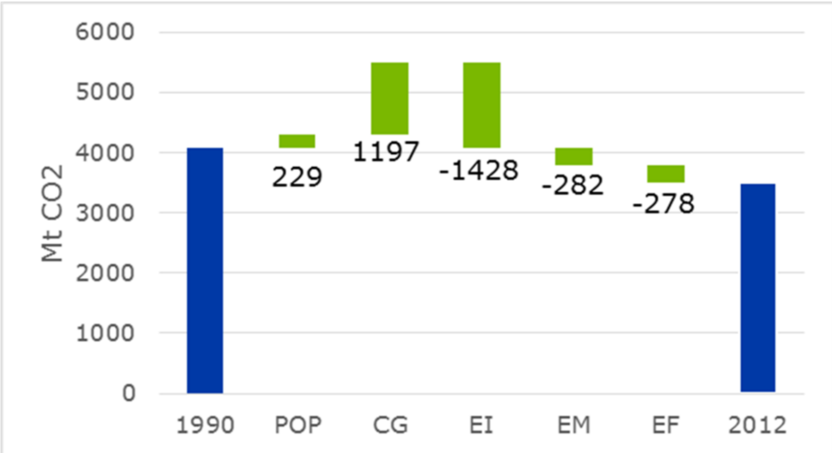
Residential buildings

The *Buildings Directive 2002/80/EC* concerned standards of energy performance and how to calculate these as well as it introduced a system for energy certificates for buildings. It further demanded regular inspections of boilers and air-conditioning systems. It was amended by *Directive 2010/31/EU on the Energy Performance of Buildings*. Buildings are further part of the *Energy Efficiency Directive 2012/27/EU*, which emphasises the leading role of the public sector to use and promote energy efficient buildings (OECD/IEA 2016).

Decomposition analysis

Macro-economy

The population of the EU grew by 6% between 1990 and 2012, whereas the GDP increased by 46% during the same time period. The share of renewable energies in its Total Primary Energy Supply (TPES) increased from 4% in 1990 to 11% in 2012 (International Energy Agency 2015). In contrast to many other countries, the European Union shows overall decreasing CO_2 emissions. The decomposition analysis of CO_2 emissions for the EU on a macro-level is depicted in Figure 3. The small growth in population is reflected in the CO_2 emission increases due to the population factor. The per capita GDP factor contributes significantly more to emission increases, which is in line with a much larger growth in GDP compared to the growth in population. This development points at an augmented welfare. The energy intensity, in contrast, contributes to large CO_2 emission decreases. Next to technological learning and scaling effects that positively influence the energy intensity, several policies promoted an improved energy intensity (e.g. *Energy End-Use Efficiency and Energy Services Directive*). However, as most of the policies on energy efficiency were implemented over the time span of 2008 – 2012, which is the recession period of the financial crisis, it is difficult to say something about the magnitude of the effects of these policies. As production processes and power production are most efficient at a certain load (Ummels 2009), the energy intensity decreased in the aftermath of the financial crisis. While the energy intensity reduced by -443 Mt CO_2 in the four years before the recession, it only achieved improvements of -194 Mt CO_2 between 2008 and 2012. Energy efficiency improvements could be enhanced by the EU ETS, however, the success of the EU ETS is highly bound to the price of



EF (emission factor)
= CO_2/ F

EM (energy mix)
= F/E

EI (energy intensity)
= E/GDP

CG (per capita GDP)
=GDP/POP

F = conventional energy

E = primary energy

Figure 3: CO2 decomposition analysis of the macro-economy in the European Union

carbon certificates, which is determined by the number of certificates on the market. Particularly due to the financial crisis in 2008, the amount of certificates exceeded the demand, which resulted in a crash of the price to below 1 to 4 €/t CO_2-eq.. In contrast, it is estimated that the certificate price should amount to 30€/t CO_2 to “have a reasonable chance (…) limiting warming to 2°C” (Dirix et al. 2015). Taking into account that the international community made this target even more ambitious in 2015 (to 1.5°C), this price would need to increase as well. At the same time, the per capita GDP emissions are also less distinct due to the financial crisis. The emission mitigations due to the energy mix enhanced over time, signifying that the policy to increase renewable energies by 20% affected a reduction in CO_2 emission. While between 1990 and 2007 135 Mt CO_2 were mitigated, between 2007 and 2012 153 Mt CO_2 were mitigated despite the much shorter time period. Due to a shift from oil and coal towards natural gas and nuclear, the emission factor contributed to a decrease in CO_2 emissions (Figure 4).

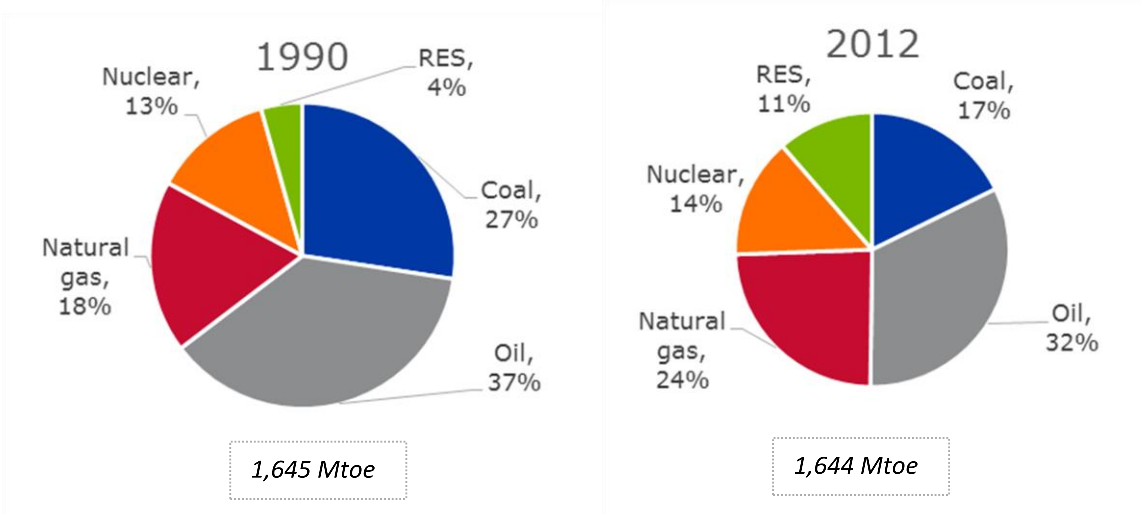
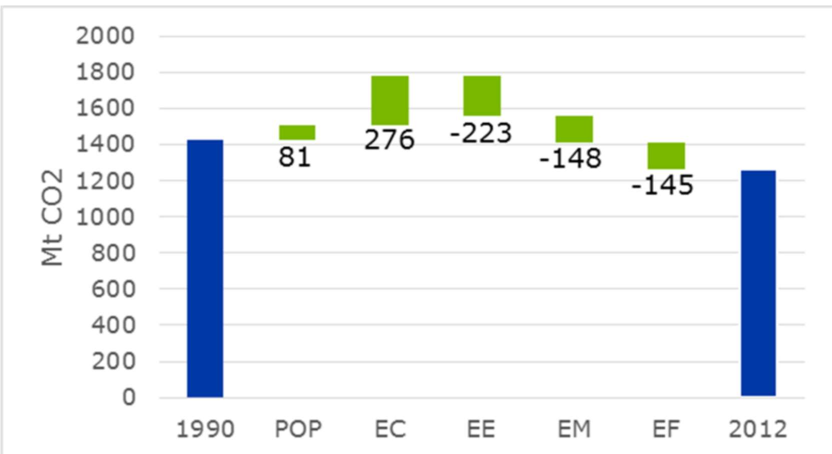


Figure 4: Energy mix of the macro-economy in the EU

Electricity

The electricity sector contributed with 35% in 1990 and 36% in 2012 to total CO_2 emissions (International Energy Agency 2015). The population growth contributed similar to the macro-economic observations only to a certain extent to emission increases (Figure 5), which is a result of the low population growth of 6%. The increased electricity consumption led to increasing CO_2 emissions, which is in line with the observation that there is an increase in welfare and a continuous electrification of society. The energy efficiency displays decreasing emissions, which points at an increased overall power plant efficiency (1/EE), which increased from 43% in 1990 to 51% in 2012. The share of renewable energies in the energy input for electricity increased from 5% to 15% (Figure 6),



EF (emission factor) = CO_2/ F

EM (energy mix) = F / E

EE (electric efficiency) = E /EL

EC (electricity consumption) =EL / POP

F = conventional energy

E = primary energy

Figure 5: CO_2 decomposition analysis of the electricity sector in the European Union (1990-2012)

hence also mitigation in emissions due to the energy mix can be observed. If all targets specified in *Directive 2001/77/EC (on the Promotion of Electricity from Renewable Energy Sources*, later on repealed by *Directive 2009/28/EC*) are met, 21% of total European electricity consumption was estimated to be produced by renewable energies in 2010 (OECD DATABASE). This target was almost achieved at 20% RES in the electricity consumption (and not energy input for electricity) in 2010 (IEA DATABASE). The emission factor contributed similar to the macro-economic decomposition analysis to decreasing emissions (Figure 5). This is due to a shift mainly from coal and oil towards natural gas (Figure 6).

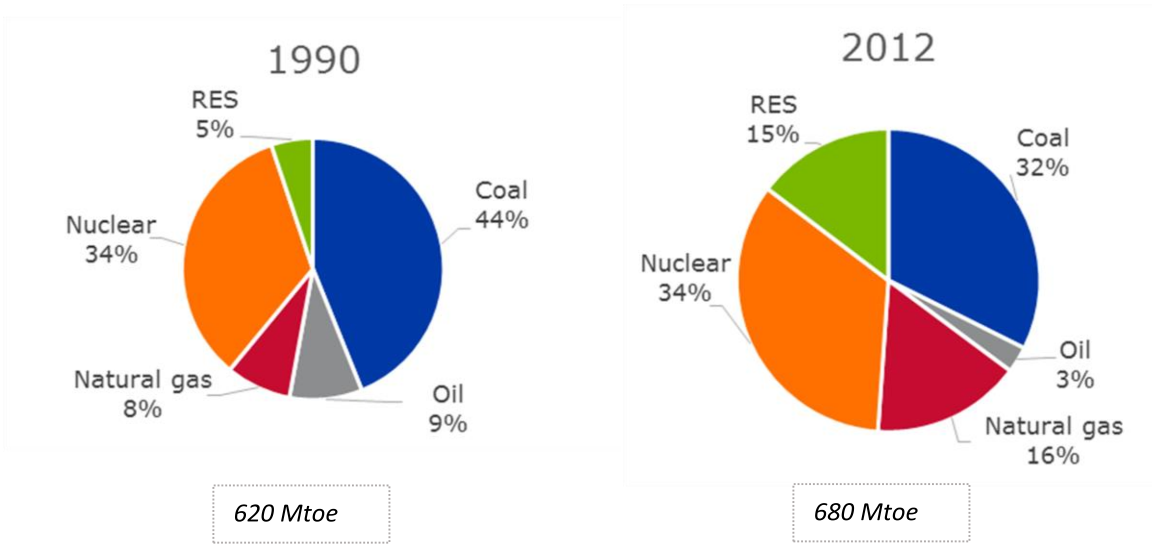
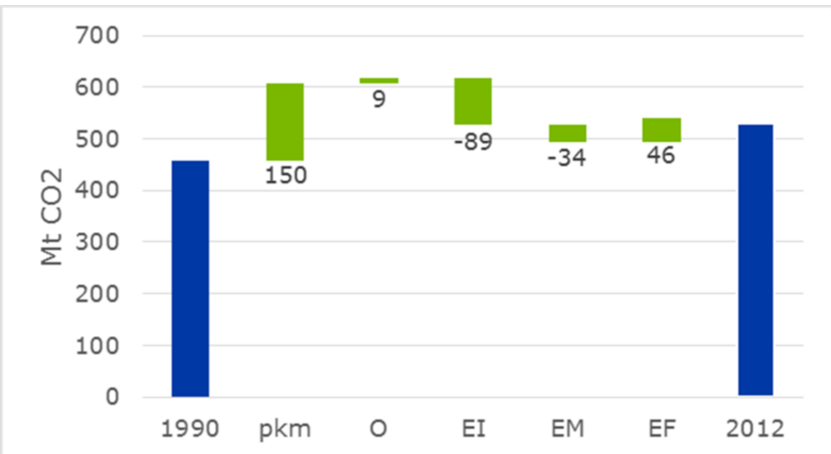


Figure 6: Energy mix of the electricity sector in the EU

The above mentioned policies on CCS technology are not reflected in the outcome of the decomposition analysis as they are mainly about basic geological guidelines and demonstration plants. The effect of the eco-design and labelling policies is hard to determine. The electricity consumption only showed decreasing emission in the years 1991 to 1993, 2006 to 2009, and 2010 to 2012. Consequently, these years can be connected to the fall of the Soviet Union and the financial crisis. Therefore, no conclusions can be drawn on these energy conservation/efficiency policies that were implemented in 2009 and 2010. The electric efficiency can be translated into power plant efficiencies that increased from 43% in 1990 to 53% in 2012. Next to power plant improvements and the shift towards more gas, this efficiency mainly increased due to non-thermal energy sources.

Transport

The contribution of cars to total CO_2 emissions increased from 11% in 1990 to 15% in 2012 as well as the absolute volume of CO_2 emissions increased in the car sector. The share of biofuels for cars increased from 0% in 1990 to 6.7% in 2012, a decrease of 13% in average distance travelled (vkm) could have been recorded (between 1990 and 2012), the number of cars increased by 56%, and driven passenger km increased by 33%. The total energy consumption increased by 13% (International Energy Agency 2015). The decomposition analysis of the passenger transport sector (cars only) can be seen in Figure 7. The factor passenger kilometres, which is the product of total passenger transported and kilometres driven, drives emissions upwards, which is in line with the observation that passenger km increased. The occupancy rate, thus average distance driven (vkm) over passenger km led to an increase in CO_2 emissions corresponding to an increase in the number of cars by 56% (while the population grew by 6%). The energy used per vkm travelled (energy intensity) contributed to CO_2 emission mitigations. In general, vehicle efficiencies increased. Furthermore, a continuous shift from gasoline to diesel has been observed due to a tax regime in the EU that favours the use of diesel (Groot 2014), because diesel engines are more efficient than gasoline engines as well as diesel contains more energy (U.S. Department of Energy n.d.). The change in energy intensity corresponds to the regulations on the production of more efficient cars. Eurostat (2015) points out that new cars decreased its CO_2 emissions by 14% between 2009 and 2014, which resulted largely from EU regulations as *Regulation 2007/715/EC* and *Regulation 2009/443/EC*. The policy to implement a 10% share of renewable energy sources corresponds to decreasing emissions due to changes in the energy mix. It should be noted that the EM factor only accounts for biofuel changes. The emission factor displays increasing emissions, which indicates the use of more polluting conventional fuels (e.g. from gasoline (18.9 tC/TJ) to diesel (20.2 tC/TJ) or LPG (17.2 tC/TJ) to gasoline/diesel (Ipcc 1997)), which is in line with the tax regime that favours the use of diesel.



EF (emission factor)
= CO_2/ F

EM (energy mix)
= F / E

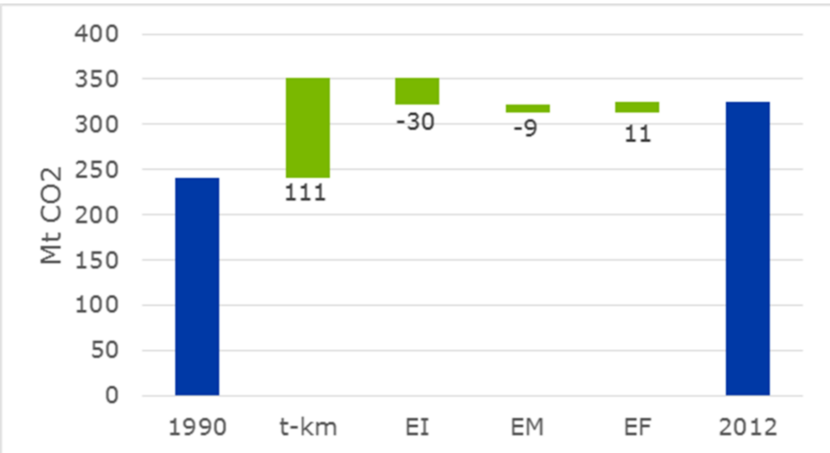
EI (energy intensity)
= E / vehicle-km

O (occupancy rate)
=vehicle-km / pkm

Pkm = passenger-km
F = conventional energy
E = primary energy

Figure 7: CO_2 decomposition analysis of the passenger transport sector (cars) in the EU (1990-2012)

The freight transport emitted more emissions in 2012 (324 Mt CO_2) than in 1990 (241 Mt CO_2), which resulted in an increase of the percentage contribution to total CO_2 emissions (from 6% to 9%). The biofuel share increased from 0% in 1990 to 3% in 2012. While the energy consumption increased by 34%, the tonne-km increased by 49%, and the number of vehicles increased by 75% during the same time period (International Energy Agency 2015). The factor tonne-km contributed the most to the emission increase (Figure 8), which was mainly a reason of economic growth between 1993 and 2007. With the financial crisis this factor led between 2007 and 2012 to a mitigation of CO_2 emissions (with a small exception in 2009/2010). It therefore shows that this factor is sensitive to the state of the economy as a recession leads to less goods being demanded and hence produced/transported. In Eurostat, data for the EU-28 is only available from 2008, and for single Member States from 1999 onwards. However, in these time frames both the vkm and goods transported peak in 2008, clearly reflecting the financial crisis (European Union 2016b). The energy intensity led to a decrease in CO_2 emissions, showing a more efficient transport sector. This, however, does not indicate much about efficiency changes of vehicles as in this context the factor litre fuel/100km is more meaningful. The slight decrease in CO_2 emissions due to the energy mix is reflected in the increase in biofuels. The emission factor led to a small increase in CO_2 emissions that can be correlated to a higher use in diesel, especially in light-duty vehicles, while trucks already run mainly on diesel. The incentive for increasing the use of diesel vehicles are diesel-friendly taxes in the EU (Groot 2014).



EF (emission factor)
= CO_2/ F

EM (energy mix)
= F / E

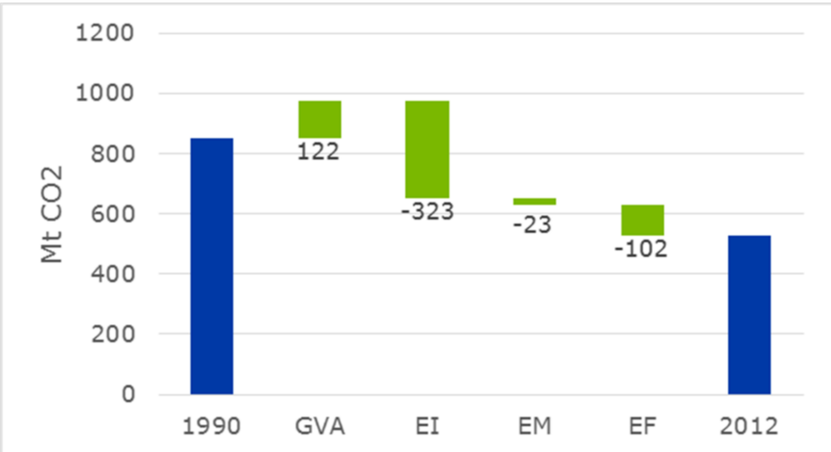
EI (energy intensity)
= E /t-km

t-km = tonne-km
F = conventional energy
E = primary energy

Figure 8: CO_2 decomposition analysis of freight transport sector in the EU (1990-2012)

Industry

The industrial sector contributed with 20% to total CO_2 emissions in 1990, which decreased to 15% in 2012. The decomposition of industrial CO_2 emissions can be seen in Figure 9. Overall, CO_2 emissions are decreasing, which is mainly an effect of the energy intensity. The GVA factor contributed to an increase in CO_2 emissions, which can be explained by an increase in GVA by 20% between 1990 and 2012 showing that the industry sector in the EU has been growing. The energy intensity, which equals energy consumption over industrial GVA, contributes to a reduction in CO_2 emissions. As GVA is an economic measurement, it is not possible to specify how energy usage per unit of output developed. While consequently energy efficiency developments cannot directly be depicted, it is possible to say something about the structural change of the industry. Overall, between 1990 and 2012 a small shift from an industry-oriented towards a service-oriented market can be observed in the EU (Enerdata 2015b). Within the industry, it was observed that the primary metal and textile and leather industry reduced volumes in terms of value added between 1995 and 2012 by 12% and 30% respectively. The chemical and machinery industry increased volumes in terms of value added by 38% and 49% in the same time period (Enerdata 2015a). When comparing the energy intensity in terms of energy cost over value added for the respective sectors, iron and steel and non-ferrous metals (36% and 23%) had higher energy intensities than chemicals and machinery (12% and 3%) in 2012 (ICF Consulting Ltd 2015). This shows that there has been a shift towards less energy intensive sectors, which partly explains the enhanced mitigation of CO_2 emissions due to the energy intensity factor. Energy efficiency improvements also contributed to this development (e.g. due to *Directives 2004/8/EC and 2006/32/EC)*, however, due to the use of GVA instead of a physical output, the contributions cannot directly be depicted. Renewable energies in the industry increased from 4% in 1990 to 12% in 2012, driving the mitigation of CO_2 emissions, which is reflected in the energy mix factor. The mix in conventional fuels (EF) also led to a decrease in CO_2 emissions as there has been a shift from coal and oil towards natural gas and electricity.



EF (emission factor)
= CO_2/F

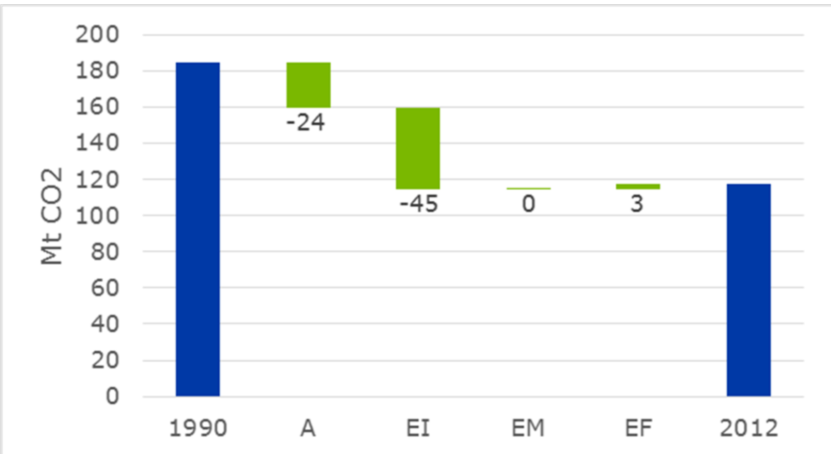
EM (energy mix)
= F/E

EI (energy intensity)
= E/GVA

F = conventional energy
E = primary energy

Figure 9: CO_2 decomposition analysis of the industry sector in the EU (1990-2012)

The iron and steel sector shows decreasing CO_2 emissions between 1990 and 2012 (Figure 10) signifying a contribution of 22% to industrial CO_2 emissions in both years. It is not only a highly capital intense but also a very energy intense industrial sector. Due to its complex material and energy flow, the iron and steel sector is not likely to introduce radical technological changes (The Boston Consulting Group 2013). Despite this observation, there has been a potential to implement smaller energy efficiency and conservation measures that led to a mitigation of CO_2 emissions due to the energy intensity. The physical activity contributed to the mitigation of CO_2 emissions, corresponding to a decrease in the quantity of steel produced (which decreased by 16% between 1990 and 2012). By having a look at different time periods, one can see that CO_2 emissions are mitigated due to the physical activity factor in the beginning of the 1990s and after 2008, while CO_2 emissions show an upward trend during other time periods. This suggests that the CO_2 reduction was mainly caused by events as the fall of the Soviet Union in 1989/1990 and the financial crisis in 2008. The energy intensity (here E/A) is the largest contributing factor to CO_2 emission reductions. As it was possible to use a physical unit, structural effects are less dominant in this factor, hence one can conclude that production processes became more energy efficient. The energy mix is the only factor that has no effect on CO_2 emission changes as the increasing share of renewables in the iron and steel sector stays marginal at 0% in 1990 and 0.2% in 2012. The emission factor contributes to a small increase in CO_2 emissions, which indicates that the conventional energy mix became more polluting. This, however, is not in line with the conventional energy mix that displays a decreasing average emission factor due to a shift from coal to electricity. A possible explanation for this is a change of the type of coal and discrepancies in data sources (for the decomposition analysis ODYSSEE was used while for the energy mix IEA data was used).



EF (emission factor)
= CO_2/F

EM (energy mix)
= F/E

EI (energy intensity)
= E/A

A = physical activity
F = conventional energy
E = primary energy

Figure 10: CO_2 decomposition analysis of the iron and steel sector in the EU (1990-2012)

The chemical sector contributed with 16% and 17% to total CO2 emissions in the years 1990 and 2012 respectively. As it is a very heterogeneous sector, the energy intensity cannot be depicted in terms of physical activity but needs to be decomposed by means of GVA (Figure 11). The GVA that increased by 50% led to increasing CO_2 emissions, indicating that there has been a growing demand in chemical products. The energy intensity contributed to CO_2 emission mitigations, which indicates next to a possible structural change within the chemical sector that processes became more efficient. This can be underlined by the European Chemical Industry report that shows the energy intensity as energy input per unit of chemical output indexed to 1990 values. A decreased energy consumption together with an increased production led to a more than halved energy intensity between 1990 and 2013 (cefic 2016). The energy mix does not contribute significantly to emission changes as the renewable energy share decreased form 1% to 0.5% between 1990 and 2012. The emission factor led to decreasing CO_2 emissions, which is the result of a higher use of heat and electricity instead of coal.

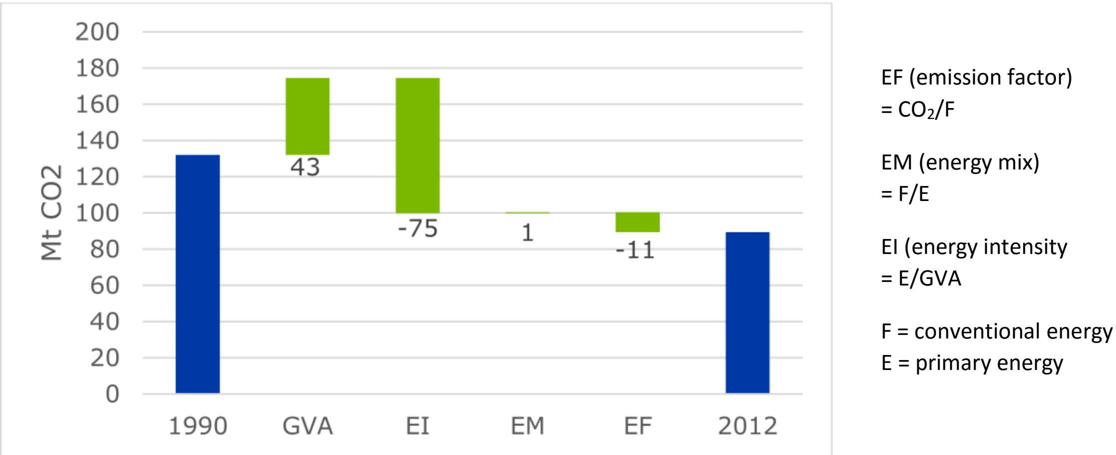


Figure 11: CO_2 decomposition analysis of the chemical sector in the EU (1990-2012)

The cement sector contributed with 20% in 1990 and 21% in 2012 to industrial CO_2 emissions. Its production is very energy intense. Madlool et al. (2011) estimated that there are still large potentials to reduce the process related energy consumption. Overall, CO_2 emissions in the cement sector decreased (Figure 12). This happened mainly due to a reduction in production, which is suggested to be caused by both events, the fall of the Soviet Union and the financial crisis. During the years of these two events the physical activity factor mitigated CO_2 emissions, while it contributed to an increase in

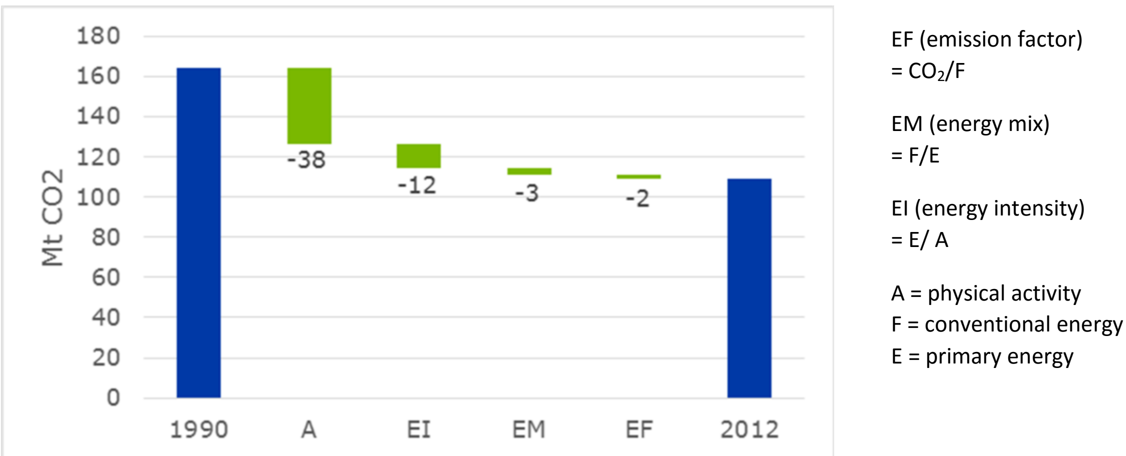
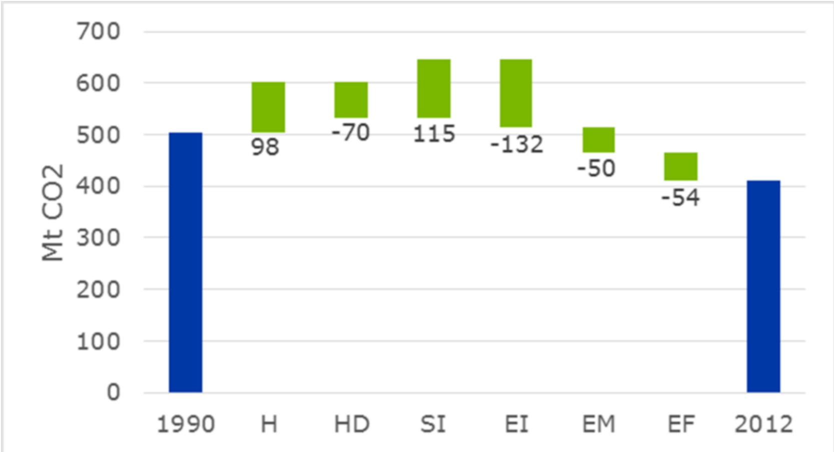


Figure 12: CO_2 decomposition analysis of the cement sector in the EU (1990-2012)

CO_2 emissions in the other time periods. Due to an improved energy intensity CO_2 emissions decreased. The renewable energy share cannot exactly be determined as the statistics only represent non-metallic minerals (where RES increased from 1% to 3%). However, as cement makes up 80% of this sector and the share in renewable energies is marginal, it can be used as a good approximation. The emission factor only contributes marginal to emission increases. Decreasing CO_2 emissions due to the emission factor are observed due to a shift from oil and coal towards electricity and natural gas (indicative from non-metallic mineral sector).

Residential buildings

The residential buildings sector contributed with 12% to total CO_2 emissions in 1990 and 2012. The results of the decomposition analysis can be examined in Figure 13. The overall change in CO_2 emissions shows a decreasing trend. The number of households increased by 24%, leading consequently to an increase in CO_2 emissions due to the number of households factor. As the population grew much less (6%) than the number of households, the household density (POP/H) decreased and therefore contributed to a mitigation of CO_2 emissions. It shows that relatively seen, the energy consumption decreased per household, even though energy consumption per person is higher, the fewer people live in one household. The *Buildings Directive* is linked to these developments. The surface intensity led to an increase in emissions as the surface area grew faster (37%) than the population suggesting that new houses/apartments are larger as well as less people moved into existing houses/apartments. This can be underlined by looking at the average surface area per household that increased by 10% between 1990 and 2012. As insulation of houses improved and also the energy production got more efficient, CO_2 emissions decrease due to the energy intensity. This can be connected mainly to the *Energy Efficiency Directive 2012/27/EU* that amending *Buildings Directive 2002/31/EU and Energy Performance Directive 2010/31/EU*. In the decomposition analysis more CO_2 emissions are mitigated due to the energy intensity between 2002 and 2012 (-78 Mt CO_2) than between 1990 and 2002 (-55 Mt CO_2). The share of renewable energies increased from 8% to 14%, thus also the energy mix contributed to a mitigation of CO_2 emissions. The conventional energy mix shifted from coal and oil to natural gas and electricity leading to a decrease in CO_2 emissions due to the emission factor. As the electricity consumption does not only compromise electricity use for cooking, space and water heating but also for electric appliances and lighting, it needs to be kept in mind that a mitigation of CO_2 emissions due to this factor by means of an increasing electricity share could also mean a significant increase in the use of electric appliances instead of a shift towards a cleaner conventional energy production for cooking and heating. Generally, households tend to own more electrical appliances; the rate of equipment ownership for refrigerators, freezers, washing machines, dishwashers, TVs, and dryers increased between 1990 and 2012.



EF (emission factor) = CO_2/F

EM (energy mix) = F/E

EI (energy intensity) = E/S

SI (surface intensity) = S/POP

HD (household density) = POP/ H

H = #households
S = surface area
F = conventional energy
E = primary energy

Figure 13: CO_2 decomposition analysis of the residential buildings sector in the EU (1990-2012)

Concluding remarks on the sectoral analysis

The sectoral analysis covered 85% of total CO_2 emissions in 1990 and 87% in 2012. During that time period, emissions on a macro level decreased more (-14%) than the summed emissions of the sectors in this analysis (-12%), indicating that significant CO_2 emission reductions could have also been achieved in other sectors. While the electricity, the residential, and all the industrial sectors contributed to the mitigation of CO_2 emissions, the transport sector increased its CO_2 emissions between 1990 and 2012.

Overall, population, GDP, GVA, tonne-km, and passenger-km contributed to an increase in CO_2 emissions. The physical activity factor for the iron and steel, and cement sector drive a decrease in CO_2 emissions. The energy intensity that is expressed in different terms, led to the mitigation of CO_2 emissions for all sectors. Next to other effects that influenced these developments (e.g. technological learning, and scaling) several policies that concern energy efficiency and conservation contributed to enhance these reduction (e.g. *Directive 2006/32/EC on Energy End-Use Efficiency and Energy Services,* 20% GHG emissions reduction target, and *Energy Performance Directive 2010/31/EU*). However, as this is not an in-depth policy analysis, this link can only be indicated. In all sectors except for the iron and steel, and chemical sector an increasing share of renewable energies could have been noticed, and hence CO_2 emission mitigations due to the energy mix factor were observed. The comparison to what degree sectors mitigated CO_2 emissions underlines that it is easier to introduce RES in the electricity sector (-148 Mt CO_2) than in heavy industry (e.g. cement: -3 Mt CO_2, and chemicals: 1 Mt

CO_2). While the share in renewable energies increased from 4% to 7% in the industry sector resulting in emission decreases of -44 Mt CO_2, the share of renewables stays marginal for the three sub-sectors covered in this decomposition analysis. This shows that the increase in renewable energies occurred in another sub-sector. The CO_2 emission mitigation due to renewable energies (EM factor) can be connected to the energy policy (non-binding) in 2007 that communicated the 20% renewable energies target first, which was made binding in the directive 2009/28/EC. This can be underlined with the decomposition analysis where CO_2 emission reductions in the macro-economy due to the energy mix are larger between 2007 and 2012 (-153 Mt CO_2) than between 1990 and 2007 (-135 Mt CO_2). CO_2 emissions were further mitigated due to the emission factor in all sectors but the transport (passenger and freight), and iron and steel sector. In the macro economy and the electricity sector this was caused by a shift from oil and coal towards natural gas. In the industrial, cement, and residential sector the reason was the shift from oil and coal towards electricity and natural gas. The chemical sector shifted from oil and coal towards heat and electricity.

The financial crisis had a large influence on the emission regime as the global demand collapsed which decreased the production output, and hence also emissions decreased. Consequently, CO_2 emissions due to the per capita GDP decreased significantly. The lower demand resulted in lower production capacities. This affected the energy intensity, which decreased as a lower output usually comes along with a lower efficiency because processes and power plants are most efficient at a certain (higher) load (Ummels 2009). This resulted in a lower CO_2 emission mitigation due to the energy intensity or electric efficiency after 2007/2008. It can be concluded that CO_2 emission reductions are not only a result of the implemented climate change policies but also of economic circumstances.

Due to data constraints the more detailed sectoral analysis could have only been conducted for the EU, however, it can be seen that it bears several advantages to conduct a more in depth analysis. The most prominent advantage is that on a macroeconomic level several effects are summarised in one factor, for example for the energy intensity, the sectoral changes of various sectors, real energy intensity achievements, and economic fluctuations. By splitting the macro-economy into different sectors, in an optimal case, physical units instead of GDP and GVA can be used, and hence the influence of structure effects on the factor diminishes leading to a better understanding in how far real energy intensity improvements could have been achieved. Another advantage is to get a better insight into what sectors contributed most to CO_2 emission changes. This enables one to better link specific policy measures to the CO_2 emission changes of different sectors and to get a better insight into what the significant sectors that contributed to CO_2 emission changes were.

4.2 People's Republic of China

Policy overview

Since China gradually opened up its economy starting in 1978, it is considered to be the fastest growing economy in the world with an average annual growth in GDP of 9.9% (Zhang et al. 2012). Next to an increase in global consumption of products, China's economy also profited from a shift of production of goods from foreign economies towards their own economy. Mostly heavy industry sectors as steel, chemical, and cement were subject of this change (Zhang et al. 2007). Even though China's efforts in environmental policies started relatively early as well as these efforts are continuously increasing, they did not keep up with its fast developing economy. In the 1990s a shift from end-of-pipe treatment towards whole-process pollution avoidance occurred (Zhang & Wen 2008). The World Bank estimated that in 1995, 7.7% of China's GDP was lost mainly due to air pollution (The World Bank 1997). Over time, China implemented several policies that mainly concern energy conservation and energy efficiency measures as well as the promotion of renewable energies (OECD/IEA 2016).

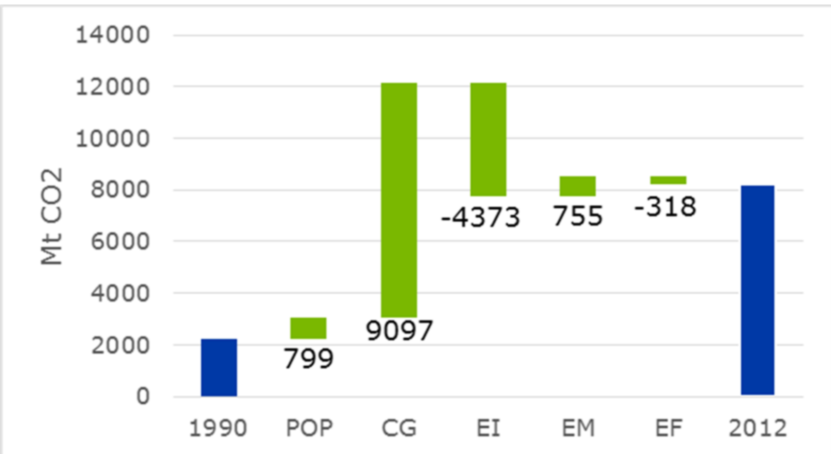
One major component of China's climate change policy concerns the energy conservation and energy efficiency improvements throughout all sectors. The *Medium and Long-Term Plan of Energy Conservation Programme* from 2004 provides details on energy conservation targets as for example fuel switching measures and energy efficiency improvements in the industry. The *Energy Label* from 2005 gives details on labelling product's efficiency performances to stimulate the purchase of energy efficient products. The *Efficiency Upgrade for Coal Burning Industrial Boilers and Kilns* from 2006 aims at reducing the kiln and boiler energy consumption as well as to make processes cleaner. The *Expansion of Local Cogeneration (CHP) and the Retirement of Inefficient Plants* aim at improving the energy efficiency of the power sector. The *Aluminium Industry Permitting Standards* from 2007 introduce measures to make the aluminium industry cleaner and more efficient. An improved energy efficiency in the transport sector is promoted by the *Vehicle Fuel Economy Standards* from 2006, a tax relief stated in the *Vehicle Excise Tax Rates* from 2006, and the *China Urban Transport Development Strategy and Partnership Demonstration Projects* from 2011 (OECD/IEA 2016). In the 11th five-year plan (2006-2010) the government of China stated to reduce its energy intensity (E/GDP) by 20% in 2010. The target was newly set in 2009 and increased to realise a 40-45% reduction by 2020 compared to 2005 values (Wang et al. 2011). The 11th five-year plan further presents several measures to reduce petroleum consumption in transport and industry, e.g. by replacement towards less polluting fuels and by the development of alternative fuels. Furthermore, electric motors, which currently run at efficiencies 10-30% lower than in other nations, are subject of improvement. The *National Building Energy Standard Plan* tackles energy conservation and improved energy efficiency in the buildings sector (OECD/IEA 2016). The *Energy Conservation Law*, being implemented in 2008, examines how residential demand can be met by the promotion of energy conservation and energy efficiency improvements as well as a reduced environmental impact of energy use. (OECD/IEA 2016).

Another major component of China's climate change policy is the promotion of renewable energies. In 2001, the country implemented a tax relief in form of half of the Value-Added Tax (VAT) for wind power (8.5% instead of 17%), in 2003 the reduction of VAT to 13% for biogas production followed. In the same year, the income tax for both wind power and bio-energy was reduced from 33% to 15%. Further to this, customs duty rates were changed to benefit wind turbines and their main components as well as photovoltaic modules. In 2007, income taxes were further cut for producers and consumers of renewable energies and the import tax for 'green' equipment was reduced. The *Wind Power Concession Programme* from 2003 further encouraged the planning and establishment of wind parks by guaranteeing a fixed feed-in tariff for successful bidders participating in this competition. The *Renewable Energy Law* came into force in 2006 and presents a framework policy to promote renewable energies, where the State Council will plan renewable energy shares and make sure that these targets are achieved. It further states a fixed feed-in tariff for renewable energies. The first plan stating renewable energy shares is the *Medium and Long-Term Development Plan for Renewable Energy* and came into force in 2007. It specifies targeted shares of renewable energies for 2020, i.e. a 10% share of total energy consumption by 2010 and 15% by 2020 (OECD/IEA 2016).

Decomposition analysis

The unsustainable growth of China's economy is clearly reflected in its CO_2 emission increases. Whereas in 1990 the national CO_2 emissions were 2,200 Mt CO_2, it increased to 8,200 Mt CO_2 in 2012. China is nowadays not only the largest emitter of CO_2 emissions but also recorded the largest increase in carbon emissions during that time period. China's population grew by 60% from 841 million to 1351 million, while its GDP rose more than 35 fold from 363 billion US$ Purchasing Power Parity (PPP) to 12,970 billion US$ PPP (International Energy Agency 2015), which is a result of both the high migration of production of goods from other countries to China and the increased consumption of China's population (Lin 2011).

Having a look at the decomposition analysis of the overall time period (Figure 14), one can see that there is one factor, the per capita GDP factor, contributing most significantly to CO_2 emission increases. Emissions increased more than eleven fold due to that factor compared to the population factor. Due to the large penetration of industry from other economies, the economic growth expanded exponentially, which led to CO_2 emission increases and a growth in per capita GDP. The population growth itself did not contribute as significant as the per capita GDP change to emission increases as the GDP grew much faster than the population. One possible reason for the small growth in population could be the one-child policy, which was softened in 2013 (BBC 2015). Whether or not the softening of the policy has an effect on CO_2 emission changes will only be observable in the decades to come. The continuously improved energy intensity mitigated the growth in CO_2 emissions as less energy is needed per output of economic unit, which is in line with the policy goal to reduce the energy intensity by 20% in 2010. Lewis (2011) estimated that this goal was almost achieved at a 19.1% reduction in 2010. Even though China made an effort in reducing emissions by improving its energy intensity (e.g. *Efficiency Upgrade of Coal Burning Industrial Boilers and Kilns, Medium and Long-Term Plan of Energy Conservation Programme*), which decreased on average annually by around 4%, the primary energy consumption developed significantly unsustainable. (Xu et al. 2002; Zhang & Wen 2008). The energy mix contributed to an increase in CO_2 emissions, which is related to the decrease in the share of renewable energies (cf. Figure 15). The cumulative installed wind power capacity in China, however, was with 115 GW worldwide the largest and represented 31% of total global installed wind power capacity (GWEC 2014). Many policies, especially by lowering taxes and providing fixed feed-in tariffs enabled renewable energy sources to grow in absolute terms (e.g. *Wind Power Concession Programme*, *Renewable Energy Law*). The share in renewable energies still decreased as the total energy demand grew significantly more than renewable energies. The policy target to have 15% renewable energies in the primary energy mix by 2020 might not be achieved despite increasing absolute values for renewable energies as so far the share in renewable energies decreased from 24% to 11% in 2012 (International Energy Agency 2015). The emission factor mitigates CO_2 emissions as the average emission factor for the conventional energy mix decreased from 93.2 Mt CO_2/ktoe to 90.4 Mt CO_2/ktoe. This is reflected in an increase in the share of natural gas and nuclear, while the share of coal energy decreased in the conventional energy mix (hence excluding renewable energies, cf. Figure 15).



EF (emission factor)
= CO_2 /F

EM (energy mix)
= F/E

EI (energy intensity)
= E/GDP

CG (per capita GDP)
= GDP/POP

F = Conventional energy
E = primary energy

Figure 14: CO_2 decomposition analysis of the macro-economy in China (1990-2012)

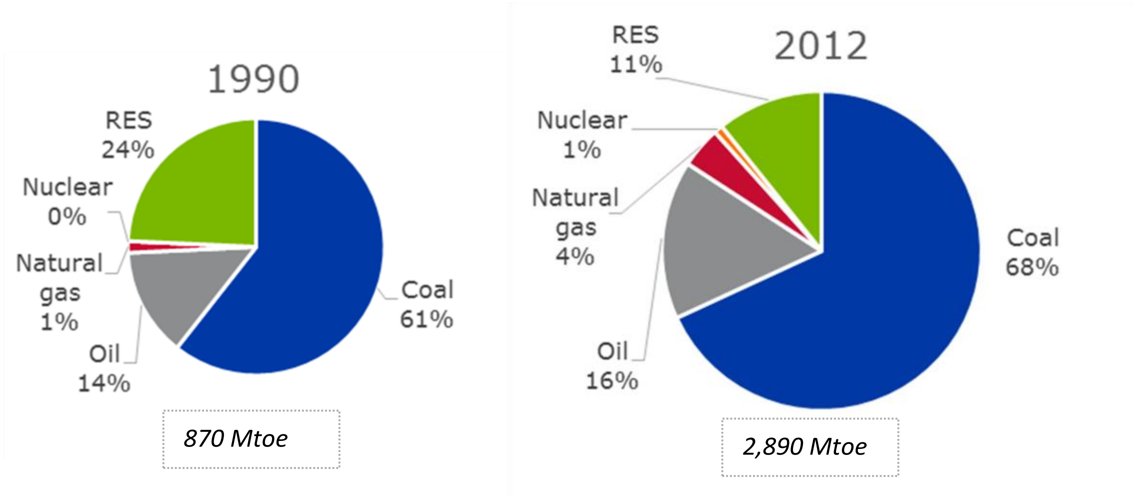


Figure 15: Energy mix of the macro-economy in China

The decomposition analysis for the electricity sector (Figure 16) is largely in line with the analysis above. While in 1990, the electricity sector made up 25% of the total CO_2 emissions, this share increased to 44% in 2012. The major factor contributing to the increased importance of the electricity sector in terms of CO_2 emissions is the electricity consumption per capita (EC). The access to electricity was already in 1990 with 94% relatively high in China and increased to 100% in 2012 (The World Bank Group 2016a). This indicates that the main reason for the increase in CO_2 emissions due to the electricity consumption per capita is an increased welfare and higher industrial productivity in China. Similar to the macro-economic decomposition analysis, the population growth also led to CO_2 emission increases, however, compared to the energy consumption per capita this is not very significant. The electric efficiency factor drove the mitigation of CO_2 emissions throughout the time period, while the later years showed more significant reductions, which is likely a result of energy efficiency measurements of the Chinese government, e.g. by the *Medium and Long-Term Plan of Energy Conservation Programme* from 2004 or the Expansion of Local Generation (CHP) program from 2006. It needs to be kept in mind that these improvements were also influenced by the financial crisis. The electric efficiency can be translated into an overall power plant efficiency of 34% in 1990 and 40% in 2012. Next to the usage of more renewable energies, which increases the efficiency, there was an effort to increase the efficiency of thermal power plants (*Retirement of Inefficient Plants*). Usually, it is easier to introduce renewable energies in the electricity sector than in other sectors; this can be seen in the energy mix factor, which contributes to no emission changes, which contrasts the macro-economic emission factor that drove an increase in CO_2 emissions. While CO_2 emissions still increased due to the change in energy mix between 1990 and 1998, there were no changes in emissions between

1998 and 2008, and a decrease in emissions between 2008 and 2012. This corresponds to policies implemented to promote renewable energies over the same period (e.g. *Renewable Energy Law* (2006), *Medium and Long-Term Development Plan for Renewable Energy* (2007)). For the emission factor, a decrease in emissions can be observed, which can be explained by an average decreased emission factor from 91.2 tCO2/TJ to 90.5 tCO2/TJ due to a shift from oil and coal towards natural gas and nuclear in the conventional energy mix (Figure 17).

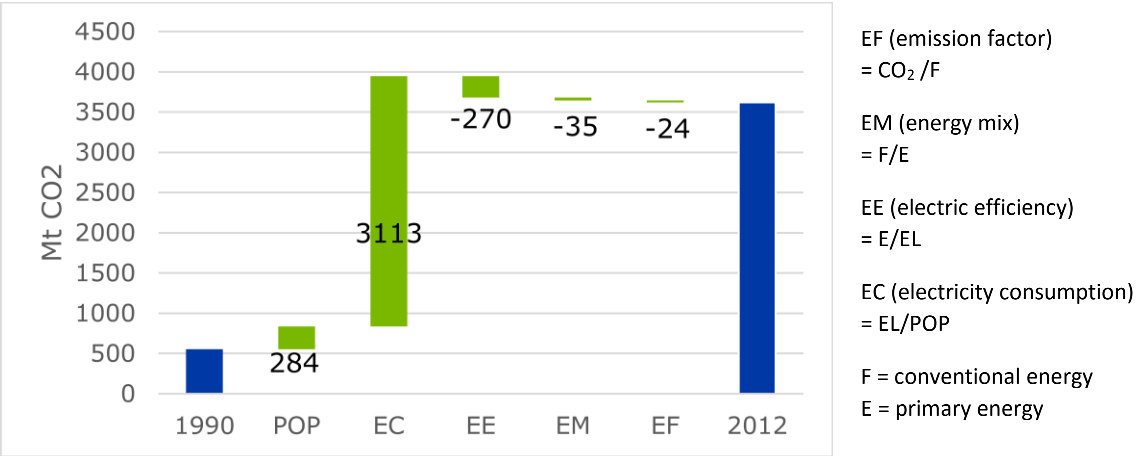


Figure 16: CO_2 decomposition analysis of the electricity sector in China (1990-2012)

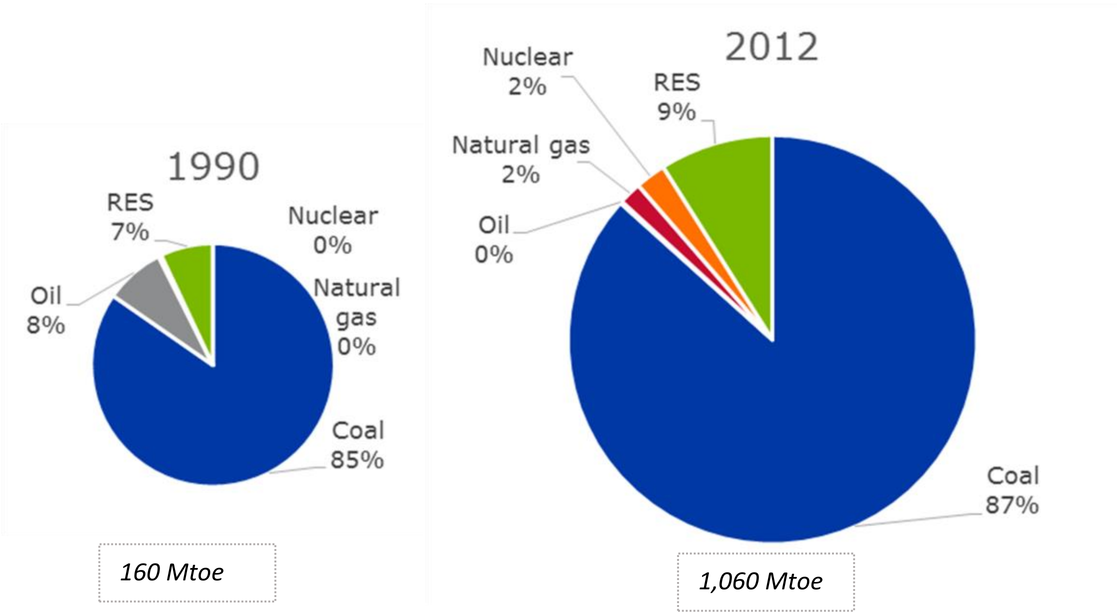


Figure 17: Energy mix of the electricity sector in China

4.3 United States of America

Policy overview

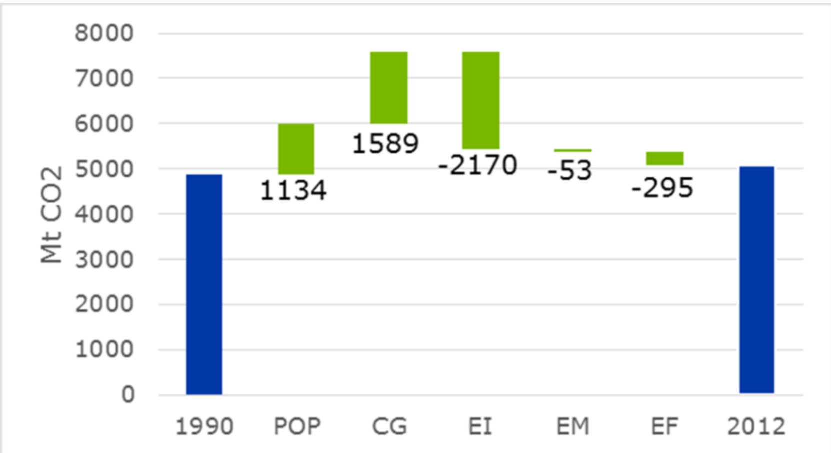
The United States' history of climate change policies was influenced by scepticism of climate change and difficulties to implement effective policies due to the opposition. While it was difficult to bring forward climate change policies on national level, many initiatives and policies arose on state level (OECD/IEA 2016). The Kyoto Protocol was signed by President Bill Clinton, but his successor G.W. Bush did not ratify it as he denied the scientific consensus about climate change due to 'uncertainties' (Byrne et al. 2007). Instead, he focused on next generation conventional fuels. With Barack Obama's presidency (2009-2016) the climate change policy efforts increased. In 2014, he managed to legislate the *Clean Power Plan*, which is considered to be an important step in US climate change policy. An increase in wind, solar and geothermal energy can be expected as well as the US developed to become a leading producer of natural gas (The White House 2013). Next to the financial crisis in 2008, which involuntarily led to emission decreases, the shale gas boom had a significant impact on the energy system, and hence also on CO_2 emission decreases (European Parliament 2015).

There are several policies aiming at an improved energy efficiency and the conservation of energy, e.g. the *Residential Energy Conservation Subsidy Exclusion* (1996), the *Energy Conservation Investment Program* (2001), and the *National Action Plan for Energy Efficiency* from 2006 (policy status: ended). The *Energy Policy Act* of 2005 (*Energy Bill*) provides tax incentives for conservation and energy efficiency as well as for (cleaner) conventional and renewable energy production plants. The *Energy Independence and Security Act* of 2007 focuses on the increase of energy security next to addressing climate change. In 2008 the *Energy Efficiency and Conservation Block Grant Program* was implemented (OECD/IEA 2016).

Despite the sceptical opinion on climate change especially by G.W. Bush and the focus on secondary conventional fuels, some policies were implemented to explore and promote the use of renewable energies. In the electricity sector, the *Renewable Energy Production Incentive* was introduced (1992) in order to promote electricity from renewable energies. The *Clean Coal and Natural Gas Power Systems Program* was launched in 1997. The *Hydrogen Program* from 2004 supports research to expand the knowledge of hydrogen usage. In 2008 the *Smart Grid Technology Research, Development and Demonstration* was implemented to conduct research on an efficient and reliable electricity network. To promote renewable energies in the electricity sector, the *Onshore Renewable Energy Development Program* and the *Offshore Renewable Energy Program* were implemented in 2009. Renewable energies were further promoted in the *Wind Powering America* policy from 1999 and the *Biomass Program* from 2000 (OECD/IEA 2016).

Decomposition analysis

The policy regime for climate change in the US that was not very ambitious for the given time period caused overall CO_2 emission increases. The total primary energy supply increased by 12% from 1,900 Mtoe in 1990 to 2,100 Mtoe in 2012 (International Energy Agency 2015). There are two factors that mitigate the increase in CO_2 emissions: the aftermath of the financial crisis in 2008 and the shale gas boom of the last years. In Figure 18 the decomposition analysis for the overall period is depicted. Not only did the per capita energy factor had a significant influence on the carbon emissions, but also the population growth itself led to a large increase in carbon emissions. Both developments are in line with a 73% increase in GDP and a 25% increase in population. The other three factors – energy intensity, energy mix, and emission factor – tempered the growth in emissions, most notably the energy intensity. The US followed in many policy decisions the 'no regret' policy, a policy strategy that only considers measurements where benefits are larger than costs associated with that measurement (IPCC 2001). Energy efficiency increases do not only lead to emission decreases but also improve the productivity, reduce the materials required for production and make the production economically more feasible. The *Energy Policy Act* (2005) and the *National Action Plan for Energy Efficiency* (2006)



EF (emission factor)
= CO_2/F

EM (energy mix)
=F/E

EI (energy intensity)
=E/GDP

CG (per capita GDP)
=GDP/POP

F = Conventional energy
E = primary energy

Figure 18: CO2 decomposition analysis of the macro-economy in the United States (1990 to 2012)

are examples for these kind of policies. From a year to year basis the CO_2 emission changes fluctuate for the energy intensity, therefore it is difficult to connect these changes to specific policies. For the energy mix (EM), it can be seen that there are only minor CO_2 emission decreases due to a shift from conventional to renewable energies. Policies on renewable energies were not very ambitious, which is reflected in the share of renewables in total energy consumption (from 5% to 6%). Even though some policies promoted the use of renewable energies as the *Onshore Renewable Energy Development Program* or the *Biomass Program*, the national focus was on secondary conventional energies. In Figure 19, it can be seen that the share of oil and coal decreased, whereas the share of nuclear and natural gas increased. The increase of the natural gas share can be directly connected to the expansion of shale gas production of the last ten years (e.g. the *Clean Coal and Natural Gas Power Systems Program*).

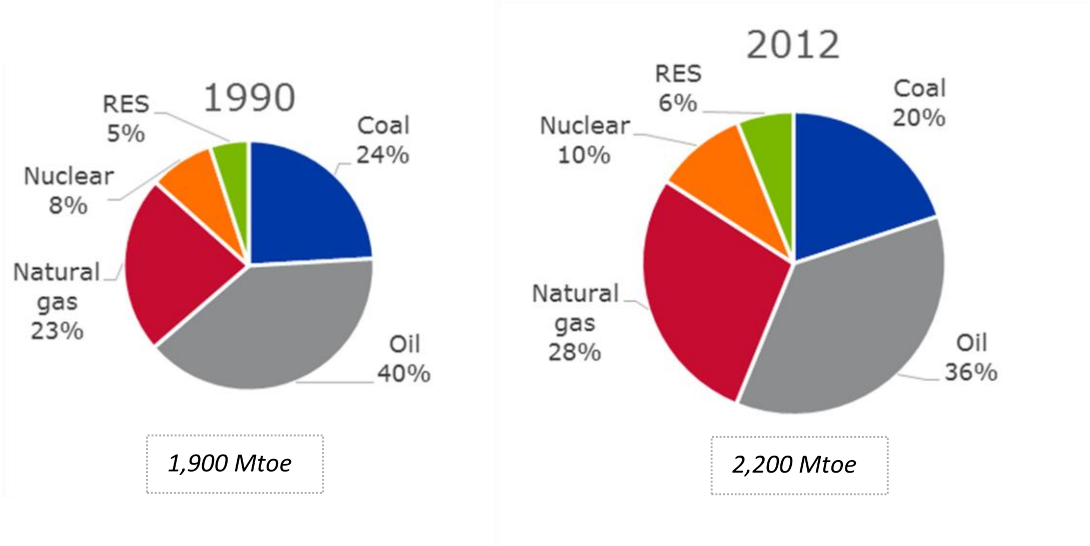
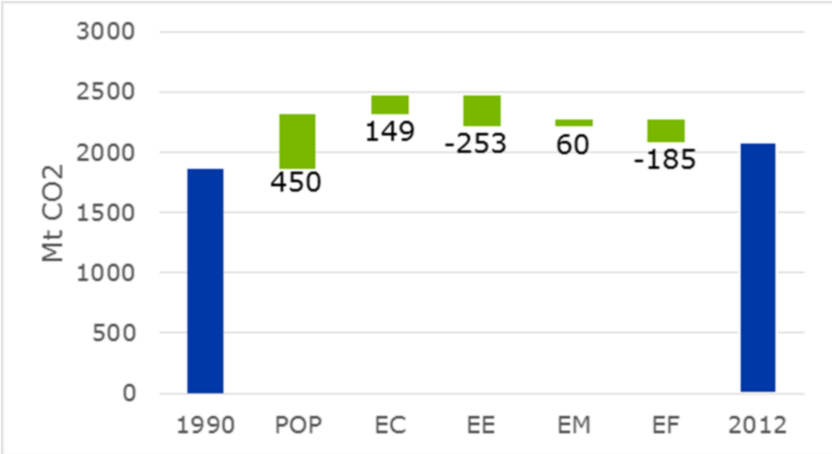


Figure 19: Energy mix of the macro-economy in the US

The decomposition analysis for the electricity sector shows similar outcomes as the one for the macro-economy (Figure 20). While 38% of total emissions were allocated to the electricity sector in 1990, the value increased to 41% in 2012. The population growth is the largest contributing factor to CO_2 emission increases, whereas the electricity consumption per capita represents a smaller contribution to emission increases. The electric efficiency mitigated CO_2 emissions; by translating this into power plant efficiencies ($1/(EE_t)$), one can see that the overall efficiency increased from 39% in 1990 to 44% in 2012. The main reason for this is a shift from coal to gas power plants (cf. Figure 21), but also several energy conservation policies, as e.g. the *Energy Policy Act* of 2005 to improve power plant efficiencies. Between 2005 and 2012 the CO_2 emission reductions due to the electric efficiency were bigger (-160 Mt CO_2) than between 1990 and 2005 (-124 Mt CO_2). The energy mix led to CO_2 emission increases, which is due to the decreased share in renewable energies in the electricity sector. As the energy consumption in the electricity sector grew more than the macro-economic energy consumption (11% and 19% respectively), it was more difficult to keep or increase the share in renewables in the electricity sector. The emission factor on the other hand contributed to a decrease in CO_2 emissions, showing that the conventional energy mix shifted from oil and coal energy towards natural gas, which clearly reflects the efforts of the last ten years to support secondary conventional fuels (as e.g. shale gas) rather than renewable energies (between 2002 and 2012 the CO_2 reductions due to the emission factor are three times bigger than between 1990 and 2002). Figure 21 displays the increasing share of natural gas at the expenses of coal and oil.



EF (emission factor)
= CO_2 /F

EM (energy mix)
= F/E

EE (electric efficiency)
= E/EL

EC (electricity consumption)
= EL/POP

F = conventional energy
E = primary energy

Figure 20: CO2 decomposition analysis of electricity sector in the US (1990-2012)

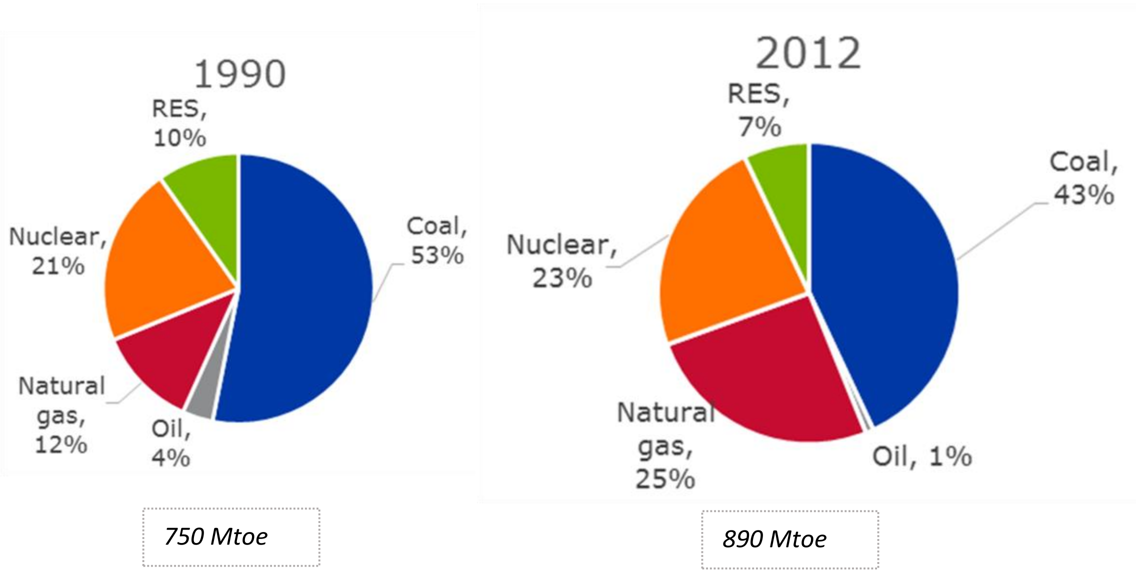


Figure 21: Energy mix of the electricity sector in the US

4.4 India

Policy overview

In the beginning of the 1990s, as many other developing countries, India did not consider the fight against global warming as an urgent necessity but as a threat to their domestic growth. In 1990 an influential report on this topic was published by the Centre for Science and Environment (based in India). It stated that the international climate change efforts are comparable with 'environmental colonialism' (Isaksen & Stokke 2014). During that time, India started to implement far-reaching economic policies that allowed for a more market oriented trade as well as it opened up for international participants (Chaudhary et al. 2014). With increasing awareness of climate change that directly affects the country, India recognised the need to decrease global GHG emissions but stating at the same time that the responsibilities to do so lie with the developed countries. One major challenge it encountered is to have on the one hand the international climate negotiations and the need to protect its nation from climate change induced natural hazards and on the other hand national problems as the fight against poverty and the support of economic development (Atteridge et al. 2012).

In 1999 the *Energy Conservation Awards* came into force in order to acknowledge energy saving measures in the industry. Between 1999 and 2005, 965 MW capacity were avoided (OECD/IEA 2016). Two years later, the *Energy Conservation Act* of 2001 was implemented with the target to further save energy in buildings, appliances and industry by improving the energy efficiency. Under this act the "*Bureau of Energy Efficiency*" was established to introduce other standards and codes to save energy, as e.g. the energy conservation building code. Another mean to save energy is to reduce the energy intensity, which is specified with an energy intensity reduction target of 20% in *the Integrated Energy Policy* from 2006. It further mentions that the broader vision is to secure the supply of the energy demand in all sectors (OECD/IEA 2016). The 11th Five year plan formulates to reduce GHG emissions by 20% and also to increase energy efficiency by 20% until 2016/2017. The *National Action Plan on Climate Change* (NAPCC) further formulates eight national missions that concern the adaptation to and mitigation of climate change (Pew Center on Gloabal Climate Change 2008), among which the 2009 *National Mission for Enhanced Energy Efficiency* was launched (OECD/IEA 2016). Under this mission, the energy efficiency in the eight most energy-intense industries is tackled by tradable energy efficiency certificates in the *Perform, Achieve, Trade Scheme* (2011) (OECD/IEA 2016).

Further to this, the government of India introduced several policies to promote renewable energies, i.e. in 2002 the *Government Assistance for Wind Power Development*, in 2003 the *Government Assistance for Small Hydropower Stations*, in 2003 the *Central Assistance for Biogas Plants*, in 2008 the *Solar Power Generation Based Incentive* and the *RE Tariff Regulations* to give guidelines on feed-in tariffs for renewable energies. In 2010 solar power was further promoted in rural areas under the *National Solar Mission* (Phase I and Phase II). The *Electricity Act* in 2003 concerned not only the availability of electricity but also the promotion of energy efficiency. The *National Electricity Policy* 2005 specified on how to increase the access to electricity, and was further extended in the *Tariff Policy* 2006 to include provisions regarding renewable energies and cogeneration (OECD/IEA 2016).

It can be seen that India did not only follow the interest of combating global warming itself but especially to secure resources and to use climate change mitigation technologies as an economic opportunity for development (Isaksen & Stokke 2014). In the NAPCC Prime Minister Singh repeated an announcement from 2007 that India's per capita emissions will not exceed those of the OECD countries (Atteridge et al. 2012).

Decomposition analysis

Some of India's policies tackle the access to electricity (as the *National Electricity Policy* 2005), which is reflected in the increase of the access to electricity (percentage of population) that rose from 62.3% in 2000 to 78.7% in 2012 (The World Bank Group 2016a; OECD/IEA 2016), while the population increased linearly by about 40% between 1990 and 2012. In the same time-period, India's GDP almost increased fourfold. The total CO_2 emissions for India more than tripled during the period 1990 to 2012. In the decomposition analysis for the macro economy (Figure 22) one can identify the major factor contributing to this increase as the per capita GDP, which reflects an increase in welfare. Even though India's per capita GDP almost tripled between 1990 and 2012 (4.5 billion US$ PPP/cap in 2012), it is still significantly lower than the one in the US (45 billion US$ PPP/cap in 2012) and the EU (27.9 billion US$/cap in 2012). Therefore, Prime Minister Singh's statement that India's per capita emissions will not exceed those of the OECD countries is valid until now. The CO_2 emission increase due to the population growth corresponds to the 40% linear increase of population. The energy intensity factor led to a decrease in CO_2 emissions, indicating that the economy became more efficient. The decomposition analysis shows that between 1990 and 2000 less emissions were reduced (-134 Mt CO_2) due to the energy intensity than between 2000 and 2012 (-407 Mt CO_2). This shows that India's policies to promote energy efficiency and to save energy at least enhanced these reductions (e.g. *Energy Conservation Act*, *National Mission for Enhanced Energy Efficiency*). As it has been described above, India promoted continuously renewable energies in the last decade of this analysis (e.g. *Wind Power Development*, *Solar Power Generation Based Incentive*, *RE Tariff Regulation*), nevertheless the CO_2 emissions increased due to the energy mix. The increase in absolute numbers of renewables (from 140 ktoe to 200 ktoe) increased less than the overall energy demand, resulting in a decrease of the renewable energy share (from 44% to 25%). The emission factor also contributed to CO_2 emission increases, meaning that the share in more polluting energies increased. In Figure 23 it can be seen that the share of coal increased more than the share of natural gas, nuclear or oil, which is emphasised by the average emission factor, which increased from 46.5 Mt CO_2/ktoe to 62.3 Mt CO_2/ktoe.

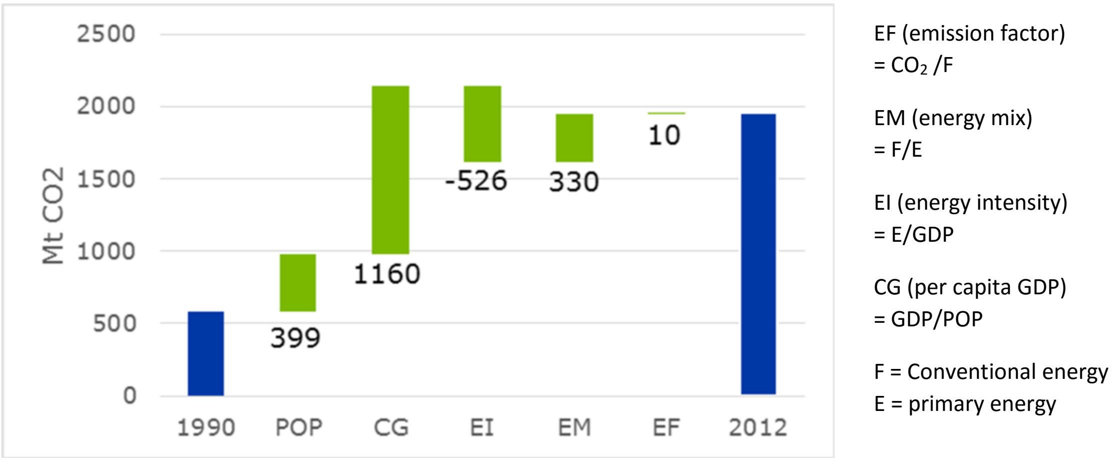


Figure 22: CO_2 decomposition analysis of the macro-economy in India (1990-2012)

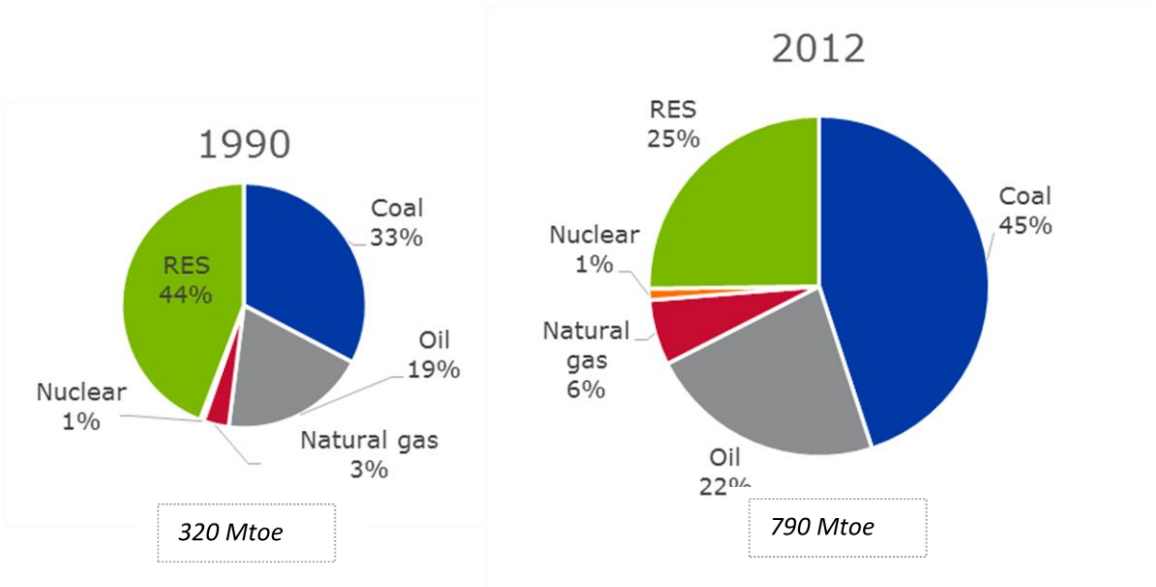


Figure 23: Energy mix of the macro-economy of India

In the electricity sector that accounted for 41% of total emissions in 1990 and 53% in 2012, one can observe a similar picture. The increase in welfare and a higher coverage of electricity is displayed in the electricity consumption factor (EC) that increased emissions significantly (absolute electricity production increased almost fourfold), while the growth in population also contributed to CO_2 emission increases according to the population growth (Figure 24). Despite several policies aiming at making the electricity production more efficient (as the *National Mission for Enhanced Energy*

Efficiency), the electric efficiency factor displays increasing CO_2 emissions. The reasons for this are three-fold. A shift towards less efficient thermal power plants (from natural gas and oil towards coal), and a reduced share of renewable energies can be observed (Figure 25). Further, a possible decrease in power plant efficiency despite policy measures might have occurred (physical and other losses). Overall, the power plant efficiency decreased from 35% in 1990 to 31% in 2012. The energy mix shows a similar behaviour as in the macro economy, hence increasing CO_2 emissions due to a decreasing share in renewable energies. In contrast to the macro-economy, the emission factor does not influence CO_2 emission changes in the electricity sector (Figure 24) as the average emission factor changed only marginal from 80.1 Mt CO_2/ktoe to 80.8 Mt CO_2/ktoe. A shift from oil towards natural gas, nuclear, and coal can be depicted (Figure 25).

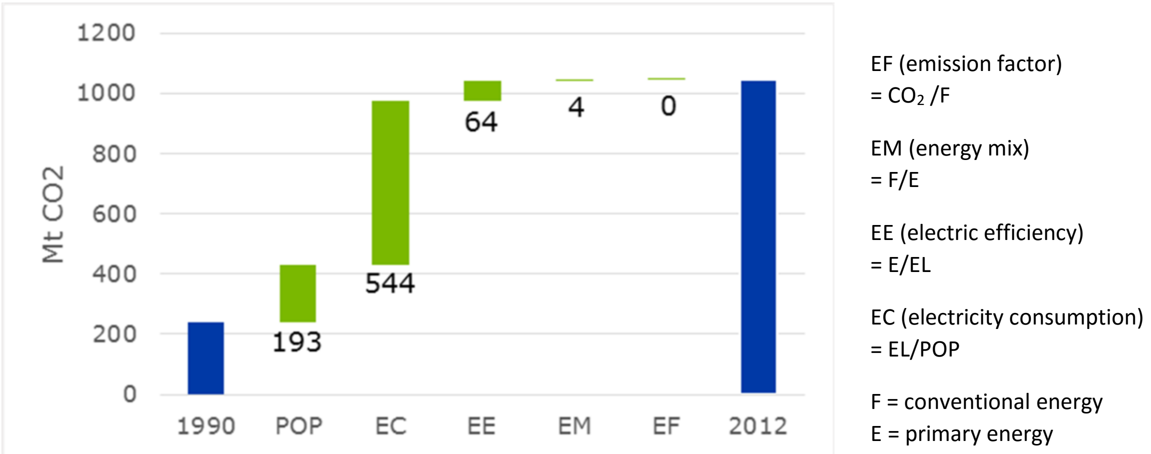


Figure 24: CO_2 decomposition analysis of the electricity sector in India (1990-2012)

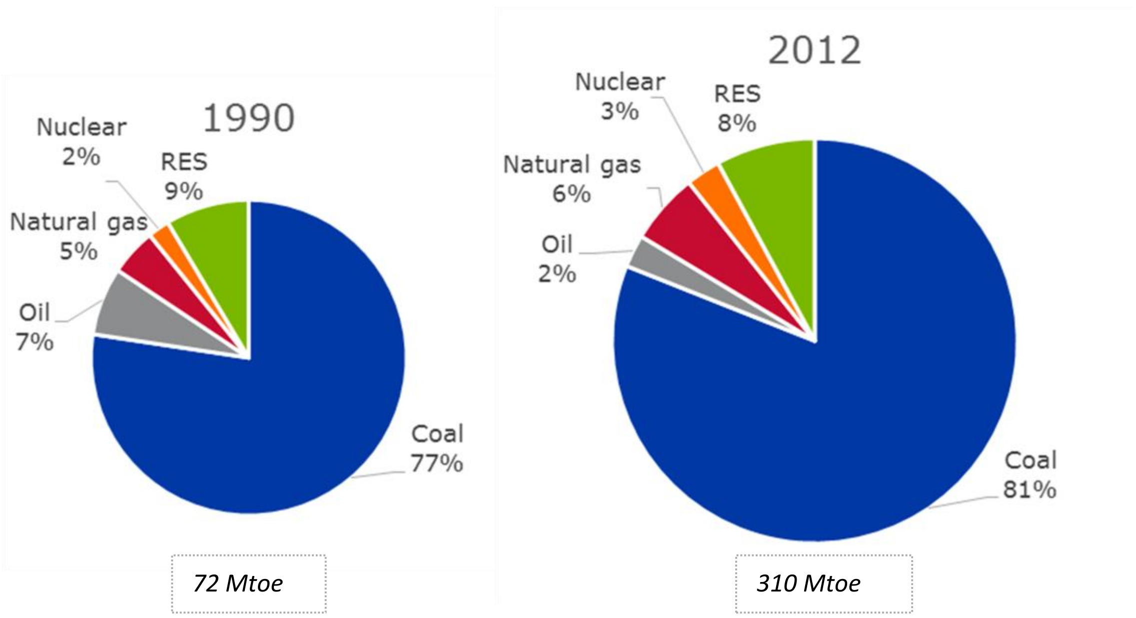


Figure 25: Energy mix of the electricity sector in India

4.5 Comparison of macro-economic results

The outcome for the decomposition analysis of the four countries for the macro-economy and the electricity sector are summarised in Table 2. One can see that the population and the per capita GDP led in all countries to an increase in CO_2 emissions, while the energy intensity contributed to CO_2 emission mitigations with an exception in India's electricity sector. In the EU and the US the energy intensity had a higher effect on CO_2 emission mitigations than the per capita GDP on CO_2 emission reductions in the macro-economy, hence there was a net decrease in CO_2 emissions due to these two factors. This was reversed in China and India. The underlying factors that contributed to the development of the decomposition factors for the macro-economy, are presented in Table 3. The population grew the least in the EU (6%) and the most in India (42%), while China continues to have the largest population. It should be kept in mind that China's population growth was restricted due to the one-child policy that was softened in 2013 (BBC 2015). Consequently, CO_2 emissions due to the population growth could have increased significantly more without that policy. While the US and the EU already started with a high GDP value in 1990, China and India used to have a very low value in 1990 that increased exponentially. China's GDP almost exceeded the one from the US and the EU in

Table 2: Overview of decomposition factor values for the macro-economy and electricity sector for the four countries (1990-2012)

Decomposition factors, macro-economy (1990-2012) [Mt CO2]					
Country	Population	per capita GDP	Energy intensity	Energy mix	Emission factor
EU	229	1,197	-1,428	-282	-278
China	799	9,097	-4,373	755	-318
US	1,134	1,589	-2,170	-53	-295
India	399	1,160	-526	330	10

Decomposition factors, electricity (1990-2012) [Mt CO2]					
Country	Population	Electricity consumption	Electric efficiency	Energy mix	Emission factor
EU	81	276	-223	-148	-145
China	284	3,113	-270	-35	-24
US	450	149	-253	60	-185
India	193	544	64	4	0

2012. Therefore, the emissions increased significantly more due to the per capita GDP (GDP/POP) in India and China than in the US and the EU. While in 1990 the primary energy consumption was highest in the US, in 2012 it was highest in China. At the same time China did not exceed the US's GDP showing that China's economy is more energy intense, which indicates a lower efficiency in energy terms and points at structural differences of the two economies (cf. Zhang et al. (2007) pointing at the augmented export of heavy industry products). The energy mix led to a mitigation of CO_2 emissions in the EU and the US on a macro level, whereas it increased CO_2 emissions in China and India (both on macro level) (Table 2). In Table 3 the share in renewable energies is displayed, which increased in the

US and the EU, while it decreased in China and India. While all countries implemented more or less effective policies to promote the use of renewable energies, China's and India's increase in energy demand exceeded the growth in renewables, which decreased the share in renewable energies. Thus, CO_2 emissions increased for India and China due to the energy mix factor, while they decreased for the US and the EU. Except for India, a reduction in CO_2 emissions due to the reductions in the emission factor can be observed. While the EU, China, and the US display a shift from coal and oil towards natural gas (for China also towards nuclear), India shows an increase in coal energy, which led to an increase in CO_2 emissions due to the emission factor.

Table 3: Overview of key values for the macro-economy of the four countries for the decomposition analysis

Year	1990					
Country	**GDP (billion 2005 US$)**	**POP (million)**	**CO2 (Mt CO2)**	**Conv. energy (Mtoe)**	**primary energy (Mtoe)**	**Share RES**
China	1,500	1,140	2,200	700	900	0.24
US	8,200	250	4,900	1,800	1,900	0.05
EU	9,700	480	4,100	1,600	1,600	0.04
India	1,400	870	600	200	300	0.44

Year	2012					
Country	**GDP (billion 2005 US$)**	**POP (million)**	**CO2 (Mt CO2)**	**Conv. energy (Mtoe)**	**primary energy (Mtoe)**	**Share RES**
China	13,000	1,350	8,200	2,600	2,900	0.11
US	14,200	310	5,100	2,000	2,100	0.06
EU	14,200	510	3,500	1,500	1,600	0.11
India	5,600	1,240	2,000	600	800	0.25

For the electricity sector, the outcome of the decomposition analysis is also presented in Table 2, while underlying key values are presented in Table 4. For most of the factors, developments are in line with macro-economic trends. This holds for primary and conventional energy as well as for CO_2 emissions. While the share in renewable energy behaves similar to the macro-economy for India and the EU, one can see that the renewable energy share in electricity increased for China and decreased for the US, which is different to its macro-economic behaviour. This underlines that China's efforts in promoting renewable energies focused on the electricity sector. In contrast to this, the US expanded the share of natural gas in the electricity sector, while the share of renewable energies decreased. With these findings in mind, one can explain the changes in power plant efficiency that are the quotient of electricity output and primary energy. The IEA assumes a 100% conversion efficiency for non-thermal power plants (International Energy Agency 2015), hence for most of the renewable energies as hydro and wind. This means that with increasing renewable energy penetration, the efficiency increases and less primary energy is needed to produce the same amount of electricity. Another factor that improves overall efficiency is the shift towards more efficient power plants, e.g. by shifting from coal to natural gas or by building more efficient coal power plants. Consequently, China and the EU mainly increase their efficiency due to a higher share in renewable energies. The US increased its efficiency despite a decreased renewable energy share due to a shift towards natural gas power plants. India's overall efficiency decreased because on the one hand its share in renewable energies decreased and on the other hand, its conventional energy mix shifted towards coal power plants.

Table 4: Overview of key values for the electricity sector of the four countries for the decomposition analysis

Year	1990						
Country	**GDP (billion 2005 US$)**	**POP (milion)**	**CO2 (Mt CO2)**	**Conv. energy (Mtoe)**	**primary energy (Mtoe)**	**Electricity output**	**Share RES (energy input)**
China	1,500	1,140	550	145,000	156,000	53,000	7%
USA	8,200	250	1,900	676,000	750,000	293,000	10%
EU	9,700	480	1,400	588,000	620,000	267,000	5%
India	1,400	870	240	66,000	72,000	25,000	9%

Year	2012						
Country	**GDP (billion 2005 US$)**	**POP (milion)**	**CO2 (Mt CO2)**	**Conv. energy (Mtoe)**	**primary energy (Mtoe)**	**Electricity output**	**Share RES (energy input)**
China	13,000	1,350	3,620	964,000	1,059,000	429,000	9%
USA	14,200	310	2,100	831,000	894,000	398,000	7%
EU	14,200	510	1,300	582,000	685,000	348,000	15%
India	5,600	1,240	1,040	287,000	311,000	97,000	8%

In terms of climate change policies, one can see that polices can have a significant influence on CO_2 emission changes. One common motivation in all four countries is the security of energy, resulting in energy conservation and efficiency policies. As with these legislations energy security and monetary savings are combined, they are usually effective and therefore also contribute significantly to emission reductions (CO_2 emissions were mitigated due to the energy intensity). Evidently, other factors as technological learning and scaling up also play a role in energy intensity improvements. Policies on renewable energies were promoted extensively in the EU, China, and India while the US focused on the promotion of secondary conventional fuels (shale gas). In the EU mostly normative policies (as standards and fixed targets) have been introduced as Member States are responsible by what means directives are translated into national law. The EU ETS falls under economic instruments, which incentivises firms to invest into cleaner production technologies given that the emission price is high enough. Another policy instrument in the EU is communication, with which consumer behaviour is supposed to be influenced. China used many economic policy instruments in form of tax releases and feed-in tariffs in order to promote renewable energies. An energy label (communication instrument) and several regulations and standards (normative instruments) were introduced to promote a higher energy conservation. The US mainly used economic instruments (subsidy schemes, tax incentives) to improve its energy efficiency. Many policies concerning renewable energies are limited to research and development. India set several standards to promote the conservation of energy and energy efficiency (normative instrument) as well as it introduced a trading market for energy efficiency certificates in the eight most energy-intense industries. Renewable energies are promoted mainly by means of subsidies and feed-in tariffs (both economic instruments). Concluding, one can see that renewable energies and a cleaner conventional energy mix can be promoted by introducing policies. Policies on population and GDP are usually not subject to climate change policies. Except for China's one-child policy, no country implemented policies on population growth. Policies on GDP are usually meant to increase economic growth, and hence tend to increase CO_2 emissions.

It can be concluded that the four countries had different perspectives on climate change policies, which consequently led to different implementations and effectiveness of policies. While the US strongly focused on the expansion of secondary fossil fuels, the other three countries implemented more renewable energy policies. Nonetheless, CO_2 mitigations in the EU due to the emission factor are in the same order of magnitude as those in the US (with comparable total CO_2 emissions and energy use). For the energy mix, it can be indicated that China and the EU implemented most effective policies to increase renewable energies. While the EU increased the share of RES, China increased its absolute values in renewable energies significantly. India made some efforts to implement policies that support renewable energies but neither in the decomposition analysis nor in absolute values can a significant change be seen. The US did not show major improvements in increasing RES as its climate change policy did not focus on this. The outcome of the decomposition analysis indicates that China's policies on energy intensity were most effective, however, taking into account that emerging industry's potential to increase energy intensity is much larger and therefore easier to implement, it is difficult to say which country implemented the most effective policies on this.

The other important factor that contributes to emission changes are not policies but changes in the economy. In this decomposition analysis, the effects of the fall of the Soviet Union (for the EU) and the aftermath of the financial crisis in 2008 (for all four countries) are reflected. For the latter event, it can be concluded that emissions mainly decreased due to a fall in economic purchasing power, thus lower CO_2 emissions due to the per capita GDP (while the energy intensity led to lower reductions in CO_2 emissions as the efficiency decreases with a lower load (Ummels 2009)). This can be underlined by looking at the decomposition analysis of the EU between 2004 to 2008 and 2008 to 2012. Before the financial crisis, CO_2 emissions are mitigated by 443 Mt CO_2 due to the energy intensity, and increase by 321 Mt CO_2 due to the per capita GDP. After the financial crisis, the energy intensity contributed to 194 Mt CO_2 reductions, while the per capita GDP contributed to a decrease of 89 Mt CO_2 emissions. When referring back to the RCP2.6 that was stated to be the only emission reduction pathway that is likely to limit global warming to 1.5 °C, it becomes clear that it will be difficult to reach that target with the efforts currently made by the four countries particularly as the financial crisis had such a significant impact on CO_2 emission reductions. It has been shown that the energy intensity is an important factor that offsets (part of) the CO_2 emissions connected to the per capita GDP. However, in order to offset the CO_2 emission increases due to population and economic growth (which are in the current system unavoidable and wanted), CO_2 emission reductions due to the energy intensity and efficiency improvements need to be maintained and enforced as well as a change in the energy mix towards renewable energies and a cleaner conventional energy mix need to occur. The alternative to decrease CO_2 emissions by means of the per capita GDP would require a fundamental change of the current system.

5 Discussion

In the discussion, the contributions to the CAT and data quality are discussed, as well as a link to existing research and recommendations on further research are given.

5.1 Contribution to Climate Action Tracker

One can see that the factors contributing the most to CO_2 emission changes are the per capita GDP (GDP/POP) and the energy intensity (E/GDP) in the macro-economy as well as the electrification of society (EL/POP) and electric efficiency (primary E/EL) in the electricity sector. This follows that these factors are particularly valuable to be used as indicators to monitor CO_2 emission changes. These factors give a good approximation over the dynamics on technological improvement (energy intensity and electric efficiency) and on societal consumption (GDP/POP and EL/POP). It needs to be stressed, however, that GDP is an economic approximation that is calculated in monetary terms, hence its explanatory power is limited. Further, the electric efficiency is rather difficult to be used as an indicator as it can compromise either an improvement in power plant efficiencies or a higher integration of renewable energies. In the Climate Action Tracker (CAT) these indicators are included except for the electric efficiency factor.

Renewable energies and a change in the conventional energy mix did not contribute significantly to CO_2 emission changes compared to other factors in the specified period. As this, however, can change in the future it is nonetheless of importance to include such indicators. In the CAT, indicators concerning the share of fossil fuels, coal, and electricity for the macro-economy and the share of renewables for the electricity sector have been included. This corresponds to the factors used in this thesis, however, to get a better insight into how far the conventional energy mix changed, it would be of interest to include the indicator that concerns emissions per conventional energy (EF). Furthermore, the electricity sector includes the indicator CO_2/kWh in the CAT, which needs to be monitored with attention as a change in this indicator can either mean a change in the renewable energy share or a change in the conventional energy mix. As the share in renewables is also monitored, it should be considered whether the $CO_2/kWh_{(conventional\ and\ renewable\ energy)}$ indicator is changed to $CO_2/kWh_{(conventional\ energy)}$.

Furthermore, population itself is not monitored as an indicator in the CAT. This, however, can have a significant impact on CO_2 emission changes as the decomposition analysis for the United States showed. Especially with the softening of the one-child policy in China this might get even more important. The decomposition analysis tool that was compiled in this master thesis can be adjusted and used to visualise driving factors in projected CO_2 emission reduction pathways that are an essential part of the CAT.

5.2 Data quality and method reflection

The main data source that was used on a macro-economic and electricity sector level is taken from the IEA World Key Statistics 2015 (International Energy Agency 2015). This database is built up comprehensively and many definitions exist clarifying the meaning of values. As with every database, the values do not reflect the real world as assumptions always have to be made to collect and structure data from different countries and sources. However, it offers the opportunity to use harmonized data that is available for many countries, categories, and energy types. The database that was mainly used for the sectoral approach for the EU is the ODYSSEE database (Enerdata 2015a). While this database offers to gather more specific data for different sectors for the EU, it bears several disadvantages. First of all, it aggregates data from the 28 Member States on EU level, meaning that many assumptions had to be taken as for several categories data is only available for a few Member States. Secondly, data from Member States can be very heterogeneous but are aggregated on EU level. Lastly, there is little information on how data is collected, what data exactly the different categories compromise, and which assumption were taken.

The LMDI I approach that was used for the decomposition analysis is widely accepted and used as well as it was continuously improved to match emission change studies. The logarithmic mean that is used in the method has the advantage to pass the time-reversal test that ensures that the same result is obtained no matter whether it is measured forward or backward in time. It, however, the disadvantage is that the magnitude of emission changes of specific factors depend on the ratio of the value for the start and the end year, which will only be the same at random. Consequently, the CO_2 emissions of specific factors for different time periods cannot be added up to equal the CO_2 emissions changes of that factor for the overall time period. The sum of all factors over a specific time period, however, can still be added up to match the sum of all factors over the overall time period. The decomposition factor equations are true by definition as well as the factors are assumed to be independent from each other (European Environment Agency 2012), which requires results to be correctly interpreted. The Eco-Design policy in the EU, for example, targets energy-consuming products to be more energy efficient. Taking the residential sector as an example, electricity consumption should decrease if the policy is effective. Despite not taking the rebound effect into account (the phenomena that energy savings are less than expected due to energy efficiency measures as the usage of that product increases (Gillingham et al. 2015)), a shift from coal towards electricity for heating is also a good mitigation measure to decrease the emission factor of the conventional energy mix. Consequently, a decrease in electricity could either mean the effective implementation of the policy or a more polluting conventional energy mix. Therefore, more data than the sole outcome of the decomposition analysis is needed to correctly interpret the results. Furthermore, for some events as the financial crisis, policy effects are not visible in the decomposition analysis as the economic event has a much greater influence on the CO_2 emission changes, which can be detected for most of the policies after 2008. Consequently, a decomposition analysis can always only be a good start to either visualise emission changes or to point at interesting factors that should be looked into in more detail.

5.3 Implication on existing and further research

The thesis adds to already existing research by forming a basis to compare the four countries with each other on both the macro-economic and electricity sector. It further gives insights into sectoral CO_2 emission changes of the EU, which gave more argumentation power on why CO_2 emissions changed. While a study for the EU found that the emission factor in the power sector (here: emitted gas/consumed energy) between 2001 and 2010 contributed to an increase in CO_2 emissions (Fernández González et al. 2014), both the energy mix and the emission factor of this thesis display a mitigation of CO_2 emissions. The results of the decomposition analysis for the EU between 1990 and 2012 by the European Environment Agency (2012) are in line with this thesis. While the study has detailed data on each Member State, this thesis looks more in depth into decomposition analyses for the respective sectors. The outcome of the decomposition analysis in China is in line with the study conducted by Wang et al. (2005), which showed that the CO_2 emission increase was mitigated to a certain extent by the energy intensity, renewable energies, and a shift towards a cleaner conventional energy mix between 1957 and 2000. The outcome of the thesis showed that also between 2000 and 2012 this trend can be seen. A study for the US before the time period of this thesis (1973-1991) revealed that the improved energy intensity almost offset the CO_2 emission increases due to a higher productivity and energy consumption (Golove & Schipper 1997). This thesis shows that in the time period 1990 – 2012 this effect was even reinforced. A decomposition analysis in India between 1980 and 1996 showed that economic growth was the major factor contributing to CO_2 emission increases (Paul & Bhattacharya 2004), which is in line with the outcome in this thesis. Next to examining a more recent time period, this thesis contributed towards comparing the outcome of the decomposition analysis of two developed and two developing countries. Due to the compilation of a dynamic Excel sheet it is further very easy to add all the countries covered by the IEA database to the decomposition analysis for both the macro-economy and the electricity sector.

Recommendations on further research are the extension towards other countries to have a more extensive comparison of factors that contribute to CO_2 emission changes. Other emissions than CO_2 should also be considered in more depth in further research as well as the analysis should be extended to a sectoral approach where possible. However, due to data availability constraints, and language barriers this does not seem very realistic. It has been seen that it was difficult to relate certain factors to reasons that drive its behaviour, for example in the chemical sector it was difficult to disentangle structural effects from policy influences. With further research on more specific chemical sub-sectors and on the structural evolution of industrial sectors, this could be explained in more detail. The research should further be extended to other industrial sub-sectors (as pulp and paper) as for now the increase in renewable energies in industry could not have been explained by means of the three sub-sectors. Finally, the thesis only concentrates on CO_2 emissions, which makes up a large part of energy-related GHG emissions, however, as other GHG emissions have a larger impact in the atmosphere caused by a higher global warming potential (EPA 2016), these should not completely be ignored and integrated in further research.

6 Conclusions

The thesis sought to find major drivers that are responsible for CO_2 emission changes as well as it links these drivers to policies that contributed to CO_2 emission reductions.

For the given time period and the countries that were subject of this thesis it can be said that for the macro-economy the per capita GDP was the major factor leading to an increase in CO_2 emissions and the energy intensity the major factor leading to a decrease in CO_2 emissions. For the electricity sector, the increase in electricity consumption was the major factor contributing to increasing CO_2 emissions (only for the US the population growth contributed more to emission increases than the electricity consumption), while the electric efficiency was the major factor contributing to a decrease in CO_2 emissions (only in India this factor led to increasing CO_2 emissions). While countries try to sustain their population and GDP growth, one can conclude that it is important to keep an emphasis on the improvement of energy intensity and efficiency on the one hand and to increase the focus on implementing a cleaner energy mix (more renewable energies and cleaner conventional fuels) in order to balance out emission increases due to population, per capita GDP, and electricity consumption. It also points at the difficulties to reach the 1.5 °C target in the current system that aims at continuously increasing economic growth.

Policies influencing CO_2 emission changes were often motivated by taking economic opportunities rather than climate change concerns. While the population and the per capita GDP were not subject of climate change policies, the energy intensity and efficiency improvements in power plants are a major part contributing to CO_2 mitigations as it increases productivity and secures energy supply. The share of renewable energies is highly dependent on policy regimes and usually set by the government in form of a target and supported by means of economic incentives. It can be seen that in the EU this target has almost been achieved and also China's economic incentives increased renewable energies significantly in absolute numbers. This is similar to the emission factor, however, what kind of conventional energy dominates the market also depends on national reserves, energy prices, economic changes, and natural disasters as the Fukushima Daiichi nuclear accident (WEC 2013). The US, for example, supported the extension of shale gas in order to become more energy self-sufficient (Wang & Krupnick 2013).

Overall, it can be seen that the 'aggressive mitigation' behaviour that is needed to achieve the 1.5 °C target (IPCC 2013) lacks all countries, whereas the EU shows the best results as it decreased its CO_2 emissions. As population and per capita GDP will not directly be affected in terms of climate change policies, it is important to maintain efforts to improve the energy intensity, and to increase efforts in shifting towards more renewable energies and cleaner conventional fuels. The pattern that the energy intensity contributed to larger CO_2 emission mitigations than the per capita GDP contributed to CO_2 emission increases in the EU and the US, indicates that there is still potential in China and India to achieve the same pattern. Next to these improvements, it is important to keep in mind that a general reduction in energy consumption does not only mitigate CO_2 emissions in the per capita GDP factor but also allows the share in renewable energies to grow more easily, and hence leads to larger CO_2 emission reductions.

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