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CO_2 Emissions from Freight Transport in the EU-15 between 1995 and 2008:

main drivers and problems in accounting for the international perspective

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Abstract: The share of transport sector green house gas emissions has been increasing in the EU-15 in the recent decades. Moreover, the development in passenger and freight transport subsectors has diverged. This thesis provides drivers of freight transport carbon emissions in the EU-15 between 1995 and 2008 by conducting Log Mean Divisia Index (LMDI) decomposition. It differentiates between structure, intensity and economic growth effects. The traditional LMDI analysis suggests that economic growth was the sole driver of increases in freight transport carbon emissions. However, the thesis points to inconsistencies in the existing literature when considering the international transport and trade growth. Incorporating the international dimension, economic growth stays coupled with freight transport carbon emissions. However, decreases in energy intensity point at relative decoupling between freight transport fuel consumption and economic growth. This fact suggests that reduced energy intensity slowed down increases in freight transport carbon emissions.

Keywords: freight transport, carbon emissions, decoupling, trade, EU

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Contents

1 Introduction

Transportation is a derived demand that facilitates growth of economies and mobility of people. Despite its supplementary role, transport Greenhouse Gas Emissions (GHG) accounted for around 22% of total GHG in 2009 in the EU-15[1] (Eurostat, 2012a). In turn, carbon dioxide (CO2) composed a major environmental threat of the transport sector, constituting over 98% of total transport GHG emissions in the EU in 2009 (EC, 2011). It is important to note that total transport sector is heterogeneous. A major fact observed in recent decades is the convergence between trends in passenger and freight transport emissions (ECMT, 2007). Freight transport in particularly is related to the economic growth and therefore very difficult to target without affecting the economic performance. Moreover, increases in trade volumes have encouraged growth in international freight transport which is neglected by national environmental policies. This emphasises the need to analyse the passenger and freight transport subsectors separately.

Reduction of freight transport carbon emissions requires identifying the underlying drivers of this pollution. Thus firstly, this thesis aims at illustrating the development of carbon emissions from freight transport in the EU-15 region. Besides descriptive statistics, Logarithmic Mean Divisia Index (LMDI) decomposition is applied on the EU-15 and 10 member countries between 1995 and 2008. Carbon intensity of fuels, freight transport sector energy intensity, the structure of the sector in terms of fuel and modal mix as well as total economic activity are considered as potential drivers. Secondly, the paper attempts to provide a full picture of freight transport sector by including international maritime and air transport. In relation, problems with GDP as a measure of economic activity are discussed. Finally, an improved measure is suggested to account for international trade.

This thesis is structured as follows. Section 2 provides background on freight transport sector in the EU-15 while section 3 presents previous research on the subject. Section 4 describes the methodological approach and data on the selected variables. The LMDI decomposition results and their reliability are discussed in section 5. Section 6 argues that the traditional LMDI decomposition does not include a systematic approach towards trade and suggests an extension to the method. Main conclusions are made in section 7.

2 Background to freight transport sector

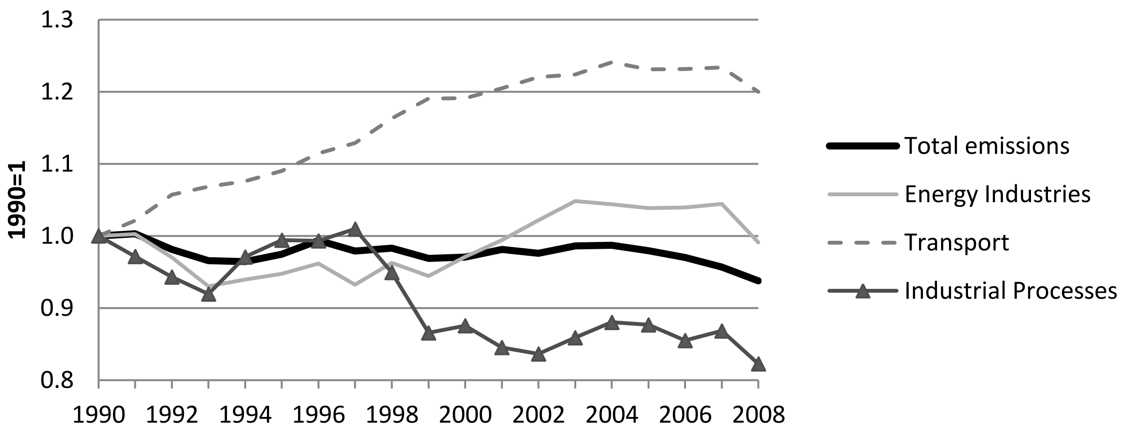
In general, increased economic activity leads to higher demand for industries and transport which, everything else equal in the sector characteristics, generates more GHG emissions. A theory of en-

[1] Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

vironmental Kuznets curve predicts that richer developed countries are expected to reduce this relationship between economic growth and GHG emissions through reduced energy intensity (Ansuategi and Escapa, 2001). However, most of empirical studies have found an ever-increasing curve of GHG emissions globally and regionally (Ansuategi and Escapa, 2001; Lane, 2011).

Transport sector is crucial for environmental studies due to its growing contribution to overall GHG emissions. Power generation, industry and transport sectors have been the main polluters in the EU-15 since 1990, representing 57% of total GHG in 2009 (Eurostat, 2012a). However, as Graph 1 illustrates, transportation GHG emissions have been increasing while the other two sectors and the total economy have achieved a decrease. There are a few explanations to the increase in transport emissions as opposed to the other major sectors.

Graph 1. Change in Greenhouse Gas Emissions from the three most polluting sectors in the EU-15 (1990=1), in comparison to total emissions, 1990-2008



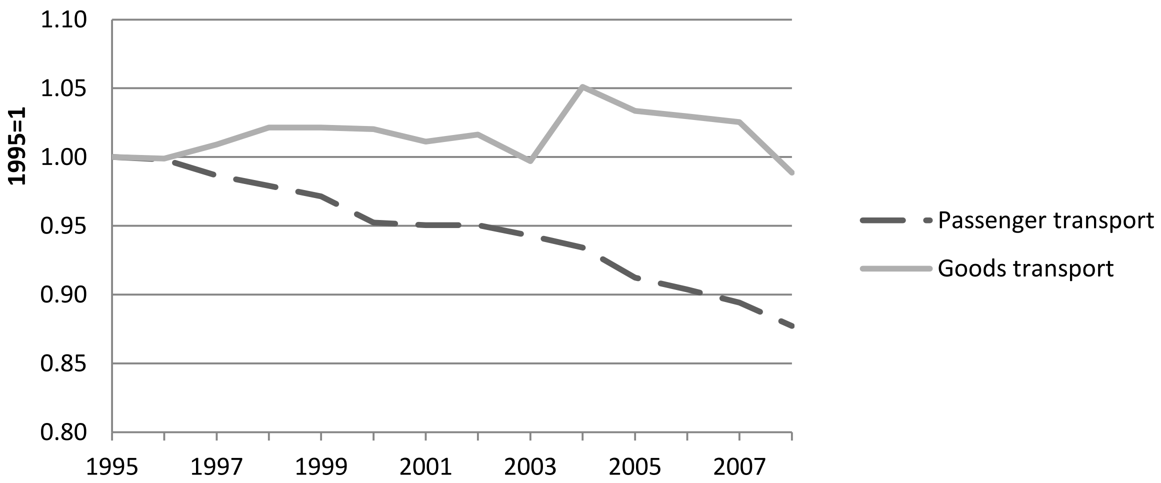
Source: Eurostat (2012a)
GHG emissions measured in million tonnes of CO2 equivalent.
Transport sector excludes international bunkers

Firstly, direct demand is easier to target by policies than transport (Schipper et.al, 2000). As opposed to industry and energy sector, it is difficult to identify the polluters in the transport sector. Moreover, international transport carbon emission targeting is held back by difficulties to identify the emitting country. *Inland freight transport modes* (road, rail and inland water ways) are rather well documented and comparable across countries. *International freight transport modes* (aviation and maritime) are reported by countries but not included in national fuel consumption under the Kyoto protocol (ECMT, 2007). They are treated under international conventions which do not allow taxing their consumption of fuel (Timilsina and Shrestha, 2009). National regulations and strategies are therefore ineffective against increases in energy consumption of international transport modes.

Secondly, there is a lack of alternative technologies in the transport sector. The transportation sector has developed a dependency on internal combustion engine and oil, while energy production and industry sectors have a more flexible technology to shift to renewable energy sources. This shift is mainly enabled by changes in the primary energy sources for electricity production.

Finally, it is important to note the difference between goods and passenger transport performance. Graph 2 illustrates the growth of the two subsectors compared to GDP. While growth in passenger transportation has been weaker than the GDP growth, the contrary is true for the goods transport. Thus the passenger transport has been relatively decoupled[2] from GDP while goods transport experienced a stronger relative coupling.[3] In a more formal study, Tapio (2005) observes the same trend on decoupling in the EU-15 since the 1990's.

Graph 2. Growth in the EU-15 passenger and goods transport volume relative to GDP (1995=1), 1995-2008



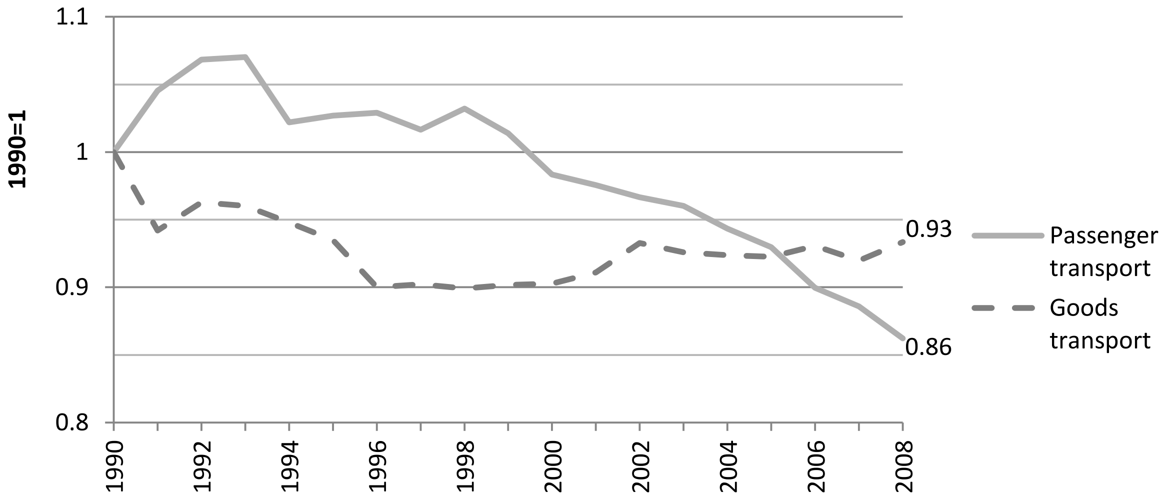
Source: Eurostat (2012b)
Passenger transport includes personal transportation.
Calculations based on inland transport modes: tonne-kilometres and passenger-kilometres.

A similar convergence is detected when considering transport pollution. Graph 3 demonstrates changes in volumes of CO2 emissions from passenger and goods transport in the EU-15. Despite an initial increase in personal transport carbon emissions from 1990 to 1993, the sub-sector showed a rather smooth decline in carbon intensity. Passenger transport carbon intensity decreased by 14% from 1990 to 2008. Besides a large decrease over the first 5 years, freight transport unit emissions

[2] Relatively decoupled in this thesis is used for decoupling in growth terms.
[3] Different passenger and freight transport linkages to the GDP complicate somewhat the comparison in Graph 2. The graph includes personal cars, which constituted over 83% of passenger transport volume in the EU in 2008. However, GDP includes value added of commercial transportation sector but not personal transportation. Thus freight transport sector is expected to affect GDP while passenger transport has a smaller influence on the measure.

have stayed rather constant during the period with a total decrease of only 7%. Thus the recent trend in carbon emissions of freight transport has been less positive than for passenger transport.

Graph 3. Change in weighted energy intensity of passenger and goods transport in the EU-15 (1990=1), 1990-2008



Source: Weighted average on the basis of the existent data at Odyssee (2012) energy database.
Passenger transport: CO2 emissions per passenger-km; goods transport: CO2 emissions per tonne-km.

The diverging pattern between freight and passenger transport can be explained by several factors. Renewing freight transport equipment requires larger investments. Moreover, labour and capital savings are prioritised in firms as opposed to transport costs that usually constitute a small share of total operating costs (Greening et. al, 1999). Moreover, freight transport is directly affected by trade flows. Trade is an outcome of internalisation processes as multinational companies are expanding and become increasingly dependent on trade of inputs and final products (Lakshmanan and Han, 1996). Furthermore, trade is expected to be especially stimulated by deeper EU integration, such as creation of the Single Market, Euro area as well as recent enlargements (Flam, 2009). As a result, trade of the EU-15 countries (in constant prices) increased on average by 6% annually between 1995 and 2008 compared to barely 2% annual change in GDP (Eurostat, 2012f).

3 Previous research

Decomposition studies on industrial energy demand and methodology of measuring it stretch back several decades. The main idea of the decomposition methods is to extend an energy identity by observing production processes, such as structural, intensity or size changes, which are correlated to the decomposed variable. The decomposition methods traditionally performed a shift-share analysis that mainly aimed at singling out structural change in the economy or its sectors by comparing the base year energy intensity to target energy intensity in a future period (Ang and Zhang, 2000). An equivalent technique was used to separate the intensity and size effects. In mid 1980's, more advanced decomposition methods were proposed that added sector weights and new driving factors (Ang and Zhang, 2000). The developed methodology also attracted studies focusing on individual sectors of economy as well as the environmental aspect of energy demand. Despite this trend, studies on freight transport have been rare. Ang and Zhang (2000) review 124 decomposition studies in industrial energy demand and environmental economics and find four studies on transportation. Even in the recent period, most studies on transport do not differentiate between passenger and freight transport or they focus on a single transport mode.

In a greatly cited study, Schipper et. al (1997) consider energy consumption and CO2 emissions of goods transport in 10 OECD countries between 1973 and 1992. The authors use Laspeyres decomposition to disentangle increases in the analysed measures into provided freight services, fuel and modal mix as well as energy intensity. Schipper et. al find a close positive connection between energy consumption and freight activity. Modal shift toward road transport is also a significant driver of increased energy consumption. The authors identify mixed trends in energy intensities with decreases only in 5 countries. Schipper et. al conclude that increased goods transport energy consumption directly affects growth of CO2 emissions in the subsector.

Greening et. al (1999) decompose aggregate carbon intensity from freight in the same 10 OECD countries for time period of 1971-1993. They analyse emission coefficient (i.e. fuel carbon intensity), fuel and modal mix as well as energy intensity of the freight transport sector. Greening et. al apply Adaptive Weighting Divisia Index (AWDI) decomposition which uses a rolling-base year technique to construct a weight on the entire analysed period and not only the benchmark years. The authors compare their results to Schipper et. al (1997) where Laspeyres decomposition method was used for freight transport in the same OECD countries. Due to accumulated information in a rolling-base year technique, the residual is significantly reduced in Greening et. al. The same methodological advantage of AWDI decomposition allows considering intra-period changes of variables in their final effect. This leads to large differences in the magnitudes of carbon emission drivers. The main sources of increases in carbon emissions however are still the shift in modal mix and the general economic activity. For most of the countries, energy intensity of the transport sector was decreasing less than in Schipper el. al due to a stronger modal shift towards carbon-intensive modes.

Even though the rolling-base year technique has some theoretical advantages compared to Laspeyres index, the comparison should be taken with caution. Firstly, Schipper el. al (1997) decompose aggregate carbon emissions from freight transport while Greening et. al (1999) analyse carbon intensity. Secondly, Schipper el. al consider changes from 1973 while Greening et. al use year 1971 as a benchmark. This complicates the comparison of the different magnitudes.

In addition, Greening et. al (1999) investigate price effects on freight transport emissions but find a very small impact. Economic growth, geographic location and other underlying factors primarily stand for the increases in freight transport demand. This result confirms the generally accepted view on transport as a derived demand that has very low price elasticities (Schipper et. al, 2000). Moreover, if the decomposition analysis is conducted in constant prices, the prices can be disregarded. In that case, the decomposition analyses only volume effects.

Lakshmanan and Han (1997) compare freight and passenger CO2 emissions in the US for the period between 1970 and 1991. The authors decompose the measures into mode energy intensity, modal mix, energy intensity of transport sector and GDP by Divisia index decomposition with time weights on each variable. Lakshmanan and Han (1997) find that GDP is the main source of increased CO2 emissions in passenger and freight subsectors. An important factor specific for freight transport is modal shift toward more carbon intensive modes. Mode and transport sector energy intensities were slowing down the growth of CO2 emissions, especially since 1980. Lakshmanan and Han (1997) conclude that freight transport is responsible for around 60% of the total transport CO2 emission growth between 1970 and 1991 compared to 40% caused by passenger transport. This was mainly due to relatively low energy intensity decreases in freight transport as the modal shift occurred.

The mentioned studies conduct CO2 analysis for the time period from the 1970's to the mid 1990's. This period was strongly affected by oil price shocks that led to significant substituting away from fossil fuels. Moreover, the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992 in order to initiate an international agreement on emission cuts, which in turn led to binding constraints of the Kyoto Protocol in 2005 and adjustment of national policies, such as EU targets for 2020 (ECMT, 2008). Thus the environmental policies are expected to play a bigger role since the 1990's, even though one might question whether they have had any noticeable effect.

Timilsina and Shrestha (2009) analyse the total transport sector in 12 selected Asian economies from 1980 to 2005. They decompose CO2 emissions into six factors: fuel and modal shift, change in emission coefficients, changes in sectoral energy intensity as well as per capita GDP and population growth. The authors conduct a Log-Mean Divisia Index (LMDI) decomposition which is seen as superior to previously described methods due to a zero residual. The authors do not explicitly differentiate between goods and passenger transport but are cited here due to their methodology. Timilsina and Shrestha find that GDP per cap and population growth were the most pronounced drivers of increases in carbon emissions. Some countries experienced an increase in energy intensities while in others carbon emission growth slowed down because of improvements in transport energy intensity.

Kveiborg and Fosgerau (2007) apply a micro-perspective on the freight transport. They use national accounts and transport survey data on Danish national road freight traffic from 1981 to 1992. They conduct a Divisia index decomposition method to decompose road freight traffic growth to total production weight by commodity group, trip length and energy intensity. In general terms, the authors follow Lakshmanan and Han (1997) approach but extend the aggregate energy intensity measure into weight to value ratios, average load and commodity handling (tons lifted in road transport divided by the weight of total production). The study finds that transport service growth coupled with increases in production weight (i.e. economic growth) while structural change toward less transport-intensive sectors and more efficient handling (i.e. energy intensity) have reduced the growth somewhat. Even though the study is thorough and applies a micro-perspective, it has a disadvantage of only considering one mode of transport. The study thus should be seen as an example of a data-intensive approach rather than a direct comparison to the previously described research.

4 Methodology and data

This section motivates the choice of the Logarithmic Mean Divisia Index (LMDI) methodology and discusses the considered driving factors of carbon emissions from freight transport in the EU-15. The choice of variables was partially influenced by data availability and therefore the data and own estimations are explained carefully. The decomposition of freight transport carbon emissions is conducted for time period from 1995 to 2008. In order to make the analysis more complete and account for sensitivity towards benchmark years, the decomposition in section 5.2 is performed in two time periods: 1995-2002 and 2002-2008. The analysis is carried out on aggregate EU-15 as well as 10 selected member countries: Austria, Denmark, Germany, Italy, Finland, France, Netherlands, Spain, Sweden and United Kingdom (UK). The countries account for around 90% of total transport emissions in the EU-15 during the studied period (Eurostat, 2012a).

4.1 Logarithmic Mean Divisia Index decomposition

This paper follows the LMDI methodology that is suggested by Ang and Zhang (2000). The authors argue that LMDI is superior to earlier widely used Laspeyres index because it does not give a residual and is more tractable when there are more than three driving factors. LMDI is also able to solve a problem of zero values in the data by replacing them with small numbers. Ang and Zhang (2000) argue that the small numbers converge to zero values better than in other suggested decomposition methods. Moreover, LMDI allows a long-term analysis as the benchmark years can be chosen far apart and the adjustment mechanisms might be disregarded. Thus LMDI is a good tool for a general analysis on the drivers of carbon emissions. It provides background for the discussion whether the structure, intensity of the freight transport or total economic activity is responsible for increasing carbon emissions.

Nevertheless, the results should be analysed with a few criticisms in mind. By some authors, the LMDI is suggested as a superior method because it removes the residual and thus the uncertainty of the real driving variables. On the other hand, LMDI considers the choice of chosen variables as the true one and distributes the change in carbon emissions between them. By removing the residual one also removes a traditional signal of model misspecification or lack of explanatory variables. Muller (2006) compares the goal of zero residual to striving for a high R^2 value in regression analysis, which instead of consistent results might provide collinearity problems with skewed coefficients. The author argues that a residual should be expected in decomposition due to logarithmic approximations of continuous time function to fit the discrete time periods. However, Muller also admits that LMDI performs most exact from the other decomposition methods in a case of unknown function between two benchmark years.

Following articles in section 3, this thesis includes emission coefficients, modal mix, fuel mix, energy intensity and GDP[4] as hypothetical sources for freight transport CO2 emissions. Population growth, included in Timilsina and Shrestha (2009), is left out of the analysis in this paper because it is likely to have small importance for goods transport in the EU compared to total transport sector in Asia. The final decomposition applied in this thesis follows Timilsina and Shrestha (2009) and is the following:

$$\boldsymbol{CO2_t} = \sum_{ij} \frac{CO2_{ijt}}{FC_{ijt}} \times \frac{FC_{ijt}}{FC_{jt}} \times \frac{FC_{jt}}{FC_t} \times \frac{FC_t}{GDP_t} \times \boldsymbol{GDP_t} \qquad (1)$$

t: benchmark year;

[4] The tradition to include this parameter as economic activity comes from an observed close correlation between CO2 emissions and GDP as illustrated in Graph 5 on page 19. The drawbacks of the measure are discussed in section 6.

i: fuel sort;

j: transport mode (air, inland water ways (IWW), sea (maritime), rail and road)

CO2: carbon dioxide emissions from freight transport

FC: fuel consumption of freight transport

GDP: Gross Domestic Product

Equation 1 can be simplified to a more intuitive version:

$$CO2_t = \sum_{ij} EC_{ijt} \times FM_{ijt} \times MM_{jt} \times EI_t \times GDP_t \quad (2)$$

EC_{ij}: fuel emission coefficient

FM_{ij}: fuel mix of a freight transport mode

MM_j: modal mix of freight transport in terms of fuel consumption

EI: energy intensity of goods transport

Emission coefficient (carbon intensity of a fuel) and energy intensity are together called intensity effects. Fuel mix and modal mix constitute the structure of the freight transport sector while GDP represents total economic activity. Moreover, there are two important relationships that will be considered in the following sections. Decreases in energy intensity would signal relative decoupling between transport fuel consumption and economic activity. On the other hand, negative economic activity effect on CO2 emissions would point to absolute decoupling between the two variables.

The decomposition analysis is based on the following derived equation:

$$D_{TOT} = \frac{CO2_T}{CO2_0} = D_{EC} \times D_{FM} \times D_{MM} \times D_{EI} \times D_{GDP}\ , \quad (3)$$

where *T* is the year at the end of the considered time period and *0* is the base year. $D_k = exp\left[\sum_{ij} w_{ij}\, ln\frac{k_{ijT}}{k_{ij0}}\right]$, where k is the considered explanatory variable, e.g. in the case of change in emission coefficient $D_{EC} = exp\left[\sum_{ij} w_{ij}\, ln\frac{EC_{ijT}}{EC_{ij0}}\right]$, and in GDP growth: $D_{GDP} = exp\left[\sum_{ij} w_{ij}\, ln\frac{GDP_T}{GDP_0}\right]$. The weight parameter w_{ij} is the share of logarithmic mean of carbon emissions of the subsector (in terms of a transport mode or a fuel) and the total carbon emissions of goods transport sector: $w_{ij} = \frac{L(CO2_{ijt}, CO2_{ijt-1})}{L(CO2_t, CO2_{t-1})}$, where $L(a,b) = \frac{a-b}{ln\frac{a}{b}}$ for $a \neq b$ and $L(a,b) = a$ for $a = b$.

An important point to the LMDI analysis is that the decomposition provides correlation but not causation. Interaction among explanatory variables is difficult to trace from the LMDI decomposition. For instance, modal mix of the freight transport sector affects the aggregate fuel mix in the economy while economic growth might enable reductions in energy intensity. Well-motivated statements require a deeper research on the links. Therefore, this thesis focuses on establishing the correlation between the carbon emissions and considered variables and does not discuss the causation in larger detail.

4.2 Potential driving factors and data

This subsection considers theoretical and practical issues of the variables as well as it discusses expected results. Due to complexity, the descriptive statistics are mainly presented for aggregate EU-15. Table 1 summarises the data sources and variable estimation for equation 1. Raw data on the variables is provided in the Appendix 1.

This thesis studies inland as well as international freight transport modes. Data on inland transport modes is coordinated by Eurostat and is rather systematic and comparable among countries. Finding reliable data on maritime transport and aviation proved to be challenging due to its specific treatment outside the national emissions. Fuel consumption for aviation is provided by Eurostat while data on international marine bunker fuels from the same source is assigned maritime transport mode. According to the official Eurostat definition, marine bunker fuels are loaded on ships that engage in international navigation and exclude fishing and military vessels (Eurostat et. al, 2009).

The problem with assigning bunker fuels to the loading country is that the goods are aimed at being shipped to some other country. Countries with important harbours might thus be assigned too large amounts of bunker fuels. This emphasises the difference between the 'producer' and the 'consumer' of the emissions. The thesis, however, aims at providing a picture of aggregate EU-15 and the freight transport pollution, linked to the region rather than at pointing out individual countries as polluters. Maritime transport is crucial for international goods flows and therefore is included despite the possible misrepresentations in national consumption. Moreover, the decomposition analysis focuses on CO2 pollution growth and its driving factors rather than absolute measures.

The main issue with international freight transport data arose on transport performance. The initial intension was to include freight transport performance in tonne-kilometres (tkm). This is a common measure in the literature, combining weight and distance of goods moved. However, the measurement of international transport performance, especially at sea, proved to be too difficult to measure as national statistics only account for distances on national territory and no systematic information on international routes exists (REALISE, 2005). Data in tonnes could be obtained in Eurostat database only for a shorter period of time (starting in 1997). These limitations of data on transport performance influenced the decision to leave the variable out of the analysis[5].

Table 1. Data sources and estimation of variables for the LMDI decomposition in equation 1

Variable		Unit	Source	Remarks
CO2 emissions (CO2)	EU-15	Mt	TRENDS ITF Eurostat	TRENDS database does not include air freight transport. The CO2 emissions of air cargo were approximated using emissions data from ITF. Following Shipper et. al (1997), energy share of air freight transport was estimated using passenger and freight data in Eurostat.
	National		ITF Odyssee Eurostat	Data for total CO2 emissions. Following Shipper et. al (1997), freight share was estimated using data for passenger and goods transport in Odyssee and Eurostat.
Emission coefficient ($CO2_{ij}/FC_{ij}$)		kgCO2/ toe[1]	IEA	Fuel emission coefficients are assumed constant over time. Electricity emission coefficient is variable. For the EU-15, electricity emission coefficient for OECD-Europe is used.
GDP		M EUR	Eurostat	Constant prices (reference year 2000)
Passenger/freight transport performance (A)		pkm/ tkm	Eurostat Odyssee	Aviation data from Eurostat. Data for rail and road from Odyssee.
Total fuel consumption (FC)		Ktoe[1]	Eurostat	By transport mode and fuel

[1]*toe* stands for tonnes of oil equivalent.

4.2.1 Carbon emissions

Data on national CO2 emissions from total transport is extracted from International Transport Forum (ITF, 2012). This data is used to estimate freight transport share of the emissions. Maritime transport and IWW are both assumed to transport goods only. Transport and Environment Database System (TRENDS, 2012) data indicates that freight transport is responsible for over 98% of CO2 emissions in international maritime transport. Moreover, the ratio remains stable during 1970-2010. Thus freight energy consumption is only slightly overestimated by considering total carbon emissions of maritime transport. Eurostat and Odyssee databases report inland water transportation for goods. However, only seven EU-15 countries, where transport of goods exceeds a million tonnes, are obliged to report the data (Eurostat statistics explained, 2012). The rest of countries report on a voluntary basis and therefore might bias the IWW carbon emissions downwards.

[5] Moreover, transport services in tkm and tonnes are criticised for ignoring value added of the goods, time required for the shipment and the split between the weight and the distance of goods shipped. These disregarded parameters of goods are changing most significantly if a country is shifting its specialisation sector (Schipper et. al, 1997). In case of the EU-15, sector value added shares in GDP have been stable in 1995-2008 (Eurostat, 2012d). The largest change was in service sector share that increased by 4% in constant prices. However, the weight of the goods could have changed within the sectors. For instance, manufacturing goods could have become lighter, shifting from bulky goods to pharmaceuticals and electronics.

Rail, road and air transport freight share is estimated analytically as described below. The freight shares are then applied on the ITF data on total transport CO2 emissions in order to retrieve carbon emissions for each freight transport mode.

Freight share in energy consumption (*F*) of transport mode *j* is estimated following the Schipper et. al (1997) weighting procedure that is also used by Greening et. al (1999). Statistics on passenger (*p)* and freight (*f)* transport performance (*A*) are used in the following formula:

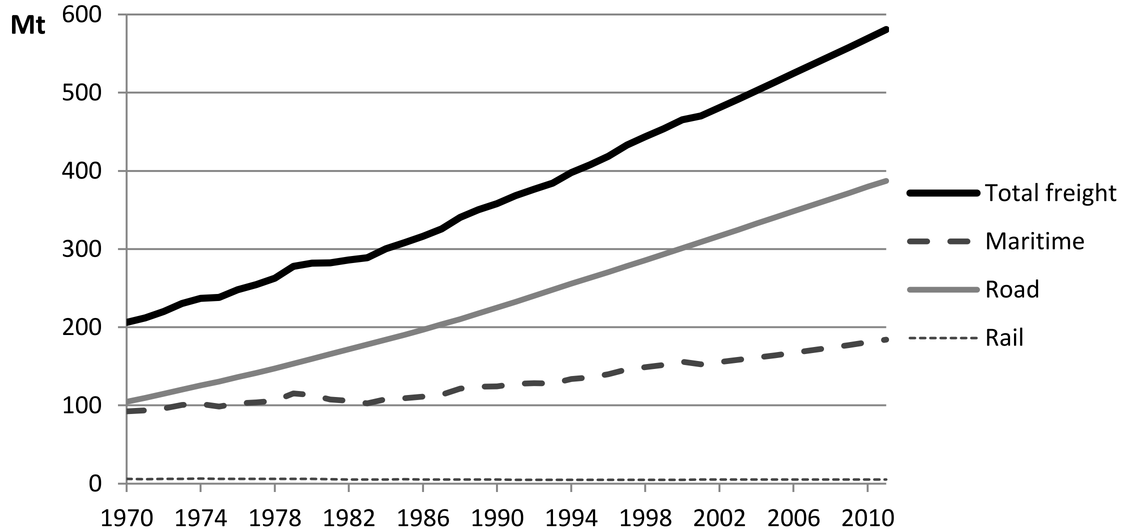
$$F_j = \frac{A_f}{A_f + w_p A_p}, \qquad (4)$$

where the weights for passenger transport w_p in road, rail and air are 1, 2 and 7 respectively. This implies that one passenger on road consumes equally much energy as one tonne of freight. On a train, one passenger consumes half the energy needed to transport a tonne of goods. Finally, an air-plane energy requirement is the same as energy requirement of 1/7=140 kg of freight. The advantage of this approach is its ability to retrieve time and country variant estimates due to variable transport performance variable *A* (Eurostat (2012c) and Odyssee (2012)). The weights are however rather arbitrary as they are constant over time and countries. Moreover, the method is constant over fuel types and therefore implies a strong assumption that freight and passenger transport possess the same fuel mix.

Aggregate EU-15 CO2 emissions from freight transport are available in TRENDS (2012) database. The source excludes air transport, however. Schipper et. al (1997) method described above is applied on total air transport services in order to calculate freight share of transport. The share is multiplied with total air transport CO2 emissions (data from ITF, 2012).

Aggregate EU-15 freight transport carbon emissions have been increasing since 1970 in absolute terms as illustrated in Graph 4. Road freight transport emissions have been growing the most during the period. Maritime transport has been the second most polluting freight transport mode thus pointing out the importance of including maritime transport in the analysis of freight transport emissions. Share of maritime transport carbon emissions has decreased from around one half in 1970 to approximately one third in 2011. Rail accounts for a marginal share of CO2 emissions. Air constitutes an even smaller share of carbon emissions. Due to lack of continuous time-series this transport mode is excluded from Graph 4.

Graph 4. Freight transport carbon emissions by transport mode in the EU-15, 1970-2011



Source: TRENDS (2012) database, excludes air freight transport

4.2.2 Emission coefficient

Everything else equal, carbon content in a fuel directly affects transport carbon emissions. Table 2 lists fuel emission coefficients in 1995, 2002 and 2008 provided by IEA (2011). Average carbon content in a certain fuel is expected to be the same over time and countries (Schipper et. al, 1997). Biodiesels might pollute atmosphere by CO2 depending on their production techniques (IPCC, p.18). Despite this possibility, biodiesel and bioethanol are assumed to have zero carbon content. The only potential cause of changes in CO2 emissions is thus primary energy sources for electricity generation.

Table 2. Fuel emission coefficients (kgCO2/toe[1]), years 1995, 2002 and 2008.

Fuel	1995	2002	2008	Fuel	Country	1995	2002	2008
Jet kerosene	2994	2994	2994	*Electricity*	OECD-Europe	4582	4222	3954
Biodiesel	0	0	0		Austria	2489	2291	2152
Bioethanol	0	0	0		Denmark	5059	3966	3547
Diesel	3102	3102	3102		Finland	2873	2931	2175
Fuel oil	3241	3241	3241		France	884	896	1012
Gasoline	2901	2901	2901		Germany	6071	5908	5129
LPG	2642	2642	2642		Italy	6338	5827	4896
					Netherlands	5396	4664	4559
					Spain	5268	5047	3803
					Sweden	582	605	465
					UK	6152	5350	5699

Source: IEA (2011)
[1]*toe* stands for tonnes of oil equivalent.

Electricity carbon coefficient varies over time and countries, depending on the access to renewable energy sources and historical energy production. Table 3 presents shares of primary energy sources in the electricity supply in the considered countries year 2008. On the one hand, Austria and Sweden are examples of large resources of renewable hydro power. Moreover, Sweden and France have invested in carbon-neutral nuclear power. On the other hand, at least 70% of electricity in Denmark, Italy, Germany, Netherlands, Spain and UK is produced by conventional heating which is very carbon intensive. UK, Germany and to some extent Netherlands historically have had easy access to fossil fuels which illustrates the existing path dependence on fuels due to changes in infrastructure required.

Table 3. Shares of primary energy sources in total energy supply in 10 the EU-15 member countries in 2008.

Country	Hydro	Geothermal	Nuclear	Conventional thermal
Austria	0.68	0	0	0.32
Denmark	0.19	0	0	0.81
Finland	0.22	0	0.29	0.48
France	0.13	0	0.76	0.11
Germany	0.04	0	0.26	0.70
Italy	0.16	0.02	0	0.82
Netherlands	0.04	0	0.04	0.92
Spain	0.17	0	0.20	0.63
Sweden	0.47	0	0.43	0.10
UK	0.04	0	0.13	0.82

Source: Own calculations from Eurostat (2012e) data on electricity supply

A surprising fact emerges when comparing carbon intensity of electricity to other fuels in Table 2. Fuel oil is the most carbon intensive direct fuel with carbon emissions of approximately 3241 kgCO2/toe. In 2008, however, the electricity carbon emission coefficient exceeded fuel oil in all the countries that depend on conventional thermal electricity production (Denmark, Italy, Germany, Netherlands, Spain and UK). Electricity has the advantage of flexibility in primary energy sources. This enables less costly reduction in its carbon content and justifies electrification from environmental perspective. However, the comparison of emission coefficients of fuel oil and electricity emphasises the importance of critical investigation of primary energy sources. Electricity is not yet the generally most carbon efficient fuel.

Reasonably estimating carbon content of electricity in the EU-15 requires detailed data on electricity production. As electricity is only used by railway mode, which constitutes a small share of total energy use, average Euro-OECD emission coefficient of electricity production is used for the purpose of this thesis.

4.2.3 Fuel mix

Estimating fuel mix for goods transport requires detailed data for each transport mode. In absence of the exact data, some approximations and assumptions are required. In air transport, jet fuels amount to 99% of its energy consumption (Eurostat, 2012e). An approximation is therefore made that freight air transport is powered solely by aviation fuel. The same approximation is made in other modes of transportation where only the major fuels, constituting at least over 95% of total energy consumption of the considered mode, are taken into account. Freight fuel consumption in rail, road and air transport is retrieved by multiplying freight shares of a transport mode in equation 4 by total modal fuel consumption data from Eurostat (2012e). The estimates are further compared to data on rail and road freight shares, provided by Odyssee (2012). The level and development of the freight share is similar to the estimated freight shares thus the results are evaluated as reasonable.

A final methodological note is that freight transport fuel consumption data is used to estimate CO2 emissions from each transport mode and fuel type ($CO2_{ijt}$) by multiplying fuel emission coefficient by the fuel consumption of each transport mode ($EC_{ijt} \times FC_{ijt}$). The retrieved values surprisingly precisely sum up to the total CO2 emissions for each transport mode ($CO2_{jt}$), which confirms the suitability of the method.

A scheme on the common fuels in each mode is presented in Figure 1. The largest fuel variety exists in road transport. Presumably the variety is affected by relatively lower investment costs of changing the vehicle and its fuel system. This fact is promising when considering that road transport occupies the largest share of freight transport carbon emissions in Europe (see Graph 4 on page 14).

Figure 1. Freight transport modes and the most commonly used fuels that are considered in the LMDI decomposition analysis

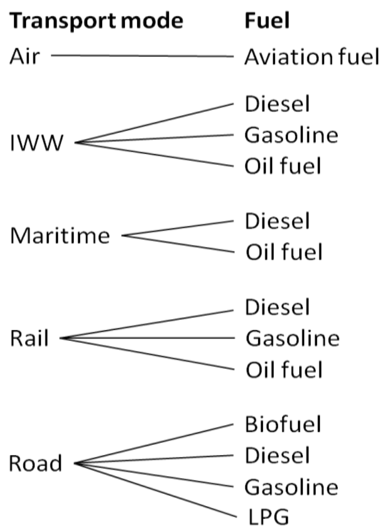
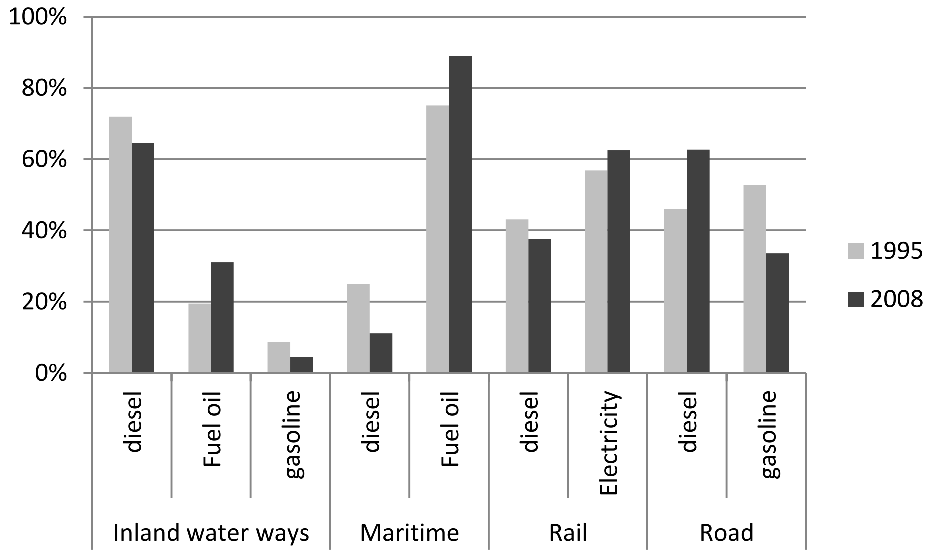


Figure 2 presents the estimates of freight transport fuel mix. It illustrates that the main shift in road freight transport occurred from gasoline to diesel. Timilsina and Shrestha (2009) observe the same pattern in several Asian countries. They argue that even though diesel has larger carbon content, it is used in smaller quantities and therefore the shift should not have any significant effects on total carbon emissions. Another significant shift in Figure 2 is rail electrification that is likely to reduce carbon emissions as electricity carbon content is rapidly declining (see Table 2 on page 14). For the time being, however, electricity is still the most carbon-intensive fuel in 6 out of 10 analysed countries. Furthermore, fuel oil has increased significantly in water transport which is expected to dampen any positive effect of electrification.

Figure 2. Fuel mix in freight transport modes in the EU-15, years 1995 and 2008, major fuels



Source: see section 4.2.3.
Fuels that constitute less than 5% of total mode energy consumption are excluded (includes fuel oil in rail transport; biodiesel, bioethanol and LPG in road transport). Aviation uses 100% jet fuel.

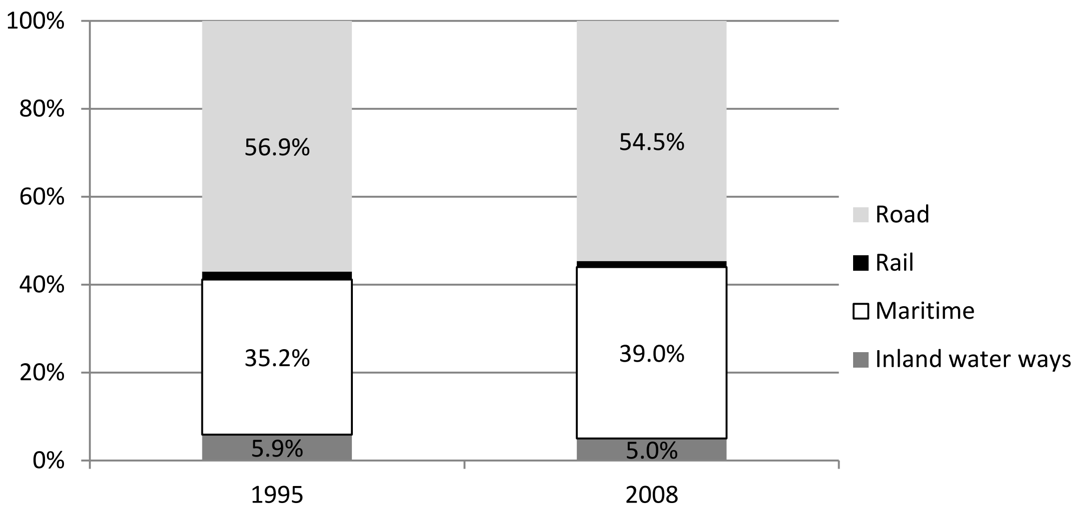
4.2.4 Modal mix

A shift to less carbon-emitting transport modes provides another alternative to reducing freight transport CO2 emissions. Road transport is the most carbon intensive inland transport mode in the EU, followed by IWW and rail (ECMT, 2007). Estimating carbon intensity in international transport modes is a more difficult task. In general terms, maritime transport is even less carbon intensive than rail while aviation is at the other extreme, being the least energy efficient freight transport mode (ECMT, 2007)[6].

[6] The picture is rather different for passenger aviation. Transport costs in passenger aviation make up to 20% of total operational costs which has pushed the largest passenger planes to the same intensity as small passenger cars by year 2000 (ITF, 2008).

Studies that analyse total economy energy demands use value added statistics of each subsector in order to observe structural changes within the economy. Equivalent approach in this thesis would require value added statistics for each transport mode which is difficult to obtain, especially for international transport modes. This problem is solved by calculating the modal shift in terms of fuel consumption. Goods fuel transport consumption data is retrieved as described in section 4.2.3 and the share of energy consumption of each mode in the total energy consumption of goods transport is computed. The results are provided in Figure 3.

Figure 3. Modal mix of freight goods transport in the EU-15, based on energy consumption, years 1995 and 2008



Total energy consumption: **97.9 Mtoe** **130.1 Mtoe**

Source: see section 4.2.4.
Air transport constitutes 0.1% and is removed from the figure.

Modal mix depends on the relative fuel consumption share of each transport mode. In turn, fuel consumption share for a transport mode is dependent on its energy intensity. A transport mode might thus gain a larger share of fuel consumption either because of diminished efficiency or increase in its transport performance relative to other modes. Moreover, the shift from gasoline to diesel in Figure 2 (page 17) also illustrates the interrelations between variables. Lower modal share of road transport in Figure 3 above might instead reflect the lower required consumption of diesel compared to gasoline. Standardised measures of international transport activity in tkm would facilitate measurement of modal mix. It would allow estimating shares of each mode in total transport activity, disconnecting them from the relative efficiency improvements.

It is important to note that the choice of a transport mode depends on the distance of freight transport (Schipper et. al, 1997). Inland transport modes are often complementary to international transport modes, while transport modes within the two groups are often supplements. This structure is an indication rather than a rule and for example much intra-European trade might be executed either by air or by land transport. However, a shift between the two groups of transport modes primary indicates a shift in the openness of the economy while within-group shift might imply a structural change. The choice of the mode can also be influenced by the type of goods transported. High value-added goods are usually a subject to just-in-time air and road transport (Schipper et. al, 1997). Schipper (2000) argues that as countries become more industrialised, final and intermediate goods take up a larger share of production. As they are more reliant on flexible and just-in-time delivery, road and air traffic becomes more preferred.

EU-15 members are not expected to have gone through a significant industrial shift in 1995-2008. Figure 3 supports this expected structural stability where only a small decrease in road transport energy consumption is illustrated, mainly in favour of maritime consumption. Due to complementarity of these transport modes, the shift might indicate that long-distance transportation has become more important together with the growing trade. Another possibility is the relative decrease of energy intensity in goods road transport as compared to maritime shipping that has been less regulated due to its international classification. To sum up, there are many factors that affect the choice of transportation mode and the modal mix is therefore expected to depend on individual country industry and geographical characteristics.

Figure 3 also reveals that maritime transport in the EU-15 accounts for around one third of total fuel consumption of goods transport. Even though air transport in not a big player in fuel consumption, it is crucial for firms because of its flexibility. It is widely used for high value added goods thus generating significant incomes for the trading firms[7]. Moreover, the environmental impact of aviation is believed to have increased damage because the pollution occurs above the surface of the Earth (ECTM, 2007). The importance of these transport modes points at the biases that might be generated if international transport modes are not accounted for.

4.2.5 Energy intensity

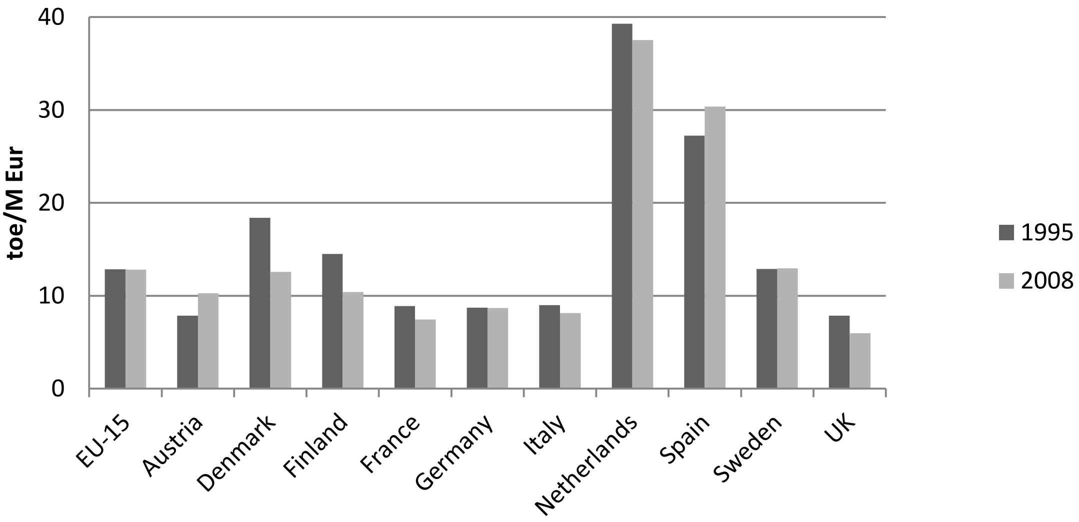
In this section, energy intensity is defined as freight transport fuel consumption (i.e. freight transport demand) per million Euros of GDP. In general, energy intensity is expected to decline due to technological improvements, such as better infrastructure, logistics management etc. This is expected to lead to a relative decoupling of freight transport energy consumption and GDP. However, energy intensity measure is an aggregate for the whole goods transport sector and is not able to separate which mode is responsible for the changes (Schipper et. al, 1997). Moreover, the energy

[7] In 2008, air transport accounted for 10% of gross value added in EU-15 in total transport sector (excl. traffic that consumes marine bunker fuel) (Eurostat, 2012d).

intensity bias that might be introduced if international transport flows are not accounted for is discussed in section 6.2.

Figure 4 illustrates energy intensities in the considered countries in 1995 and 2008. Overall, energy intensity does not show an expected general decrease due to technological improvements. 6 countries experience energy intensity decreases while energy intensity increases in Austria and Spain. Aggregate EU-15 energy intensity remains stable

Figure 4. Energy intensity EI in the EU-15 and 10 member countries in 1995 and 2008; toe/M EUR (constant prices, 2000=100)



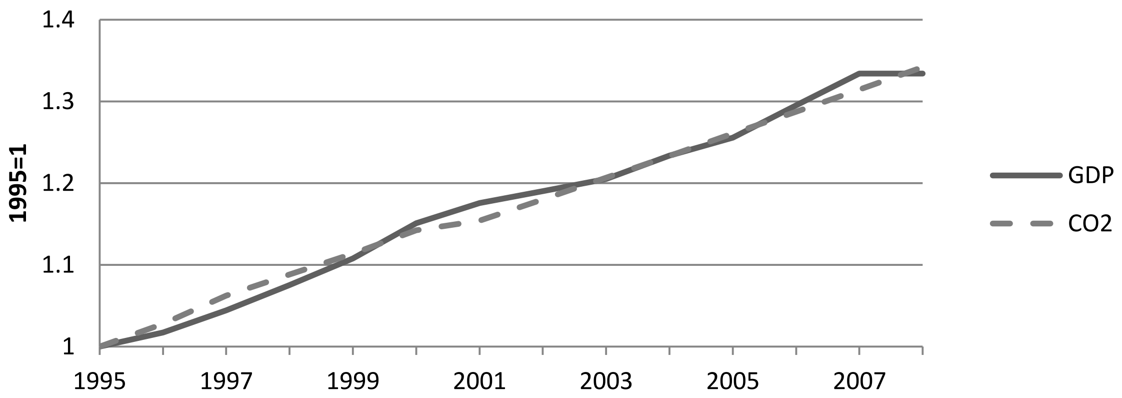
Source: Own calculations using Eurostat (2012f) data on GDP

4.2.6 GDP

GDP is included to capture economic growth of the countries which in turn indicates freight transport demand to serve the economies. Therefore, it can be argued to be a good approximation of sector economic activity. The argument is used in all the reviewed articles in section 3, except for Kveiborg and Fosgerau (2007) who use production weight.

Graph 5 compares the development of freight transport carbon emission and GDP in the EU-15 during the studied period. GDP executes a cyclical growth while CO2 has a more stable development. Nevertheless, the two variables follow each other closely and show no pattern of decoupling in relative or absolute terms. While the correlation between freight transport CO2 emissions is unquestionable, the actual relationship between them is less clear. This section conducts the LMDI analysis with the traditional GDP measure. Next section will, however, argue for an extension of the indicator of economic activity.

Graph 5. Freight transport carbon emission and GDP growth in the EU-15, 1995-2008 (1995=1)



Source: Own calculations for CO2 and GDP data from Eurostat (2012f)

5 Results and discussion

5.1 LMDI decomposition for period 1995-2008

The results for LMDI decomposition between 1995 and 2008 are presented in Table 4 below and should be interpreted in the following way. If the value of a driver in the LMDI table is 1, it did not have any effect on freight transport carbon emissions. If the driver takes a value above 1, it has contributed to the freight transport carbon emissions and vice versa if the value is below 1. For example, if the value is 1.1, the driver has contributed to the CO2 emission growth by 10% and if the value is 0.9, the variable has slowed down the CO2 growth by 10% during the period.

Table 4. Results for multiplicative LMDI decomposition of freight transport CO2 emissions in the EU-15 and 10 member countries in 1995-2008

		Contributing factors						
Country	$\frac{\mathbf{CO2(2008)}}{\mathbf{CO2(1995)}}$	**EC**	**FM**	**MM**	**EI**	**GDP**	$\mathbf{D_{TOT}}$	**Residual**[1] **(%)**
EU-15	1.341	0.999	0.995	1.001	0.996	1.330	1.317	-1.8
Austria	1.770	0.999	0.995	1.015	1.299	1.374	1.801	1.7
Denmark	0.868	1.000	0.990	0.979	0.687	1.272	0.847	-2.5
Finland	1.161	0.998	0.973	1.005	0.718	1.583	1.109	-4.7
France	1.057	1.000	0.976	1.007	0.840	1.292	1.066	0.9
Germany	1.189	0.998	0.980	1.005	0.996	1.221	1.196	0.6
Italy	1.084	0.999	0.974	0.964	0.910	1.173	1.002	-8.2
Netherlands	1.363	1.000	0.973	1.000	0.955	1.423	1.322	-3.1
Spain	1.748	0.999	0.997	1.014	1.113	1.542	1.734	-0.8
Sweden	1.536	1.000	0.947	1.039	1.005	1.447	1.432	-7.3
UK	1.096	1.000	0.987	1.001	0.761	1.441	1.084	-1.0

[1] Computed as $1-\left(\frac{CO2(2008)}{CO2(1995)}\Big/D_{TOT}\right)$

Source: Appendix 1

As discussed in section 5, LMDI is not expected to give any residual because it simply weights all the variables with a logarithmic mean of their share in carbon emissions. However, Table 4 above shows that the method returns a residual between 0.6% and 8.2% in absolute value in this thesis. The residual is most likely generated by inconsistencies in the data and assumptions that had to be made in order to disaggregate data on freight transport. Aggregate EU-15 CO2 emission data from freight transport (except for aviation) is provided by TRENDS database. Data on fuel consumption of freight transport is however estimated using Schipper et. al (1997) method as described in section 4.2.4. This method relies on the assumption that fuel mix for freight and passenger transport is the same. A negative residual of 1.8% for the EU-15 in Table 4 indicates that the decomposition accounts for a smaller share of CO2 freight emissions than is observed. It can possibly be explained by fuel mix of passenger transport that has become relatively less carbon intensive than the freight transport (see Graph 2 on page 4). This problem should not apply for individual countries because freight transport CO2 emissions from each fuel are calculated using estimated fuel consumption of freight transport (see section 4.2.3). Even though the theoretical problem of equivalent fuel mix in freight and passenger transport remains, the changes in CO2 data are corresponding exactly to fuel consumption data.

Another potential source of inconsistency is the emission coefficient. The coefficient is taken from the IEA (2011) which is a common practice in the literature. However, the fuel emission coefficient has a lower and an upper bound which might vary across countries. Moreover, electricity used in rail transport does not necessarily have the same emission coefficient as electricity in the overall economy. Furthermore, the assumption that biodiesel and bioethanol are carbon neutral may not be true in all the countries and might lead to underestimated carbon emissions from freight transport fuel consumption. If carbon emission coefficients are not precise, FC_{ij} terms in equation 1 do not cancel out, leaving a gap between the observed CO2 emissions from total freight transport and the theoretical ones, 'observed' in the data. The magnitude of the residual varies for different countries due to different characteristics of the fuel energy emission coefficients in comparison to the country average, provided by the IEA.

One of the hypotheses was that the residual might be caused by GDP as a flawed measure of economic activity. Economic activity was tested to be removed in equation 2 and LMDI analysis was performed. The exercise however does not change the magnitudes of the different drivers and the residuals remain very similar. The correlation between GDP and CO2 in Graph 5 is therefore confirmed and cannot be held responsible for the residual problems.

Finally, LMDI is suggested to be able to deal with zero values. Muller (2006) argues, however, that replacing zero values by small numbers (10^{-50} in this thesis) might generate bias because the values do not necessarily converge to 0. An example in the LMDI calculations is IWW gasoline consumption in Italy. As zero consumption is replaced by 10^{-50}, the logarithmic mean of IWW gasoline consumption $L(CO2_{ijt}, CO2_{ijt-1})$ is calculated to be 0.0055 instead of the expected 0. Looking closer to Timilsina and Shrestha (2009), the authors perform additive LMDI as opposed to multiplicative that is applied in this thesis. There are several countries in their analysis where the observed and estimated values of CO2 do not match by 1 tonne. For countries where the changes in CO2 emissions were large, such as India or Vietnam, the error has no significance. In the case of Mongolia, however, the error makes up 25% of the changes in CO2 emissions. The authors do not comment on the fact as it is probably assumed to be an approximation error.

Having these criticisms in mind, the results of the decomposition in Table 4 are corresponding well to expectations. Moreover, the observed and calculated CO2 emissions never differ in their direction. Denmark is the only country that experienced a reduction in freight transport CO2 emissions in 1995-2002. The result is mainly due to energy intensity effect which pushed down carbon emissions by 31%. Carbon emissions from freight transport increased from 6% to 77% in the rest of the countries.

On aggregate EU-15 level, economic growth was the only significant variable that contributed to a relative increase in carbon emissions by 33% between 1995 and 2008. GDP was the main driver of freight transport CO2 emissions in all the countries with an effect of between 17% and 58%. There is thus no evidence for absolute decoupling of economic growth and carbon emissions of goods transport.

At the EU-15 level, the structure and intensity of freight transport sector did not have any significant effect on CO2 emissions from goods transport. The drivers of CO2 emissions in the member countries are more diverse. While emission coefficient did not play a role for changes in CO2 emissions, energy intensity had a significant effect in many countries, even though its direction and magnitude differed. Energy intensity decreased CO2 emissions by more than 1% in six countries. The variable did not have any effect on carbon emissions in the total EU-15, Germany and Sweden while it was a contributing factor for carbon emission increases in Austria and Spain. Thus relative decoupling between energy consumption and GDP growth receives some support in six out of ten countries while in two countries the relationship is even strengthened in 1995-2008.

The structural effect was rather homogenously small across the studied countries. Fuel mix was slightly reducing carbon emissions in some countries with a largest effect of ca. 5% in Sweden. Modal mix had a small and an expectedly mixed effect depending on national characteristics. In Denmark and Italy it slowed down the increase in carbon emissions while in Austria, Spain and Sweden it was accelerating the emissions. While in Italy and Austria the road transport share might have influenced the changes in the modal mix, the results for the other mentioned countries are less expected. As discussed in section 4.2.4, the modal shift might also capture relative energy intensity improvements. Unfortunately, this thesis does not provide energy intensities of each mode due to lack of transport performance data and thus this hypothesis remains unanswered. In general, one should be cautious about drawing strong conclusions from the small effects of fuel and modal mix because they could largely be offset by the unexpected residual.

The major impact of the general economic activity is also observed by the reviewed articles that find no evidence for absolute decoupling between economic activity and transport emissions. Similar to this thesis, scholars observe a large variation in freight transport energy intensities. Greening et. al (1999) and Schipper et. al (1997) define energy intensity as energy consumption of freight transport per tkm because they have transport performance data at hand[8]. Both articles find that in a large number of countries freight transport energy intensity increased due to a shift towards less efficient road traffic while some countries succeeded in reducing it. Timilsina and Shrestha (2009) also find mixed directions of energy intensity effect, defined in the same way as in this thesis. In contrast, Lakshmanan and Han (1997), observe a decrease in energy intensity in the US, measured as energy consumption per tkm. Kveiborg and Fosgerau (2007) study micro-measures of energy intensity and find a clear restraining effect of reduced energy intensity on freight road traffic in Denmark. The process is due to scale economies in terms of larger vehicles and more capacity utilisation as well as a shift to less energy-intensive sectors.

Emission coefficient and fuel mix are not found to be important for freight transport carbon emissions by the reviewed studies. Modal shift was a significant CO2 driving factor in OECD countries until the mid 1990‘s. The shift does not appear to have continued since 1995. The mixed and small effects on the modal mix in this thesis cannot be compared to the previous results in a consistent way. This thesis includes international transport modes and the large share of maritime shipping in freight transport has decreased the relative importance of road transport. This could have reduced

[8] Having statistics for tkm changes the measure of energy intensity. However, decomposition analysis requires ratios that can be simplified and thus the studies also introduce transportation intensity of GDP, measured as transport performance per monetary GDP unit.

the effect of modal changes when compared to only considering inland transport modes and international aviation.

5.2 Sensitivity to benchmark years

The decomposition methods have been criticised for being sensitive to benchmark selection. In order to target this drawback, LMDI decomposition of equation 2 is performed for sub-periods 1995-2002 and 2002-2008. The results are presented in Table 5 below. Despite the persistent residuals, the direction of the observed and estimated changes in CO2 emissions from goods transport is estimated correctly in all the cases. It is important to note that the magnitudes of the different periods should not be compared directly as the second sub-period is shorter by one year. The split is done mainly to ensure that the directions of the variables do not behave unexpectedly.

Table 5. Results for multiplicative LMDI decomposition of freight transport CO2 emissions in the EU-15 and 10 member countries in sub-periods of 1995-2002 and 2002-2008

			Contributing factors						
Country	**Period**	$\frac{\mathbf{CO2(T)}}{\mathbf{CO2(0)}}$	**EC**	**FM**	**MM**	**EI**	**GDP**	$\mathbf{D_{TOT}}$	**Residual (%)**
EU-15	1995-2002	1.180	0.999	1.005	1.009	1.000	1.190	1.206	2.1
	2002-2008	1.137	1.000	0.987	0.991	0.996	1.121	1.091	-4.1
Austria	1995-2002	1.647	0.999	1.017	1.014	1.335	1.195	1.645	-0.1
	2002-2008	1.074	0.999	0.972	1.003	0.975	1.155	1.096	2.0
Denmark	1995-2002	0.774	1.000	0.986	0.982	0.674	1.163	0.759	-1.9
	2002-2008	1.123	1.000	0.996	0.998	1.017	1.096	1.108	-1.3
Finland	1995-2002	1.365	1.000	0.952	1.011	0.993	1.315	1.256	-8.6
	2002-2008	0.851	0.998	1.012	0.993	0.723	1.205	0.873	2.6
France	1995-2002	1.077	1.000	0.999	1.002	0.918	1.174	1.080	0.2
	2002-2008	0.981	1.000	0.973	1.006	0.913	1.103	0.986	0.5
Germany	1995-2002	1.110	1.000	1.002	1.003	0.993	1.113	1.112	0.2
	2002-2008	1.071	0.999	0.974	1.002	1.003	1.098	1.074	0.2
Italy	1995-2002	1.087	1.000	1.007	0.966	0.958	1.119	1.043	-4.2
	2002-2008	0.997	1.000	0.970	1.007	0.946	1.054	0.973	-2.5
Netherlands	1995-2002	1.269	1.000	0.996	1.001	1.016	1.244	1.260	-0.8
	2002-2008	1.074	1.000	0.976	0.998	0.940	1.145	1.049	-2.4
Spain	1995-2002	1.528	1.000	0.994	1.007	1.162	1.298	1.509	-1.2
	2002-2008	1.145	0.999	1.003	1.003	0.958	1.197	1.154	0.8
Sweden	1995-2002	1.126	1.000	0.995	1.012	0.903	1.233	1.121	-0.5
	2002-2008	1.364	1.000	0.951	1.027	1.113	1.177	1.278	-6.7
UK	1995-2002	0.930	0.999	0.991	0.995	0.738	1.265	0.920	-1.0
	2002-2008	1.178	1.000	1.005	1.003	1.030	1.140	1.185	0.5

Source: Appendix 1

Carbon emissions from goods transport have mainly increased in both periods. Denmark and UK experience absolute decreases in the first sub-period while the CO2 emissions increase in 2002-

2008. The change was mainly driven by increases in energy intensity. An opposite trend is observed for Finland and France as the carbon emissions decrease in absolute terms in the second sub-period. Energy intensity is a clear source for decreases in CO2 emissions in Finland. In France, the decrease in carbon emissions in 2002-2008 is only by 2%. Decreases in carbon content of the fuel mix and lower energy intensity contribute to the lower pollution levels.

On the whole, the conclusions for the two sub-periods are consistent to the patterns observed for the entire period. The importance of GDP as a driving factor for CO2 emissions is confirmed. Energy intensity remains mixed for individual countries but does not have any effect on aggregate EU-15 level. Emission coefficient stays insignificant for carbon emission growth. Freight transport structure effects vary depending on a country. Fuel mix is mainly holding back the growth in the second period. Once again it is important to note that large residuals could offset the small structural effects and thus they should not be seen as very reliable.

GDP remains the major driving source for freight transport CO2 emissions in all the countries. The only exception is the first sub-period in Austria, when energy intensity had a stronger impact on the growth of carbon emissions. It is important to make a notice that year 2008 was the starting year of the financial crisis in the EU-15. GDP was stable at 2007 level in constant prices thus the crisis was not yet apparent in level terms (Eurostat, 2012f). The contraction in GDP growth might however have affected the decomposition by underestimating the GDP effect. Moreover, lower GDP affects energy intensity positively from equation 1. However, only Denmark, Sweden and UK experienced increased energy intensity effect on carbon emissions between 2002 and 2008. On the contrary, energy intensity effect decreased in Austria, Finland, Netherlands and Spain. It indicates that the results are still dependent on the individual country characteristics rather than the recession, at least when considering the direction of the effect. The magnitudes are without a doubt sensitive to cyclical fluctuations and the bias is difficult to determine. However, the role of GDP should anyway not be studied in terms of magnitudes because of the asymmetry in the two sub-periods. More generally, a “stable” economy is difficult to identify at a yearly basis and the discussion is not apparent in any of the reviewed articles in section 3.

6 Accounting for trade

6.1 Environmental trade effects

Scholars on environmental effects of trade argue that theories on welfare gains from trade do not question the assumptions of well functioning price mechanisms (Ekins et. al, 1994). They state that in reality negative externalities arise due to carbon emissions from trade. The externality is not reflected in energy prices which leads to underpriced trade and increased GHG emissions. In theory, externalities could be compensated through gains from trade by developing better technologies, increasing willingness to pay for environmental protection and offering a wider choice of 'green' products (Røpke, 1995). In reality, compensating the negative effects is problematic.

Steininger (1994) presents theoretical arguments for lack of compensation of environmental trade impacts. Even though nation states have primary decisive power in redistribution of environmental effects, they are not able to take optimal decisions due to the following reason. In a standard Heckscher-Ohlin model with two countries, Steininger (1994) introduces good 1 where country A has a competitive advantage. The production of the good, however, creates a negative externality of pollution. In case of trade, country B imports good 1 and instead reduces its own pollution. The net pollution increases, however, as imports from country A enable lower prices and higher consumption. Optimal national policy in country A could decrease the pollution by restricting the production. However, this policy also increases the production costs, pushing the supply curve down and enabling other countries with lower environmental standards to occupy the market shares (Steininger, 1994). The environmental policies by one country are therefore likely to be insufficient. If an international coordinated agreement cannot be achieved, trade barriers can thus be seen as the next best environmental policy (Steininger, 1994).

Historical investigation also suggests that trade growth has been stronger than the environmental compensation. Trade levels have historically increased due to reduced barriers to trade as well as closer global supply chain integration (Cadarso et. al, 2010). Magani (2004, referred to in OECD, 2010) performs a cross-country study of 63 countries and finds that trade growth of 1% has led to an average of 0.6% growth in country CO2 emissions in 1960-1999. In general, trade generates GHG emissions through increased production, internalisation and higher transportation demand, leading to higher carbon emissions per output unit (van Veen-Groot and Nijkamp, 1999; Ekins et. al (1994)). Extensive research accounts for the production effects of trade by estimating the actual CO2 emissions that each country consumes directly or through imported goods. Internalisation effect stems from dependence on intermediate goods by multinational companies and is also a separate area of research. In accordance to the purpose of this thesis, solely the transportation aspect of trade is considered. The next sub-section discusses consequences of decomposing transport emissions without taking trade into account.

6.2 Disregarding trade in decomposition analysis

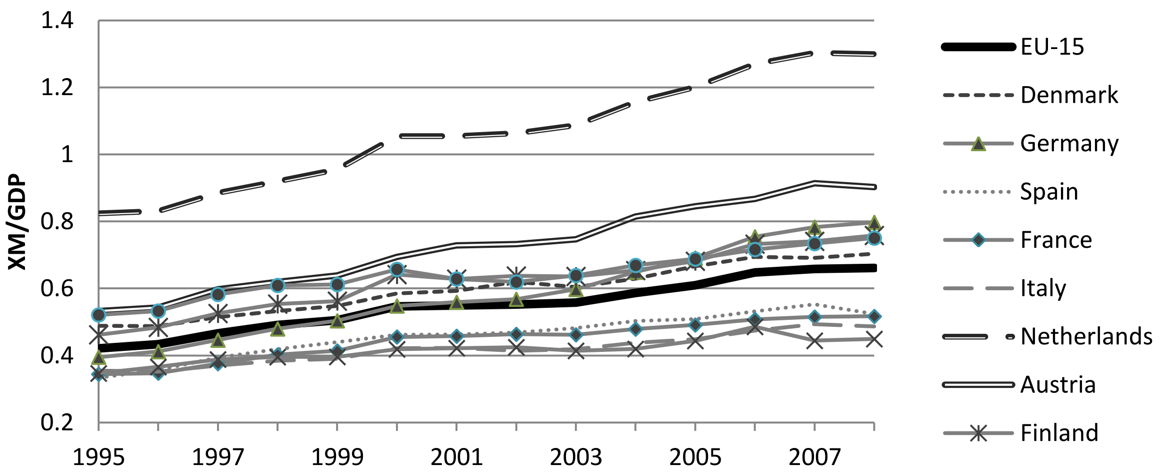
A common drawback of the reviewed literature in section 3 is disregard of the international transport dimension. Schipper et. al (1997) and Greening et. al (1999) state that they do not include international air and sea transport. However, it remains unclear to what extent the data on inland transport modes is strictly limited to national borders. Eurostat and OECD, which are the sources used in these studies, define railway and road traffic as transport on the national infrastructure (Eurostat et. al, 2009). Double counting is avoided as each country reports transport only on its own territory. The measure, however, includes transit transport and international transport that is bound to consumers abroad. A similar problem is common to the remaining studies (excluding Kveiborg and Fosgerau (2007) that only focus on road transport). These studies account for aviation but do not include maritime transport mode which is even less consistent when trying to separate national and international dimensions.

Nevertheless, the studies above include GDP as a measure of economic activity in the decomposition analysis as is also done in equation 2. GDP includes solely net exports, ignoring the actual amount of goods transported. The decomposition therefore relates national and international transport to domestic demand. However, demand of goods transport is a derived demand that also depends on the demand of foreign markets. This asymmetry reveals inconsistencies in the research.

Schipper et. al (1997) and Greening et. al (1999) have a more reasonable measure of freight transport energy intensity that is measured as freight transport fuel consumption per tkm. However, Schipper et. al (1997) point out one of the consequences of excluding international maritime transport. They observe an unexpected fall in transport activity to GDP ratio between 1973 and 1992. The authors argue that this is likely due to decreases of considered transport activity in favour of international trade at sea. In turn, the lower transport activity affects the energy intensity ratio in the study, measured as energy consumption per transport activity (toe/tkm). Thus the analysis indicates a decrease in energy intensity when in fact part of the production has been exported. The bias is expected to be relatively larger in open countries with large international transport flows.

Graph 6 below illustrates the constantly increasing goods trade share of GDP in 1995-2008. Value of traded goods amounted to over 60% of the value of GDP in the EU-15. As a result, the economic activity represented by GDP is biased downwards and in turn inflates the energy intensity value in Figure 4 (page 20). The Netherlands is a particular case where GDP does not account for the total economic activity that the transport sector has to serve. Besides the largest goods trade share to GDP in Graph 6, the country also has the largest port in Europe (Rotterdam) where a significant amount of bunker fuels is loaded to serve ships. Indeed, maritime transport in Netherlands consumes more than 80% of total freight transport fuel consumption. Nevertheless, LMDI decomposition results depend on the economic growth rather than absolute values and thus its effect on carbon emission growth remains to be seen.

Graph 6. Goods trade share of GDP in the EU-15 and 10 member countries, 1995-2008



Source: own calculations using data from Eurostat (2012f)

Disregarding international transport is also problematic from the environmental point of view because it restricts information that is vital for targeting carbon emissions from freight transport. Bunker fuels are not assigned any specific nation thus countries are able to maintain their environmental goals by simply substituting inland transport modes for the international ones. The worst case scenario suggests that a larger share of freight transport might become international which might offset the environmental achievements of individual countries. Without a doubt, confirming this statement requires different type of research. However, this concern has already been expressed by OECD (ECMT, 2008). Figure 3 (page 18) indicates an increase in maritime freight transport which could provide some support for the substitution to international transport modes. Moreover, Figure 2 (page 17) also shows increased share of fuel oil in maritime transport at the expense of less carbon-intensive diesel. This indicates deteriorating environmental standard in the maritime freight transport mode.

6.3 Trade in LMDI

This subsection discusses the ways to account for the international dimension in equation 2 of LMDI decomposition. As argued in the previous sub-section, one should incorporate international trade in the decomposition analysis of freight transport carbon emissions. Kveiborg and Fosgerau (2007) is the only article, reviewed in section 3 that does not use GDP as a measure for economic activity. The authors argue that GDP is a flawed measure when transport is considered because it subtracts inputs from total production. Kveiborg and Fosgerau argue that inputs also require transportation and suggest using production weight as a measure for economic activity. Transport itself is an input in much of the production which is again not captured by the GDP. While Kveiborg and Fosgerau restrict their study to national road transportation, this thesis aims considering total freight transport. Thus this thesis suggests accounting for total supply in the economy which considers both production and imports.

Data for total supply in current purchasers' prices is obtained from World Input-Output Database (WOID, 2012) which is funded by the European Commission, Research Directorate General. The values for total supply (including import adjustments and direct purchases from abroad) are extracted from Supply-Use tables, provided on the WOID website. Exports are not declared separately in the total supply but are included in the production data. National GDP deflator from Eurostat (2012f) is used to transform the data into constant prices. GDP deflator is chosen as a price index because the supply data is presented in final consumers' (purchasers') prices. Finally, the EU-15 supply measure is aggregated from national data for the member countries. The final total supply data is presented in Appendix 1

LMDI specification in equation 1 is transformed to the following expression:

$$CO2_t = \sum_{ij} \frac{CO2_{ijt}}{FC_{ijt}} \times \frac{FC_{ijt}}{FC_{jt}} \times \frac{FC_{jt}}{FC_t} \times \frac{FC_t}{S_t} \times S_t \ , \qquad (5)$$

where *S* is the total supply in constant prices at time *t*. The new intuitive expression, corresponding to equation 2 becomes:

$$CO2_t = \sum_{ij} EC_{ijt} \times FM_{ijt} \times MM_j \times EI_t^* \times S_t, \qquad (6)$$

where energy intensity *EI** is defined as goods transport energy consumption per million Euros supplied in the economy (including exports).

The decomposition results between 1995 and 2008 of Equation 6 are provided in Table 6 below. The residual is affected marginally and remains large for several countries. The extension redistributes the importance of energy intensity and economic activity while magnitudes of algebraically unrelated variables (EC, FM and MM) remain unchanged. The decomposition for time periods 1995-2002 and 2002-2008 is presented in the Appendix 2. The results remain similar to the decomposition for the entire period and are therefore not discussed here.

Table 6. Results for multiplicative LMDI decomposition of freight transport CO2 emissions in the EU-15 and 10 member countries, 1995-2008.

Country	$\frac{CO2(2008)}{CO2(1995)}$	Contributing factors **EC**	**FM**	**MM**	**EI***	**S**	D_{TOT}	**Residual (%)**
EU-15	1.341	0.999	0.995	1.001	0.904	1.466	1.317	1.82
Austria	1.770	0.999	0.995	1.015	1.021	1.748	1.801	1.73
Denmark	0.868	1.000	0.990	0.979	0.577	1.515	0.847	-2.5
Finland	1.161	0.998	0.973	1.005	0.600	1.896	1.109	-4.7
France	1.057	1.000	0.976	1.007	0.767	1.415	1.066	0.9
Germany	1.189	0.998	0.980	1.005	0.807	1.507	1.196	0.6
Italy	1.084	0.999	0.974	0.964	0.897	1.190	1.002	-8.2
Netherlands	1.363	1.000	0.973	1.000	0.848	1.604	1.322	-3.1
Spain	1.748	0.999	0.997	1.014	0.950	1.806	1.734	-0.8
Sweden	1.536	1.000	0.947	1.039	0.889	1.637	1.432	-7.3
UK	1.096	1.000	0.987	1.001	0.927	1.183	1.084	-1.0

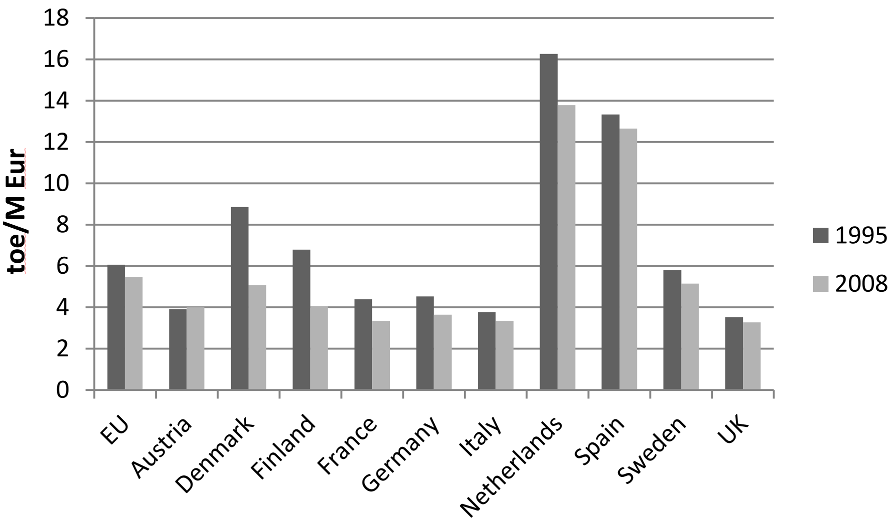
Source: Appendix 1

Economic activity measured by total supply becomes an even more important driver of the CO2 emissions. Note that the important feature of the variable in the decomposition is not its absolute value but the growth as compared to CO2 growth. The higher impact by supply is thus likely a reflection of strong growth in trade as illustrated in Graph 6 (page 29). Therefore there is no support for absolute decoupling between carbon emissions and economic growth.

Structural effect on freight transport carbon emissions stays only marginally significant in individual countries. Emission coefficient remains insignificant while the new energy intensity, *EI**, becomes a significant variable contributing to 10% relative decrease of CO2 emissions in the EU-15. Austria is the only country that experiences an increase in freight transport energy intensity which could partially reflect an increase in road transport share, in absence of the maritime transport alternative. Otherwise, the intensity effect is strongly slowing down the CO2 emission growth from 5% to 42%, as opposed to previous mixed result when only GDP is considered.

Comparing the two energy intensities (Figure 4 on page 20 to Figure 6 below), the major difference is the stronger decrease in the new energy intensity, *EI**. This reflects a relatively faster growth rates in total supply as opposed to GDP. Thus accounting for trade introduces a relative decoupling between freight transport fuel consumption and economic activity. Overall, *EI** is lower the supply includes intermediary inputs as well as exports and thus indicates a larger underlying transport demand. However, the ranking of energy intensities in different countries remains similar to Figure 4. Energy intensity *EI** remains high in the Netherlands and Spain even though it is slightly decreased relative to the EU-15. The energy intensity possibly stays high for these countries due to provided fuel bunkering services for foreign ships. As mentioned before, this exaggerates the importance of the maritime freight transport mode in these countries.

Figure 6. Energy intensities EI* in the EU-15 and 10 member countries, years 1995 and 2008; toe/M Eur (constant prices, 2000=100)



Source: own calculations using GDP data from Eurostat (2012f) and WIOD (2012)

6.4 Remaining problems

Even though the new economic activity measure of total supply incorporates international trade, it also reveals two remaining drawbacks of LMDI that are discussed below.

Firstly, without theoretical foundations, LMDI model is easy to extend but the changes are rather arbitrary. On the one hand, energy intensity $EI^* = \frac{FC_t}{S_t}$ is easy to interpret as freight transport fuel consumption (derived transport demand) per million Euros supplied by the economy. However, the measure is constructed and thus difficult to target by policies. On the other hand, incorporating a simply targeted variable in LMDI is problematic. Country trade is one of the major indicators that is targeted by other national policies and would therefore be beneficial for the environmental analysis as well. This thesis attempted to include goods trade in the LMDI analysis in equation 1:

$$CO2_t = \sum_{ij} \frac{CO2_{ijt}}{FC_{ijt}} \times \frac{FC_{ijt}}{FC_{jt}} \times \frac{FC_{jt}}{FC_t} \times \frac{FC_t}{XM_t} \times \frac{XM_t}{GDP_t} \times GDP_t, \quad (7)$$

where *XM* is the sum of imports and exports of goods in value terms (constant prices). Goods trade share of GDP, $\frac{XM_t}{GDP_t}$, partially measures country ‘openness‘ and partially its dependence on raw materials. The real problem arises when interpreting the new energy intensity, $\frac{FC_t}{XM_t}$, (freight fuel consumption per traded good). The energy intensity does not provide any intuitive interpretation.

Moreover, it introduces an opposite problem to GDP in equation 1 by only accounting for traded goods and not the domestically produced and consumed ones. This stems from the limited structure of the decomposition as all the variables need to enter as ratios.

Secondly, the total supply measure does not limit economic activity to the transport sector. Decomposition studies of transport sector lack theoretical foundations and rely on observed correlation between total economic activity and freight transport carbon emissions. Technically, GDP or total supply growth is not necessarily expected to cause an equivalent growth in the freight transport sector or its emissions. The relationship depends on which GDP component grows the most relative to the total economy. For instance, growth in the service sector (other than transport) will be apparent in GDP and total supply but is not likely to cause the same freight transport growth rates. Moreover, economic activity measure affects energy intensity in the decomposition set-up. If the economic growth is exaggerated, it would lead to an equivalent exaggerated decrease in energy intensity.

In the traditional shift-share analysis, GDP is used as an aggregate economic activity while different subsectors are assigned an equivalent value added. An equivalent approach for freight transport sector would require value added for the sector as well as for each transport mode. However, studying value added would bring back the discussion of disregarding the international transport dimension as well as the need to transport intermediate goods. On the other hand, supply-use tables that are used to extract total supply also provide supply of land, water and air transport by firms in the economy. An advantage of this method is that it provides a monetary value of transport performance. However, the data requirements are large and its reliability can be questioned. Supply data is collected by enterprise surveys, thus it does not include private transport. The data provides commercial transport supply in the economy, not differentiating between passenger and freight transport.

Table 7 presents the results for a sketched LMDI decomposition with total commercial transport supply, S^*. Once again, only energy intensity and economic activity impacts are altered. The economic effect becomes even stronger, contributing to growth of freight transport carbon emissions by 84%. This links back to faster growth in freight transport than GDP (see Graph 2 on page 4). As a result, energy intensity becomes a larger hindrance for freight transport CO2 emissions, slowing down the emissions by 28%. The decomposition suggests an even stronger absolute coupling between economic activity and carbon emissions and a stronger relative decoupling between freight transport fuel consumption and economic activity.[9]

Table 7. Results for multiplicative LMDI decomposition of freight transport CO2 emissions in the EU-15 and 10 member countries in 1995-2008

		Contributing factors						
Country	$\frac{\mathbf{CO2(2008)}}{\mathbf{CO2(1995)}}$	**EC**	**FM**	**MM**	**EI**	**S***	$\mathbf{D_{TOT}}$	**Residual (%)**
EU-15	1.341	0.999	0.995	1.001	0.721	1.838	1.317	1.8
Austria	1.770	0.999	0.995	1.015	0.847	2.104	1.798	1.6
Denmark	0.868	1.000	0.990	0.979	0.360	2.414	0.841	-3.2
Finland	1.161	0.998	0.973	1.005	0.681	1.670	1.109	-4.7
France	1.057	1.000	0.976	1.007	0.797	1.359	1.064	0.7
Germany	1.189	0.998	0.980	1.005	0.391	3.096	1.191	0.2
Italy	1.084	0.999	0.974	0.964	0.903	1.180	1.000	-8.4
Netherlands	1.363	1.000	0.973	1.000	0.875	1.554	1.322	-3.1
Spain	1.748	0.999	0.997	1.014	0.997	1.721	1.734	-0.8
Sweden	1.536	1.000	0.947	1.039	0.911	1.596	1.431	-7.4
UK	1.096	1.000	0.987	1.001	0.807	1.358	1.083	-1.1

Source: Appendix 1 and WIOD (2012)

Alternatively, traditional regression techniques are available for establishing the link between transportation and economic activity in order to get transport demand elasticities. The inclusion of new parameters is much easier in that type of investigation and the causality relation is possible to establish. Furthermore, traditional hypothesis testing allows evaluating the appropriateness of the new variables which cannot be done in a decomposition analysis as there are only two existent observations (benchmarks). However, Schipper et. al (2000) point at disadvantages of aggregate regression approach. The authors argue that it helps understanding the past development but future CO2 emissions might still be difficult to predict if one does not have information on underlying changes in the subsectors. LMDI thus has a major advantage towards regression techniques of being able to

[9] Greening et. al (1999) decompose carbon intensity rather than the total emissions. Using transport supply, $S*$, as economic activity, equation 6 on page 30 becomes:

$$CI_t = \sum_{ij} EC_{ijt} \times FM_{ijt} \times MM_j \times EI_t^*,$$

where $CI = \frac{CO2_t}{S_t^*}$ is carbon intensity of the freight transport sector. Not surprisingly, the effect of the explanatory variables is the same as in Table 7. However, the main conclusion suggests that on the EU-15 level, the freight transport carbon intensity has decreased by 9% between 1995 and 2008. This result is due to higher growth rates in total supply than in freight transport carbon emissions which suggests relative decoupling between the two variables. Thus the method analyses the relative growth of freight transport carbon emissions but does not solve the arbitrariness of economic activity.

accommodate changes to different fuel and modal structures. It allows analysing the shifts within the goods transport sector while regression techniques aim at studying the sector as a whole.

There is thus a trade-off between the simplicity of variable correlation analysis in the LMDI decomposition and applying more robust but less aggregate econometrical techniques to study causation. The interaction between different modes and fuel types is very important for decision makers and therefore LMDI is preferred as background material for transport policies. Moreover, decomposition methods are beneficial if there is strong endogeneity of several variables as they do not require disentangling causational links. However, one should be careful for extending the LMDI method too much. Once the number of sub-sectors or variables increases, the decomposition reliability decreases due to approximation errors and difficulty to interpret them.

7 Conclusion

The aim of this thesis was to suggest whether the structure, intensity of the freight transport sector or the total economic performance were the main drivers of freight transport carbon emission growth between 1995 and 2008. LMDI decomposition for the EU-15 and 10 member countries was performed to answer this question. The method provided expected results that economic activity, initially measured as GDP, was the major driving force for freight transport carbon emissions. Energy intensity did not have an effect on aggregate EU-15 emissions. However, similar to earlier articles on this subject, the variable was a source of emission increases in two countries and a hindrance in six countries. The structural effects were mainly low and varied between countries. However, they could be offset by an unexpected residual. The residual could mainly be explained by generalising assumptions and approximations. The major assumptions due to lack of data were the equal fuel mix of freight and passenger transport as well as an invariable emission coefficient.

The thesis also intended to consistently account for the international transport flows by including international sea transport and aviation. It pointed out that while many previous articles include inland transport modes, they do not consistently separate between national and international transportation. Therefore, using GDP as a measure of economic activity does not correspond to the international dimension of the analysed freight transport sector. The inconsistency does not only cause technical problems. If trade is not accounted for in research that lays background for policy decisions, this might lead to a substitution of national carbon emissions for the international ones that are not targeted under international treaties.

In order to account for trade in the LMDI decomposition, it was suggested to use total supply that includes total production and imports in the economy. The major difference introduced by the international decomposition method is the significant intensity effect that contributes to reducing freight transport carbon emissions. Economic effect is strengthened while the structural effect remains unchanged. Overall, while economic activity is still coupled with carbon emissions in absolute terms, the relative increase in transport fuel consumption is lower than economic growth. This result reflects a faster relative growth in trade compared to GDP.

LMDI decomposition performed as a practical tool for determining the carbon emission drivers by studying transport modes and fuels. However, drawbacks of the methodology were exposed during the process. Extensions to the LMDI are arbitrary and sometimes difficult to fit into the inflexible ratio format in a meaningful way. Moreover, there is no method of evaluating the fit of the new parameter other than verbal argumentation. Finally, the economic activity measures used in this thesis apply the traditional aggregate economy indicators that are based on observed correlation. It could instead be valuable to study measures of specific transport economic performance.

An additional note is that the international perspective requires a collective policy against freight transport emissions that would include international transport modes. The political feasibility of this action remains to be discussed. However, this thesis emphasises that even though accounting for international transport is not an easy task, the research should not limit itself to the reported carbon emissions – it should instead study the actual ones.

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Appendix 1

Freight transport carbon emissions in the EU-15 and 10 member countries, years 1995, 2002 and 2008

Country[1]	**Year**	***Air***	***IWW***				***Maritime***			***Rail***				***Road***				***Total***
		Total (Jet fuel)	**Total**	Diesel	Fuel oil	Gasoline	**Total**	Diesel	Fuel oil	**Total**	Diesel	Electricity	Fuel oil	**Total**	Diesel	Gasoline	LPG	
EU-15	*1995*	0.4	3.5	2.5	0.7	0.3	135.9	32.8	103.1	4.8	1.8	3.0	0.0	263.2	125.6	134.9	2.7	*407.8*
	2002	0.4	3.7	2.6	0.9	0.2	155.3	26.3	129.0	5.0	1.7	3.4	0.0	316.8	179.6	134.5	2.7	*481.3*
	2008	0.3	3.8	2.5	1.2	0.2	173.9	18.6	155.2	5.1	1.6	3.5	0.0	363.9	240.7	120.6	2.6	*547.0*
AT	*1995*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	3.9	2.0	1.9	0.0	*4.0*
	2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	6.5	4.5	2.0	0.0	*6.5*
	2008	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	6.9	5.2	1.7	0.0	*7.0*
DK	*1995*	0.0	0.6	0.4	0.1	0.0	5.0	2.0	3.0	0.1	0.0	0.0	0.0	3.0	1.3	1.6	0.0	*8.5*
	2002	0.0	0.4	0.3	0.1	0.0	2.9	1.2	1.7	0.0	0.0	0.0	0.0	3.2	1.5	1.7	0.0	*6.6*
	2008	0.0	0.4	0.4	0.1	0.0	3.0	1.3	1.7	0.0	0.0	0.0	0.0	3.9	2.3	1.6	0.0	*7.4*
FI	*1995*	0.0	0.4	0.1	0.1	0.1	1.0	0.5	0.6	0.1	0.1	0.0	0.0	2.9	1.3	1.6	0.0	*4.5*
	2002	0.0	0.6	0.2	0.2	0.2	2.0	0.8	1.2	0.1	0.0	0.0	0.0	3.4	1.8	1.6	0.0	*6.1*
	2008	0.0	0.6	0.3	0.2	0.2	1.3	0.5	0.8	0.1	0.0	0.0	0.0	3.3	2.0	1.3	0.0	*5.2*
FR	*1995*	0.0	0.9	0.2	0.1	0.7	7.9	0.8	7.1	0.4	0.2	0.1	0.0	24.1	14.5	9.6	0.0	*33.4*
	2002	0.1	0.9	0.2	0.0	0.7	7.7	0.9	6.9	0.2	0.1	0.1	0.0	27.1	18.9	8.1	0.1	*35.9*
	2008	0.0	0.9	0.2	0.0	0.7	8.0	1.1	6.9	0.1	0.1	0.1	0.0	26.2	20.7	5.5	0.1	*35.3*
DE	*1995*	0.1	1.7	1.7	0.0	0.0	6.4	1.5	4.9	0.8	0.2	0.6	0.0	38.3	16.7	21.6	0.0	*47.3*
	2002	0.1	0.7	0.7	0.0	0.0	7.5	2.4	5.1	0.6	0.1	0.5	0.0	43.6	21.5	22.2	0.0	*52.5*
	2008	0.1	0.9	0.9	0.0	0.0	9.4	2.8	6.6	0.6	0.1	0.5	0.0	45.3	25.6	19.6	0.1	*56.3*
IT	*1995*	0.0	1.3	0.7	0.0	0.6	7.6	1.8	5.8	0.1	0.0	0.1	0.0	20.3	9.1	10.4	0.9	*29.4*
	2002	0.0	4.1	2.5	1.6	0.0	6.0	1.8	4.2	0.1	0.0	0.1	0.0	21.8	11.7	9.4	0.7	*32.0*
	2008	0.0	4.4	2.2	2.3	0.0	8.0	2.7	5.3	0.0	0.0	0.0	0.0	19.4	13.0	5.9	0.5	*31.9*
NL	*1995*	0.1	0.5	0.5	0.0	0.0	35.6	7.3	28.3	0.0	0.0	0.0	0.0	6.2	3.0	2.7	0.5	*42.4*
	2002	0.1	0.9	0.9	0.0	0.0	45.6	8.4	37.2	0.0	0.0	0.0	0.0	7.2	4.0	2.8	0.3	*53.8*
	2008	0.1	0.8	0.8	0.0	0.0	48.6	7.8	40.8	0.0	0.0	0.0	0.0	8.4	5.0	3.1	0.2	*57.8*
ES	*1995*	0.0	5.8	4.6	1.3	0.0	10.0	2.4	7.6	0.2	0.1	0.1	0.0	26.5	15.3	11.1	0.1	*42.5*
	2002	0.0	4.3	3.5	0.8	0.0	21.7	5.5	16.2	0.4	0.2	0.2	0.0	38.6	27.3	11.2	0.1	*65.0*
	2008	0.0	4.1	3.4	0.6	0.0	27.7	7.4	20.3	0.4	0.3	0.1	0.0	42.2	33.9	8.3	0.0	*74.4*
SE	*1995*	0.0	0.3	0.2	0.1	0.0	3.3	0.6	2.7	0.1	0.0	0.0	0.0	4.7	1.5	3.2	0.0	*8.4*
	2002	0.0	0.5	0.3	0.1	0.0	3.8	0.7	3.1	0.0	0.0	0.0	0.0	5.2	2.0	3.2	0.0	*9.5*
	2008	0.0	0.2	0.1	0.1	0.0	6.4	1.2	5.2	0.0	0.0	0.0	0.0	6.2	3.1	3.1	0.0	*12.9*
UK	*1995*	0.1	3.5	2.8	0.6	0.0	7.6	3.5	4.2	0.3	0.2	0.1	0.0	20.0	7.8	12.3	0.0	*31.5*
	2002	0.1	2.0	1.9	0.1	0.0	5.9	2.7	3.2	0.3	0.2	0.1	0.0	20.9	9.5	11.3	0.0	*29.3*
	2008	0.1	5.1	3.1	2.0	0.0	8.0	3.2	4.8	0.3	0.2	0.2	0.0	21.0	11.8	9.2	0.1	*34.5*

Zero values were replaced by 10^{-15} where necessary.
[1]ISO country code

Variables used in decomposition of freight transport carbon emissions in the EU-15 and 10 member countries, years 1995, 2002 and 2008

Country[1]	Year	EC	FM[2]														MM[2]					EI (toe/ M EUR)	GDP (M EUR)	EI* (toe/ M EUR)	S
			Air	*IWW*			*Maritime*		*Rail*			*Road*					*Air*	*IWW*	*Maritime*	*Rail*	*Road*				
		(see table 3)	Jet fuel	Diesel	Fuel oil	Gasoline	Diesel	Fuel oil	Diesel	Electricity	Fuel oil	Biodiesel	Bioethanol	Diesel	Gasoline	LPG									
EU-15	*1995*		1	0.7	0.2	0.1	0.2	0.8	0.4	0.6	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.1	0.4	0.0	0.6	12.9	7613322	6.1	16155047
	2002		1	0.7	0.2	0.1	0.2	0.8	0.4	0.6	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0	0.4	0.0	0.6	12.9	9061254	5.7	20512536
	2008		1	0.6	0.3	0.0	0.1	0.9	0.4	0.6	0.0	0.0	0.0	0.6	0.3	0.0	0.0	0.0	0.4	0.0	0.5	12.8	10157291	5.5	23781878
AT	*1995*		1	1.0	0.0	0.0	0.0	0.0	0.2	0.8	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.1	0.9	7.9	178513	3.9	359053
	2002		1	1.0	0.0	0.0	0.0	0.0	0.2	0.8	0.0	0.0	0.0	0.7	0.3	0.0	0.0	0.0	0.0	0.0	1.0	10.5	213822	4.6	490987
	2008		1	1.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.7	0.2	0.0	0.0	0.0	0.0	0.0	1.0	10.3	246991	4.0	635220
DK	*1995*		1	0.8	0.2	0.0	0.4	0.6	0.8	0.2	0.0	0.0	0.0	0.4	0.6	0.0	0.0	0.1	0.6	0.0	0.4	18.4	150803	8.9	313014
	2002		1	0.7	0.3	0.0	0.5	0.5	0.7	0.3	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.1	0.4	0.0	0.5	12.4	175636	5.5	395392
	2008		1	0.9	0.1	0.0	0.3	0.7	0.7	0.3	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.1	0.4	0.0	0.5	12.6	192545	5.1	477220
FI	*1995*		1	0.3	0.3	0.4	0.5	0.5	0.6	0.4	0.0	0.0	0.0	0.4	0.6	0.0	0.0	0.1	0.2	0.0	0.7	14.5	104554	6.8	223522
	2002		1	0.4	0.3	0.3	0.2	0.8	0.5	0.5	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.1	0.3	0.0	0.6	14.4	137694	6.3	316393
	2008		1	0.4	0.3	0.3	0.2	0.8	0.4	0.6	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.1	0.2	0.0	0.6	10.4	166034	4.1	425476
FR	*1995*		1	0.2	0.1	0.8	0.1	0.9	0.4	0.6	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.0	0.2	0.0	0.7	8.9	1259095	4.4	2557082
	2002		1	0.2	0.0	0.8	0.1	0.9	0.2	0.8	0.0	0.0	0.0	0.7	0.3	0.0	0.0	0.0	0.2	0.0	0.8	8.2	1479649	3.8	3203182
	2008		1	0.2	0.0	0.8	0.1	0.9	0.2	0.8	0.0	0.0	0.0	0.7	0.2	0.0	0.0	0.0	0.2	0.0	0.8	7.5	1632555	3.3	3634817
DE	*1995*		1	1.0	0.0	0.0	0.2	0.8	0.3	0.7	0.0	0.0	0.0	0.4	0.6	0.0	0.0	0.0	0.1	0.0	0.8	8.7	1867155	4.5	3598248
	2002		1	1.0	0.0	0.0	0.2	0.8	0.3	0.7	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.1	0.0	0.8	8.7	2078718	4.0	4499211
	2008		1	1.0	0.0	0.0	0.2	0.8	0.2	0.8	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0	0.1	0.0	0.8	8.7	2283320	3.6	5438901
IT	*1995*		1	0.5	0.0	0.5	0.2	0.8	0.3	0.7	0.0	0.0	0.0	0.4	0.5	0.0	0.0	0.0	0.2	0.0	0.7	9.0	1090305	3.8	2608830
	2002		1	0.6	0.4	0.0	0.1	0.9	0.2	0.8	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.1	0.2	0.0	0.7	8.6	1226122	3.8	2745278
	2008		1	0.5	0.5	0.0	0.0	1.0	0.2	0.8	0.0	0.0	0.0	0.6	0.3	0.0	0.0	0.1	0.2	0.0	0.6	8.1	1292567	3.4	3140968
NL	*1995*		1	1.0	0.0	0.0	0.2	0.8	0.3	0.7	0.0	0.0	0.0	0.5	0.4	0.1	0.0	0.0	0.8	0.0	0.2	39.3	342775	16.3	828536
	2002		1	1.0	0.0	0.0	0.1	0.9	0.2	0.8	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0	0.8	0.0	0.1	39.9	426334	15.6	1092578
	2008		1	1.0	0.0	0.0	0.1	0.9	0.2	0.8	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.0	0.8	0.0	0.2	37.5	488172	13.8	1329829
ES	*1995*		1	0.8	0.2	0.0	0.3	0.7	0.6	0.4	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.1	0.2	0.0	0.6	27.2	515405	13.3	1052664
	2002		1	0.8	0.2	0.0	0.1	0.9	0.7	0.3	0.0	0.0	0.0	0.7	0.3	0.0	0.0	0.1	0.3	0.0	0.6	31.7	670719	13.7	1549174
	2008		1	0.8	0.2	0.0	0.2	0.8	0.7	0.3	0.0	0.0	0.0	0.8	0.2	0.0	0.0	0.1	0.4	0.0	0.6	30.4	803567	12.6	1929634
SE	*1995*		1	0.7	0.3	0.0	0.2	0.8	0.1	0.9	0.0	0.0	0.0	0.3	0.7	0.0	0.0	0.0	0.4	0.1	0.6	12.9	225635	5.8	502408
	2002		1	0.7	0.3	0.0	0.1	0.9	0.1	0.9	0.0	0.0	0.0	0.4	0.6	0.0	0.0	0.0	0.4	0.0	0.5	11.6	278385	4.9	654895
	2008		1	0.5	0.5	0.0	0.1	0.9	0.0	1.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.5	0.0	0.5	13.0	328066	5.1	827280
UK	*1995*		1	0.8	0.2	0.0	0.5	0.5	0.7	0.3	0.0	0.0	0.0	0.4	0.6	0.0	0.0	0.1	0.2	0.0	0.6	7.8	1338906	3.5	2976884
	2002		1	0.9	0.1	0.0	0.6	0.4	0.7	0.3	0.0	0.0	0.0	0.4	0.6	0.0	0.0	0.1	0.2	0.0	0.7	5.8	1696206	2.6	3763251
	2008		1	0.6	0.4	0.0	0.3	0.7	0.6	0.4	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.1	0.2	0.0	0.6	6.0	1937741	3.3	3529350

Zero values were replaced by 10^{-15} where necessary.

[1]ISO country code

[2]The values within the subcategories sum up to 1. Rounded numbers in the table might distort the sum.

Appendix 2

Results for multiplicative LMDI decomposition in Equation 6 of freight transport CO2 emissions in the EU-15 and 10 member countries in sub-periods of 1995-2002 and 2002-2008

Country	Period	$\frac{CO2(T)}{CO2(0)}$	Contributing factors EC	FM	MM	EI	S	D_{TOT}	Residual (%)
EU-15	1995-2002	1.180	0.999	1.005	1.009	0.938	1.269	1.206	2.14%
	2002-2008	1.137	1.000	0.987	0.991	0.963	1.159	1.091	-4.14%
Austria	1995-2002	1.647	0.999	1.017	1.014	1.172	1.363	1.645	-0.12%
	2002-2008	1.074	0.999	0.972	1.003	0.871	1.293	1.096	1.99%
Denmark	1995-2002	0.774	1.000	0.986	0.982	0.622	1.261	0.759	-1.89%
	2002-2008	1.123	1.000	0.996	0.998	0.924	1.206	1.108	-1.31%
Finland	1995-2002	1.365	1.000	0.952	1.011	0.924	1.412	1.256	-8.63%
	2002-2008	0.851	0.998	1.012	0.993	0.649	1.343	0.873	2.61%
France	1995-2002	1.077	1.000	0.999	1.002	0.862	1.251	1.080	0.20%
	2002-2008	0.981	1.000	0.973	1.006	0.888	1.134	0.986	0.54%
Germany	1995-2002	1.110	1.000	1.002	1.003	0.885	1.249	1.112	0.15%
	2002-2008	1.071	0.999	0.974	1.002	0.912	1.208	1.074	0.24%
Italy	1995-2002	1.087	1.000	1.007	0.966	1.021	1.050	1.043	-4.22%
	2002-2008	0.997	1.000	0.970	1.007	0.872	1.143	0.973	-2.52%
Netherlands	1995-2002	1.269	1.000	0.996	1.001	0.959	1.318	1.260	-0.76%
	2002-2008	1.074	1.000	0.976	0.998	0.884	1.217	1.049	-2.40%
Spain	1995-2002	1.528	1.000	0.994	1.007	1.029	1.465	1.509	-1.23%
	2002-2008	1.145	0.999	1.003	1.003	0.922	1.245	1.154	0.78%
Sweden	1995-2002	1.126	1.000	0.995	1.012	0.854	1.303	1.121	-0.46%
	2002-2008	1.364	1.000	0.951	1.027	1.039	1.261	1.278	-6.69%
UK	1995-2002	0.930	0.999	0.991	0.995	0.740	1.262	0.920	-1.03%
	2002-2008	1.178	1.000	1.005	1.003	1.251	0.939	1.185	0.52%

Source: Appendix 1