ROAD FREIGHT ENERGY EFFICIENCY AND CO_2 EMISSIONS IN THE NORDIC COUNTRIES

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ABSTRACT

1. Objective: In line with the White paper from the European Commission all Nordic countries have committed to improve the energy efficiency and decrease the CO_2 emissions of freight transportation. The aim of this paper is to compare the energy efficiency and CO_2 emissions in the road industry for the Nordic countries, except Iceland, in 2010, in order to identify the key factors and their impact on the energy efficiency and CO_2 emissions.

2. Data/Methodology: Joint analysing method for comparison is created where quantitative is used data to conduct decomposition analysis for several sectors and of several indicators, such as CO_2 intensity, transport intensity and energy efficiency. Statistics from Denmark, Finland, Norway and Sweden include continuous road haulier surveys, national accounts data and fuel consumption data.

3. Results/Findings: The CO_2 emissions of road freight transport in the Nordic countries vary from 1.14 Mt in Denmark to 2.27 Mt in Sweden. While the size of the economy, measured in gross value added (GVA), is a major determinant for the emissions, the differences in transport intensity and energy efficiency also have a significant effect on the total emissions. This is highlighted by the fact that Finland has almost the same CO_2 emissions as Sweden, but half the GVA.

4. Implications for Research/Policy: Previous research in energy efficiency in road transportation is available for some European countries. However, this study is the first of its kind for the Nordic countries and the sectoral analysis has not previously been published. Our research can be used as a first step in a continuous evaluation of the determinants of road freight CO_2 emissions in the Nordic countries.

Keywords: road freight transport, CO_2 intensity, transport intensity, energy efficiency

INTRODUCTION

Sustainable development, especially improving the energy efficiency, in this paper defined as road haulage per energy consumption (tkm/kWh), and reducing the carbon dioxide (CO_2) emissions has become highly important global goals during past few years. This development has been mainly due to the research findings on the global warming caused by human activities (IPCC 2007), but also due to limited sources of fossil oil, increasing demand of oil and the resulting rise in oil price. Information considering energy use and emissions and measures to improve energy efficiency and reduce CO_2 emissions are needed in every sector of the society in order to mitigate climate change and to respond to rising energy prices. This trend can also be seen in freight transport and logistics sector. Transport sector is currently almost entirely dependent on fossil oil and transport is also the only sector which emissions have increased in the last few years and the emissions are forecasted to increase further without determined policy measures to reduce the emissions (COM/2011/0144; Eurostat 2011; SEC/2011/0358). The new White Paper for European Transport (COM/2011/0144) launched by the European Commission sets a target for reducing 60% of transport greenhouse gas (GHG) emissions from the 1990 level by 2050 and a 20% reduction from 2008 level by 2030. The target for transport is less ambitious than in other sectors (80-95% reduction to keep the global warming below 2°C), which underlines the challenging role of transport in climate policy. The White Paper also highlights that limiting mobility is not an option, so the targets should be achieved without reducing the mobility of goods because freight transport is essential to economic growth.

The target is not further allocated to passenger and freight transport. While road traffic emissions dominate transport emissions and while passenger car emissions per kilometre are in decline (EEA 2011), addressing road freight emissions becomes increasingly relevant. It is difficult to find specific data on road freight transport emissions on an international scale, but estimates for major economies show that road freight is responsible for 30-40% of all road transport emissions (ITF 2010). More detailed studies in Germany (Léonardi and Baumgartner 2004) and UK (McKinnon and Piecyk 2009) show that the share of freight in road transport emissions has been increasing.

As an EU member states, Denmark, Finland and Sweden are also committed by the Energy Services Directive (2006/32/EC) to achieve a 9% energy savings target from the 2001-2005 average by 2016. To realise this target, EU has established an action plan for energy efficiency (COM/2006/0545). The action plan identifies transport sector as an essential sector to achieve energy efficiency improvements, as it is the fastest growing sector in terms of energy use and heavily dependent of fossil fuels. Several energy efficiency measures are identified in the action plan. However, only a few of the measures are applicable in road freight transport, such as developing markets for cleaner vehicles, maintaining the proper tire pressures and promoting co-modality, i.e. efficient use of transport modes on their own and in combination.

In line with the EU target, Norway has also committed to improve the energy efficiency and reduce the CO_2 emissions of road freight transportation. However, Norway has not worked out a similar detailed plan as the EU action plan for energy efficiency, but the Norwegian master plan for transport that is worked out every fourth year (The Norwegian Ministry of Transport and Communications 2009) has measures for how the emission targets can be realised for both passenger and freight transport.

The aim of this paper is to compare the energy efficiency and CO_2 emissions in the road freight transport for the Nordic countries, except Iceland, in 2010 and thus highlight various factors affecting these key indicators and identify opportunities for policy measures towards better energy efficiency and reduced CO_2 emissions. To enable this, a joint analysing method for comparison is created with indicators that can be used in data sets for all countries.

LITERATURE REVIEW

Earlier studies in the field of sustainable development of freight transport have performed development assessment at international and national level, though the emphasis has been at the national level. Historical development has been used to examine the trends of different phenomena. Based on historical development Liimatainen and Pöllänen (2010) establish that in Finland the energy efficiency of road freight improved during 1995-2002 and has since declined. The same kind of trend was found in US from 1975 to 2004, where efficiency improvements have been employed to increase a truck's performance and comfort rather than reduce consumption (Lutsey and Sperling 2005). Ramanathan's (2000) study reveals that in India there has been slight improvement in the energy efficiency of rail transport but road transport was more energy efficient in the late eighties than in the nineties. Ediger and Camdali (2007) argue that in Turkey the energy efficiency of the transport sector over the period from 1988 to 2004 has been cyclical but improved a little. Sorrell et al. (2012) conclude that the aggregate energy intensity, defined as road freight fuel consumption per GDP (l/£), of UK road freight sector fell considerably during the period 1989 to 2004, achieving relative decoupling from GDP. Though, Sorrell et al. argue that this development was due to current economic trends and it cannot be derived as a direct result of the policy actions.

At the international level historical development has enabled the comparison between different countries. Kamakaté and Schipper (2009) evaluate the energy intensity (MJ/tkm) of road freight in Australia, France, Japan, the United Kingdom and the United States from 1973 to 2005. The research relies on a bottom-up model which shows that the energy intensity is influenced by geography, transportation infrastructure and truck utilization. Eom et al. (2012) analyze freight CO_2 emissions in 11 IEA countries from 2007 to 2010. According to the study, an explicit trend to the energy intensity (MJ/tkm) of trucking is hard to find and thus the limiting of the freight CO_2 emissions is challenging. The whole Europe is covered in the study of Ruzzenenti and Basosi (2009), which evaluates the reliability of the energy efficiency metrics and as a result the study argues that the energy efficiency of the European transport sector has improved during 1970-2000. This is due to technological progress but also more powerful and heavier vehicles, i.e. a result of the ratio properties of efficiency; higher efficiency can either be due to lower input as well as a higher output.

Another common theme other than historical developments in freight energy efficiency research is to analyse variations of future trends of energy efficiency in freight transportation. Trucking activity will double to 2050 and grow faster than passenger transport (IPCC 2007). These trends could lead to a doubling of transport energy use worldwide (IEA 2009). For a more local context, according to Zanni and Bristow (2010) road freight CO_2 emission in London might increase about 109% by 2050. Hao's et al. (2012) study utilizes a bottom-up model to predict future fuel consumption and life cycle GHG emissions of the on-road trucks of China. According to the study China's on-road truck fuel consumption and GHG emission in 2050 will reach 498 million toe and 2125 million tons, approximately 5.2 times the level in 2010.

These are the results if a business as usual pathway is chosen and actions to counter this development are proposed by some of the researchers. Change the way goods are transported, shifting more transport to the most efficient modes, adopt cost-effective, incremental technologies to improve vehicle efficiency and shift to low-CO_2 fuels (IEA 2009) and introduce new policy actions (Zanni and Bristow 2010). Analysis of policy targets for overall reduction of emissions from transport in the UK together with emission increases in forecasts were put forward by Tight et al. (2005), concluding the need for behavioural change to complement technological improvements. Hao et al. (2012) provide impact assessment to improve the mileage utilization rate, fuel consumption rate and penetration of liquefied natural gas in the road freight sector of China. According to Usón et al. (2011) a more ecological future requires a decrease in freight tonnes and tonne-kilometres, an increase in the share of the rail transport, the optimisation of logistics and improvements on the awareness of consumers.

Ruzzenenti and Basosi, (2009), identify deficiencies in the use of fuel consumption as a measurement in energy efficiency; uncertainty over vehicle size and maximum power of the engine, and assessment method, like; fuel, load, speed, infrastructure, traffic and climate conditions. However, they conclude that this measurement is the best candidate. For a UK context, Sorell et al. (2012) point out the lack of data on total tonne kilometres, loaded and empty running vehicle kilometers by type of commodity and vehicle, truck movements of foreign trucks, as well as difficulties in translating various commodity classifications present in statistics.

METHODOLOGY

We use quantitative data to conduct a sectoral analysis of several indicators affecting the energy efficiency and CO_2 emissions. Statistics from Denmark, Finland, Norway and Sweden include national accounts data and continuous goods transport by road surveys worked out by the national statistics offices in the Nordic countries. The transport data are combined with fuel consumption data from LIPASTO (2010) and NTM (2008) to enable energy and CO_2 analysis.

Framework

The widely accepted framework for analysing the relationships between the economy and road freight transport was introduced by McKinnon and Woodburn (1996) and further enhanced in a wide European research on the subject (REDEFINE 1999). Cooper et al. (1998) extended the framework to include the environmental effects and McKinnon (2010) introduced also monetary valuation of the environmental effects for determining the external costs of logistics operations. The basic structure of the framework has, however, remained the same.

For this study, the framework is slightly altered. Monetary valuation and other environmental effects than energy consumption and CO_2 emissions are omitted from the framework (Figure 1) as the focus is on acquiring in-depth information on energy efficiency and CO_2 emissions. The framework is thus similar to the one Piecyk (2010) used, but with an addition of three key indicators and a replacement of 'lading factor' with average load on laden trips and thus an addition of laden mileage between road tonne-kms and total mileage. Furthermore, the handling factor is omitted from the framework as no distinction between 'weight of goods transported by road' and 'road tonnes-lifted' can be made with the data.

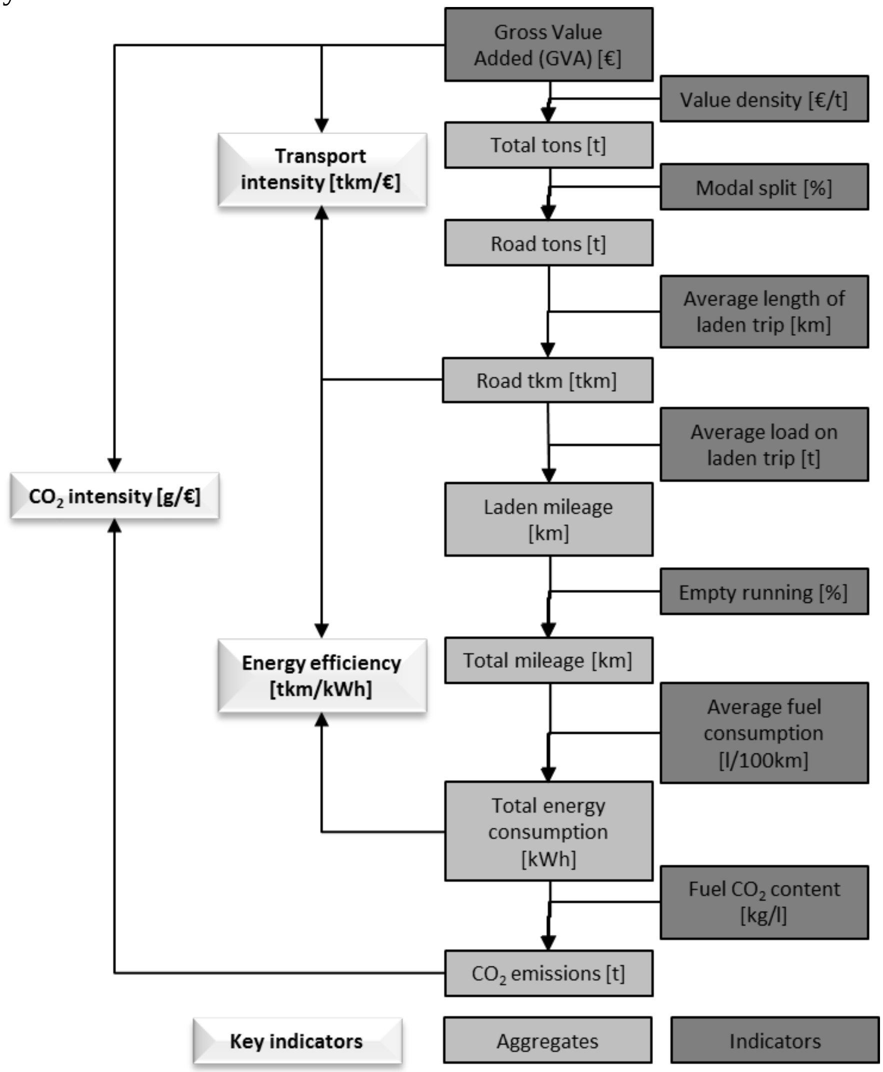

Figure 1. Road freight decarbonisation framework.

The indicators and key indicators

The decarbonisation framework disaggregates the link between the economy and CO_2 emissions of road freight transport into 8 indicators. The first indicator is the **Gross value added (GVA)** in Euros using fixed prices of year 2005 to enable time series analysis. Gross value added is widely used indicator for the national economic output.

The **value density** is in this research defined at national level as the ratio of GVA and the total weight of goods transported within each of the Nordic countries except Iceland by all modes of transport. At sectoral level the value density is the ratio of sectoral GVA and the weight of goods transported by road. Other modes are not considered at sectoral level, because sectoral data on the use of other modes is inadequate. The value density is expressed as the unit €/t.

The **modal split** is here defined as the percentage of total weight of goods transported by road. Modal split is used only on national level in this paper, because sectoral data on the use of other modes is inadequate. The energy efficiency and CO_2 emissions of other modes than road freight can be studied using a similar framework as in Figure 1 for each mode. However, the scope of this study is the road freight transport because it is the most important mode of freight in all the four target countries. In 2010, road freight transport accounted about 92% in Denmark, 90% in Finland, 88% in Norway and 86% in Sweden of total domestic freight transport when measured in the weight of goods (Finavia 2011; Liikennevirasto 2011a; Liikennevirasto 2011b; Statistics Denmark 2012; Statistics Finland 2011; Statistics Norway 2012).

Average length of laden trips expresses the average distance which trucks travel on one trip. It is calculated by dividing the mileage of laden trips with the number of laden trips. Average length can also be calculated by dividing the road haulage (tkm) with weight of goods transported by road (see e.g. Piecyk 2010), but this method is slightly misleading as the weight of goods and type of trip (long haul or pick up/distribution round) affect the road haulage.

The fifth indicator in the decarbonisation framework is the **average load on laden trips**, which is expressed in tonnes. It is calculated by dividing the weight of goods transported by road with the number of laden trips. This actually gives the value for the average maximum load on laden trips, i.e. the changes in the load during a pick up/distribution trip is not taken into account. Changes in the load during trip can be taken into account if the average load is calculated by dividing the road haulage with mileage of laden trips, as in e.g. Piecyk 2010. The difference in average load and average length on laden trips calculated with the different methods described above is about 10%, the values calculated based on the number of laden trips being 10% smaller than values calculated based on road haulage. This difference in the calculation methods should be taken into account if international comparisons are made. The average load on laden trips can be disaggregated to vehicle utilisation rate, or ‘lading factor’, and the average maximum capacity of trucks. Vehicle utilisation rate is the ratio of actual load and maximum load.

Empty running is the percentage of total mileage run without load. It is a characteristic feature of road freight transport as goods, unlike persons, almost never return to the point of origin.

Average fuel consumption is the amount of fuel needed for the trucks to travel certain distance. In this study the unit l/100km is used. Average fuel consumption is the result of a very complex system of e.g. engine, vehicle design, driving behaviour, vehicle loading and traffic conditions. There is usually no direct data available in road freight statistics on the fuel consumption, so it has to be estimated separately. One method for doing this is presented in Liimatainen and Pöllänen (2010) and used in this paper.

The last indicator in the decarbonisation framework is the **fuel CO_2 content** which expresses how much carbon dioxide is emitted when burning one litre of fuel. In Nordic countries the fuel used in trucks is virtually solely diesel. Diesel has a fixed CO_2 content of 2.66 kg/l (LIPASTO 2011). Biodiesel or some other alternative fuels may replace some or all of diesel and change the CO_2 content.

In addition to the eight indicators, three key indicators are defined. These key indicators enable analysis of the issue on more aggregate level and can be used especially in decoupling analysis. On the most aggregate level, **CO_2 intensity** can be analysed to find out whether decarbonisation, i.e. the decoupling of road freight transport CO_2 emission from economic growth (Tapio et al. 2007), has occurred. CO_2 intensity is the ratio of road freight CO_2 emissions and GVA (g/€), so decreasing CO_2 intensity means decarbonisation has occurred. However, usually some additional information about the reasons for decarbonisation is sought after and the simplest way of doing this is by introducing the key indicators of transport intensity and energy (or CO_2) efficiency.

Transport intensity is the ratio between road haulage (tkm) and economic output (GVA). It expresses the changes in the demand for road freight transport in the economy (Piecyk and McKinnon 2009, Åhman 2004, Stead 2001, Tapio et al. 2007, Kveiborg and Fosgerau 2007, Sorrell et al. 2012, McKinnon 2007).

Energy efficiency expresses the changes in the efficiency of the supply of road freight transport. Energy efficiency is defined in the Energy Services Directive (2006/32/EC) as "a ratio between an output of performance, service, goods or energy, and an input of energy". The energy efficiency of road freight transport is thus generally the ratio between road haulage and energy consumption, indicated as tonne-kilometres per kilowatt-hours [tkm/kWh]. This can also be turned other way around to energy intensity [kWh/tkm], which is consistent with some previously proposed indicators. Other possibilities for indicating the same subject include energy intensity [MJ/tkm] by Kamakate and Schipper (2009), fuel efficiency [koe/tkm] (koe means kilograms of oil equivalent) and emission efficiency [g CO_2/tkm] by Perez-Martinez (2009) as well as CO_2 efficiency [tkm/kg CO_2] by Leonardi and Baumgartner (2004). All these indicators are interdependent as the current major fuel of road freight vehicles, diesel, has fixed energy content (approximately 10.1 kWh/l, 36.3 MJ/l or

0.87 koe/l) and produces a fixed amount of CO_2 (2.66 kg/l) when burned in the engine (LIPASTO 2011).

Limitations of the decarbonisation framework

The decarbonising framework disaggregates the relationship between the economy and CO_2 emissions into indicators which can be analysed to find out the causes for changes. However, by doing that some complexity may be lost and one should be cautious not to lose sight of the various feedback loops between the indicators. For example, the value density affects the modal split as high value goods are more often transported by road or air (van Essen et al. 2009) and the average load on laden trips and share of empty running affect the average fuel consumption (Coyle 2007). Further, the rebound effect can partly offset energy savings from improvements of the fuel economy of the individual trucks as haulages may become cheaper and the demand increase (Sorrell, 2007). While the framework includes the modal split, other modes of transport than road freight are omitted from the framework, but similar analysis can be made to other modes and changes in indicators in other modes can affect road freight.

Data, classifications and calculations

The energy consumption of road freight transport is dependent on series of factors, among those the type of commodity hauled. To be able to link energy consumption to the economic activity in different sectors, a simple linkage between commodities and sectors at an aggregate level has been applied. A high aggregation level has been chosen to ease the comparison between the countries.

Although the national road survey in each of the four countries follow the same standard nomenclature (NST2007, COM/2007/1304), the implementation is quite different in the continuous goods transport by road surveys of the four countries. For the commodity classification the available statistics had different aggregation levels. For this study, the commodities have been aggregated to six large groups making the linking to the economic sectors simple. In Table 1 the six sectors and the commodities are shown. In appendix 1 the commodities and the national account sectors are defined.

Table 1 Classifications of freight commodities and national accounts sectors.

Sector	NST2007	National accounts
Agriculture and forestry	1	A
Mining and construction	3, 9	B (excl. oil and gas extraction), F
Food industry	4	CA
Chemical industry	2, 7, 8	CD, CE, CF
Wood and paper industry	6	CC
Technology industry	5, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	Rest of C

The commodity groups are linked pair wise to production sectors as shown in Table 1. There exists information for some countries on the distribution of the produced commodity types for each national accounts sector (e.g. Statistics Denmark, 2003), but since the commodities vary from country to country and the aggregation level is high, such information is difficult to apply in this context, and a one-to-one linking has been used. In appendix 2 the national account sectors are defined.

The calculations of energy consumption and CO_2 emissions follow the procedure described in Liimatainen and Pöllänen (2010). They are carried out at the individual trip level using the detailed data from the haulier surveys of the four countries. The trips are divided into urban and rural according to the reported start and end points of the trips, and the energy consumption in litres per kilometre is first calculated using the following equations:

(Eq 1) $Litres\ per\ 100\ km = 5.7767(Gross\ weight)^{0.6672}$ for urban trips, and

(Eq. 2) $Litres\ per\ 100\ km = 5.9463(Gross\ weight)^{0.5515}$ for rural trips

The gross weight includes the own weight of truck, trailer and the weight of goods, measured in tons. These equations are estimated using average fuel consumptions for trucks of various sizes given by LIPASTO (2010) and NTM (2008) and are further explained in Liimatainen and Pöllänen (2010). The rural trips have lower energy consumption because of the freeflow traffic conditions, while urban trips more often takes place under saturated conditions.

These equations estimate the fuel consumption for a truck produced before 1994. Thereafter, the specific energy consumption is reduced according to the Euro class defined according to the vintage of the truck by multiplying by the energy factors presented in Table 2:

Table 2. The effect of Euro class on fuel consumption of trucks (Liimatainen & Pöllänen 2010).

Vintage	Euro class	Energy factor
before 1994	-	1.000
1994-1996	Euro I	0.931
1997-2000	Euro II	0.924
2001-2006	Euro III	0.948
2007-2008	Euro IV	0.899
2009-	Euro V	0.909

In the next step the sector information is used to adjust fuel consumption: Agriculture and forestry is adjusted up by 30% and Mining and construction by 20%. This is because some of these hauls take place on dirt roads or under other tough conditions and the motors are running for a long time when the truck is loaded and unloaded, resulting in higher fuel consumption than would be estimated based on gross weight and type of road. (Liimatainen et al. 2012)

Finally, energy consumption is reduced by 10% if the trip is a “round trip”. Typically, these trips have multiple stops and return empty, but the weight of goods reported is the maximum weight during the trip. This adjustment is described further in Liimatainen and Pöllänen (2010).

The CO_2-emissions are simply estimated using the above mentioned emission coefficient of 2.66 kg CO_2 per litre diesel.

Limitations of national data

The method for analysis was developed using the Finnish data and although the basic principle for collecting the data is similar in all countries, there are differences, which have minor effect on the results and should be taken into account when interpreting the results. The major differences consider the definition of urban haulage, the possibility of calculating sectoral empty running and the availability of vehicle weight data.

The Danish data suffers from two main limitations: 1) it is difficult to pinpoint urban hauls since the country is divided into only 11 zones, which means that Copenhagen is the only city which can be identified. All other zones cover both rural and urban areas. 2) There is no sector information for the hauls – only commodity information. Therefore it is not possible to attach empty running to any sector.

In the Norwegian data set there is missing information for own weight, payload and/or total weight for some vehicles. In cases where we only have information about total weight, vehicle's own weight is assumed to be one third of the total weight. In cases where both these variables are missing, shipment size is used as a proxy for the vehicle payload. Own weight is assumed to be half the vehicle's payload. For Norway urban distribution is including all transport that starts and ends in the same municipality or is executed in the Oslo area, defined as transports inside Oslo and Akershus counties. This approach is similar to the one used in Finland.

Some of the trailer own weight and total weight is missing in the Swedish data. In those instances where the load rate is higher than 100 percent, the weight of an average dummy trailer of 7 tonnes has been added. Swedish data also lacks data to determine the urban hauls, so all hauls under the length of 24 km are considered as urban hauls.

RESULTS

CO_2 emissions

The CO_2 emissions of road freight transport from the four countries are presented in Table 3. Total emissions for Denmark are half the emissions of Sweden, with Finland close to Sweden and Norway in between Finland and Denmark. Although the total emissions vary considerably, the shares of emissions in different sectors are very similar. Technology industry has clearly the largest share in all countries, while chemical industry and wood and paper industry have the smallest shares.

Table 3. The CO_2 emissions and shares of sectors in 2010.

	Denmark	Finland	Norway	Sweden
Agriculture and forestry	14.4%	14.7%	9.0%	12.6%
Food industry	16.5%	11.9%	16.6%	13.3%
Chemical industry	4.8%	6.3%	5.2%	4.6%
Mining and construction	15.4%	13.9%	13.6%	10.0%
Technology industry	33.8%	28.6%	33.0%	39.3%
Wood and paper industry	3.8%	5.9%	5.2%	6.5%
Empty running	11.3%	18.8%	17.4%	13.8%
Total CO_2 emissions [Mt]	1.14	2.21	1.57	2.27

CO_2 intensity

The road freight CO_2 intensities in various sectors of economy in Denmark, Finland, Norway and Sweden are presented in Table 4, which reveals major differences in the CO_2 intensities between countries. Finland has the highest intensity in 3 of the 6 sectors and also in national total, while Denmark and Sweden have about half the CO_2 intensity of Finland when the national GVA (includes services) is considered.

Table 4. Road freight CO_2 intensities [CO_2 g/€] in 2010.

	Denmark	Finland	Norway	Sweden
Agriculture and forestry	79	75	34	89
Food industry	52	117	70	67
Chemical industry	14	45	29	12
Mining and construction	21	30	19	16
Technology industry	29	32	42	25
Wood and paper industry	30	27	47	21
Total (6 sectors' GVA)	35	50	44	31
Total (national GVA)	6	15	9	8

Sectoral differences are also apparent in Table 4. The food industry has the highest CO_2 intensity in Finland and Norway, while in Denmark and Sweden agriculture and forestry has higher intensity. The lowest intensities are found in chemical industry in Denmark and Sweden, wood and paper industry in Finland and mining and construction in Norway. This result is perhaps rather surprising as these sectors include transport of bulk goods, i.e. heavy and low value goods such as basic chemicals in chemical industry; gravel and soil in mining and construction sector and pulp in wood and paper industry. However, bulk goods are suitable for rail or water transport and may thus be left out, especially on long distances, of our analysis focusing on road freight transport. Furthermore, these sectors also include sub sectors, which have low demand for transport within the country and high global added value such as pharmaceuticals in chemical industry; valuable ores in mining and construction sector and printed media in wood and paper industry. This highlights the limitations of the statistics and highlights the importance of deep understanding of the connections of the economy, freight transport and energy use. In order to gain deeper understanding, it is necessary to analyse the sectoral transport intensities and energy efficiencies further.

Transport intensity

The transport intensities vary from 0.06 tkm/€ in Denmark to 0.18 tkm/€ in Finland (Table 5). These figures are well in line with the figures reported by Eom et al. (2012) for Denmark (0.1 tkm/$) and Sweden (0.15 tkm/$), taking into account that direct comparison cannot be made, because their figures included the haulage by light goods vehicles and their monetary value was the purchasing power parity GDP in $ at 2000 prices.

On a national level, the transport intensity is on a higher level in Finland and Sweden than in Denmark and Norway (Table 5). An explanation to this may be that the 6 sectors analysed here have approximately 30% share total added value in Finland and 25% share in Sweden, but only 20% share in Denmark and Norway. However, if only the added value of the 6 sectors is considered, Denmark still has much lower transport intensity than other countries, while Finland has considerably higher. Denmark also has the lowest transport intensity in all but one sector. This is due to the geographical location of Denmark as a part of the continental Europe, which allows Danish businesses to easily operate internationally. On the other hand, foreign transport companies can easily operate in Denmark and both these factors decrease the transport intensity in Denmark. These factors are reflected in the high share of exports and imports (50% and 45% of GDP) in Denmark as well as in the share of international (4.5% of national tonnage in t) and cabotage (3.9% of national haulage in tkm) transport on road in Denmark (Eurostat 2012). Transport intensity is affected by three indicators: value density, modal split and average length of laden trips.

The value density of the 6 sectors in Denmark and Sweden is approximately double the value density of Finland (Denmark 209 €/t, Sweden 230 €/t, Finland 111 €/t), while Norway has a value density of 136 €/t. The differences in value density between Denmark and Sweden with Finland and Norway are particularly great in the mining and construction sector, Denmark and Sweden having more than twice the value density of Finland and Norway (162 €/t and 135 €/t compared to 50 €/t and 82 €/t, respectively). In Denmark the GVA of mining and construction is 19% lower than in Finland, but the tonnage transported by road in this sector is 50 Mt in Denmark and 200 Mt in Finland. Most of the tonnage for mining and construction sector is due to short hauls of gravel and soil for the foundations of roads and buildings, so the difference between Denmark, Finland and Norway may be largely due to the greater need for gravel in foundations in Finland and Norway in order to prevent damages to infrastructure caused by ground frost during the harsh winters. This explanation is confirmed by the fact that the average length of haul in mining and construction sector is much longer in Denmark (52 km) than in Finland and Norway (20 km and 19 km, respectively).

The differences in transport intensity are largely due to the differences in value density, as the differences in modal split and average length of laden trips are smaller between countries.

Modal split can be assessed only on national level, and there is not much variation between countries. The share of the road is about 92% of total national tonnage in Denmark, 90% in Finland, 88% in Norway and 86% in Sweden. The second largest mode of transport with an 8% share in Denmark and 11% in Norway is sea transport, while in Finland and Sweden rail transport has an 8% and 11% share, respectively. Finland and Norway have an average length of laden trips of around 60 km, while in Denmark and Sweden it is around 80 km, although the average length may change more than 10 km year-on-year in each country.

Table 5. Road freight transport intensities in tonne-kilometres per added value [tkm/€] in 2010.

	Denmark	Finland	Norway	Sweden
Agriculture and forestry	0.82	1.23	0.41	1.70
Food industry	0.62	1.45	0.97	1.16
Chemical industry	0.20	0.89	0.56	0.26
Mining and construction	0.25	0.51	0.24	0.26
Technology industry	0.25	0.34	0.47	0.37
Wood and paper industry	0.31	0.57	0.61	0.45
Total (6 sectors' GVA)	0.32	0.59	0.46	0.45
Total (national GVA)	0.06	0.18	0.09	0.12

Also sectoral differences can be seen from Table 5. Food industry has the highest transport intensity in two countries as does agriculture and forestry. Mining and construction has the lowest transport intensity in three countries. The food industry has the longest average length of haul in all the countries, while having an average value density and this combination results in high transport intensity. Mining and construction sector, on the other hand, has the lowest value density, but also by far the shortest average length of haul, which decreases its transport intensity. In Finland technology industry has a very high value density compared to other sectors and it also has fairly short hauls, which results in low transport intensity.

Energy efficiency

The energy efficiency of road freight transport varies from 2.44 tkm/kWh in Denmark to 3,80 tkm/kWh in Sweden (Table 6). These values seem to be much greater than the around 2 MJ/tkm (1.8 tkm/kWh) for Sweden and 4 MJ/tkm (0.9 tkm/kWh) for Denmark given by Eom et al. (2012). However, Eom et al. included light goods vehicles in their analysis, which decreases the energy efficiency. They also included the energy used by international transport, which is omitted from our analysis and this further decreases the energy efficiency, so the values are not directly comparable.

The energy efficiency is the result of three indicators: average load on laden trips, share of empty running of total mileage and the average fuel consumption. All three indicators are interrelated as the loading directly affects the fuel consumption. Average load and empty running are also related, as the bulk goods sectors (agriculture and forestry, chemical industry, mining and construction, wood and paper industry) have higher average loads but also higher share of empty running than the general cargo sectors (food industry, technology industry) (Liimatainen & Pöllänen 2011).

Average load on laden trips is a major contributing factor to the national differences seen in Table 6. In Finland the average load is 13.9 tons, while in it is Sweden 12.9 t, in Norway 11.6 t and in Denmark 9.8 t. The high average load in Finland is partly caused by the large share of bulk goods sectors (62% of total haulage in tkm) compared to Sweden (45%), Norway (43%) and Denmark (47%).

Denmark has very low level of empty running compare to the other countries. McKinnon & Ge (2006) identify various reasons for low empty running, these include: outsourcing of road haulage operations, balance of traffic flows, long average length of hauls, high cost of transport, high share of distribution trips, high level of reverse logistics, high use of load matching services and adoption of new management initiatives. In Denmark and Sweden the average length of haul is longer and the balance of transport flows is better than in Finland and Norway, resulting in low level of empty running. Denmark has much higher population density (130 inh./km^2) than other countries, which balances the transport flow. Sweden, on the other hand, has three major economic regions in the southern part of the country (Stockholm, Gothenburg and Malmö/Öresund region), which balances the transport flows and decreases empty running. In Finland and Norway population and economic activity is to great extent centred in the metropolitan regions of capital cities while other parts of the countries are sparsely populated. This causes structural imbalance in transport flows to and from the rural areas.

Table 6. Road freight energy efficiencies in tonne-kilometres per kilowatt-hours [tkm/kWh] in 2010.

	Denmark	Finland	Norway	Sweden
Agriculture and forestry	2.75	4.29	3.15	5.03
Food industry	3.14	3.26	3.63	4.54
Chemical industry	3.58	5.28	5.04	5.82
Mining and construction	3.09	4.51	3.28	4.24
Technology industry	2.28	2.78	2.96	3.82
Wood and paper industry	2.73	5.63	3.42	5.73
Total (includes energy used in empty runs)	2.44	3.10	2.75	3.80
Empty running (share of total km run empty)	14.5%	27.4%	24.8%	19.1%

The average fuel consumption of the trucks is 33.1 l/100km in Denmark, 35.7 l/100km in Finland, 32.3 l/100km in Norway and 34.4 l/100km in Sweden. Average fuel consumption is affected by the average load, but also by the truck technology and the type of road the transport takes place. The truck technology is in our study taken into account using energy factors for trucks of different Euro classes. This energy factor is 0.922 in Denmark, 0.930 in Finland, 0.925 in Norway and 0.927 in Sweden, indicating that the truck fleet is renewed more rapidly in Denmark than in other countries. In terms of the share of mileage driven on urban roads the data from different countries does not enable a fair comparison, so its effect remains unclear.

In terms of sectoral energy efficiency, technology sector has the lowest value in all countries while chemical industry has the highest value in all countries, except Finland where wood and paper industry has slightly higher value. The greatest reason why the technology industry has the lowest efficiency for all countries is that in this sector there is a higher share of volume goods than in the other sectors, i.e. the capacity utilisation is lower in tonnes as illustrated by the average load on laden trips is 7.9 t in Denmark, 6.6 t in Finland, 8.0 t in Norway and 7.1 t in Sweden in this sector. The same reason is behind the high energy efficiency of chemical industry as the average loads are 18.6 t in Denmark, 25.2 t in Finland, 15.5 t in Norway and 25.5 t in Sweden in this sector. High loads increase the fuel consumption (l/100km), but the resulting increase in energy consumption (kWh) is smaller than the increase in haulage (tkm), so there is a decrease in energy efficiency (tkm/kWh).

CONCLUSIONS

In this paper, we have contributed to the understanding of road freight energy efficiency and CO_2 emissions in Nordic countries. The aim was to carry out a comparative study in order to identify the key factors and their impact on the energy efficiency and CO_2 emissions. In our analysis, we found a high degree of consistency in the indicators in the way that it is largely the same industries in each of the countries which have respectively the highest and lowest efficiency. Despite the uncertainty in the data and the different levels of information available in the four countries, this strengthens the validity of the results. When evaluating the research process of the study generally, the strengths lies on the quantitative joint analysing research method utilized and use of the widely accepted framework for analysing the relationships between the economy and road freight transport as a basis, when carrying out the research. Also the participation of more than one researcher in gathering and analysing the data can be seen as strength. These increase the reliability of the research results and quantitative method also enables generalizability of the results, this comparative study can be carried out in other countries as well.

For energy efficiency, measured in tonne per kilowatt hour, it is the technology industry which has the lowest values, while respectively the wood and paper industry in Sweden and Finland and the chemical industry in Norway and Denmark have the highest values. Lowest energy efficiency in the technology industry may be explained that the sector largely transports goods with relatively high unit value and the capacity utilization limited by the commodities' volume rather than weight, so that capacity utilization is generally lower for these goods than for typical bulk goods.

Also for road transport intensities (measured as tonne-kms per added value) there is high degree of consistency in the results between the Nordic countries, where the mining and construction industry has the lowest values for all the Nordic countries, except for Finland, where the technology industry have the lowest transport intensity. Agriculture and forestry industry has the highest transport intensity in Denmark and Sweden, while the food industry have the highest transport intensity in Finland and Norway.

For the CO_2-intensities (measured as grams CO_2/€) there is somewhat greater inconsistency between the Nordic countries, where the chemical industry has the lowest emission intensity in Denmark and Sweden, the mining and construction industry has the lowest emission intensity in Norway and the wood and paper industry has the lowest emission intensity in Finland. Agriculture and forestry industry has the highest emission intensities in Denmark and Sweden, while the food industry with the highest emission intensities in Finland and Norway.

The study has opened several future research avenues. Most importantly, future research could create time series of the historical development of the indicators for each country. This would also lay the foundation for future projections of these indicators. It is also of interest to study the urban context more in detail. A more uniform definition of urban distribution, taking into account the lack of urban information from all countries, would be valuable. Lastly, another approach is to analyse the total average of the indicators for all countries in relation to other countries in Europe. A Nordic average indicator would accommodate to some of the inconsistencies of each individual country's data set and make it even more robust in future comparisons.

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Appendix 1

Haulier survey commodity types

NST2007	
1	Products from agriculture, forestry, and fishery
2	Coal, crude oil and natural gas
3	Metal ores, stone, gravel, and soil
4	Food and beverages
5	Fabrics and leather
6	Wooden products (excl. furniture), pulp, and paper
7	Refined oil products
8	Chemicals, plastics, and rubber
9	Other non-metallic mineral products
10	Metal products excluding machines and equipment
11	Machines and instruments
12	Vehicle and vessels
13	Furniture and other manufactured goods
14	Household and municipal waste
15	Letters and parcels
16	Equipment for transportation
17	Removals and vehicles for repair
18	Mixed cargo
19	Unidentified goods
20	Goods not mentioned elsewhere

Appendix 2

National account sectors

A	Agriculture, forestry and fishery
B	Mining
CA	Food and beverages
CB	Fabrics and leather
CC	Wood and Paper
CD	Oil refineries
CE	Chemicals
CF	Medical industry
CG	Technology
CH	Metals
CI	Electronics
CJ	Electric equipment
CK	Machines
CL	Vehicles and vessels
CM	Furniture and other manufacturing
F	Construction