1 General introduction

1.1 Introduction

The transport of people and goods contributes considerably to economic development, welfare and well-being: production, goods transport and a growth of the gross domestic product (GDP) go hand-in-hand\(^1\) and the financial and physical possibility to travel regularly and over long distances contribute to a feeling of well-being. However, there are also negative impacts of transport on welfare and well-being. Air pollution influences health and the feeling of well-being of people, especially the people living in cities. Traffic noise disturbs many people regularly. Traffic accidents lead to high costs for the public health sector. And air pollution has negative impacts on agricultural production.

This thesis deals with the environmental consequences of freight transport. The introductory chapter gives a short overview of transport and its main environmental problems. Next, the thesis focuses on the energy use and emissions into the atmosphere. These are impacts which occur on a range of scales (local to global). More specifically, the thesis focuses on energy use and emissions related to the construction and maintenance of vehicles and infrastructure. These indirect impacts of transport are compared with the energy use and emissions related to driving and sailing.

This introductory chapter discusses the environmental problems related to both passenger and freight transport briefly and next focuses on and analyses the freight transport system in more detail. Section 1.2 discusses transport and its related environmental problems. Section 1.3 discusses the environmental problems related to freight transport as well as strategies to diminish the environmental impacts from freight transport. Section 1.4 builds on the sections 1.2 and 1.3 and discusses the scope of this thesis. This section is followed by some methodological remarks discussed in section 1.5. Finally, section 1.6 discusses the structure of this thesis.

\(^1\) In The Netherlands, the transport sector contributed almost 8% to the GDP each year in the period 1991-1994 (CBS-KVV, 1996).
1.2 Transport and the environment

Direct environmental impacts

Energy requirements and emissions related to the transport of people and goods are considerable, both on a national and international scale. For The Netherlands, figure 1.1 shows the overall atmospheric emissions of various compounds and the share of road transport in these emissions. Figure 1.1 shows that road transport is an important source for the national CO, C\textsubscript{6}H\textsubscript{6} and NO\textsubscript{x} emissions\(^2\). The share of CO\textsubscript{2} emissions related to road transport is a measure for the share of the energy use by the transport sector in the national energy use. A share of 16\% is considerable since energy use in the transport sector has been increasing for a long time and this trend is expected to continue in the (near) future. In 1984, the primary energy use of the transport sector was 425 PJ; in 1989, it was 511 PJ (BGC, 1991). During the period 1989-1996, the transport demand by the transport sector increased by 18 \%. Also internationally, the energy use by the transport sector has increased. During the period 1980-1989, the energy use by the transport sector in OECD Europe increased by almost 30\% while in all OECD countries, it increased by about 20\% (IEA, 1991). For the long term, scenarios exist in which the world passengers mileage increases by a factor 2 over the period 1990-2020 and a factor 4 over the period 1990-2050 (Schafer, 1997).

Besides emissions to the air, emissions to surface water, waste and noise are other main environmental impacts from transport (RIVM, 1991). Emissions to surface water stem from overseas transport and inland waterways transport mainly (e.g. oil). Emissions from road surfaces are of minor importance. In 1993, lead from passenger cars only contributed significantly to the national lead emissions by a share of 16\%. However, this share has been reduced since the introduction of unleaded gasoline in September 1996.

Waste from the transport sector in The Netherlands mainly consists of passenger car wrecks and waste from transport over water. Tyres are the third important category of waste. Most waste materials resulting from the transport sector are recycled. In 1995, this percentage was 87\%.

\(^2\) Of the mobile sources, road transport is responsible for most emissions. However, transport over water, rails and in the air also contribute to the national emissions. In 1993, these other sources contributed to the national CO\textsubscript{2}, CO, C\textsubscript{6}H\textsubscript{6}, NO\textsubscript{x}, aerosols and SO\textsubscript{2} emissions by 2.8, 3.9, 3.9, 17, 9.6 and 10.8\% (CBS-JB, 1993). Besides road transport, the most important source of SO\textsubscript{2} emissions is sea-borne shipping.
Figure 1.1 The share of the road transport emissions in the total national emissions in The Netherlands (1993)⁷ (CBS-JB, 1996; Klein, 1993).

Figure 1.2 The shares of passenger and freight transport in the total emissions from road transport in The Netherlands (1993)⁷ (Klein, 1993).

* In this figure, aer = aerosols.
Noise from traffic, and nuisance, noise experienced by people, are connected but not the same. Research showed that people are more disturbed by noise from road than from rail transport (Bouman, 1990), even if the level of the noise level measured in decibels (dB(A)) is equal. Nuisance is caused by road transport (1995: 30% of the Dutch people bothered) and air transport (1995: 21% of the Dutch people bothered) mainly. Road transport gives rise to nuisance in the built-up area mainly (RIVM, 1997).

Passenger and freight transport

The distinction between passenger and freight transport is important in studying the total environmental impacts from transport. The type of emissions in both sectors are similar but the contribution of both sectors to the various compounds differs. Figure 1.2 shows the share of passenger and freight transport in the emissions from road transport in The Netherlands. CO and C\textsubscript{xy} emissions mainly stem from passenger cars and are related to the use of gasoline. C\textsubscript{xy} emissions also depend on the style of driving. About two-third of the national aerosols and SO\textsubscript{2} emissions are produced by freight transport vehicles and are associated with the use of diesel fuel. Both passenger and freight transport contribute significantly to NO\textsubscript{x} emissions. However, NO\textsubscript{x} emissions expressed per vehicle kilometre are much higher for trucks than for passenger cars (Mensinga, 1995). The amount of NO\textsubscript{x} emitted increases with the combustion temperature which is higher for trucks.

Since 1993, CO, C\textsubscript{xy} and NO\textsubscript{x} emissions per vehicle kilometre by passenger cars have been decreased due to the introduction of the three-way catalyst. Also the CO, C\textsubscript{xy} and NO\textsubscript{x} emissions per vehicle kilometre by trucks have been decreased due to adaptations in the combustion engine. The freight transport share in the total CO, C\textsubscript{xy} and NO\textsubscript{x} emissions from transport in 1993 was 11.2%, 17.2% and 46.7%. In 1996, these shares were 10.4%, 17.9% and 45.3% respectively. In the future, the share of the freight transport sector in the total emissions from transport will probably increase. In a comprehensive study for The Netherlands in which the future with respect to the environment is explored, the increase of the vehicle kilometres from passenger road transport in the 1990-2020 period is less than 50% while the increase of vehicle kilometres in freight road transport varies between 80% and 300% depending on scenario assumptions (RIVM, 1997).

Environmental impacts from passenger and freight transport differ in some aspects. Strategies to reduce emissions also differ for passenger and freight transport. In the first place, the strategies differ due to the differences in the technological characteristics and other differences in both sectors. Alternatives for the combustion engine are less promising for freight than for passenger...
transport since the diesel engine used in freight transport mainly is energy efficient and very economical. One expects the diesel engine not to be substituted by any other technologies on a large scale in the next 15 to 20 years (Elzen et al, 1996; Wit, 1995). However, some alternatives fuels for diesel may be LPG (Liquid Petroleum Gas), LNG (Liquid Natural Gas), diesel with biofuel additives and hydrogen and some alternatives for the diesel truck may be the electric truck, with batteries or fuel cells and fuelled by hydrogen or methanol. In general, these alternatives compete easier with the diesel engine in urban areas than in rural areas since the diesel engine is not used optimally in urban areas.

Besides, the emissions from diesel are less treated since the three-way-catalyst is not suitable for the diesel engine.
Second, strategies for passenger and freight transport differ due to the different logistic characteristics of the passenger and freight transport networks. Regarding these logistic differences, it is important to realise that the difference between moving goods and people is not only the fact that goods have to be moved while people move themselves. Also of big importance is the phenomenon that in freight transport, at production locations, the composition and shape of goods to be transported may change and that goods may be stored for shorter or longer periods (cf. section 1.3). Different vehicles may be required to transport the different goods to and from the production location. The complexity of the logistic network increases due to this phenomenon.

The spatial distribution and the sensitivity of individuals

Several data above showed the large environmental impacts of transport. However, the impacts on nature and human beings do not only depend on the total amounts of energy use or emissions. Also relevant in this sense are the sensitivity of the various species or individuals and the location of the impacts. With regard to the location, in environmental transport research, urban and non-urban areas should be distinguished. First, the transport systems in these areas differ with regard to the share of the different transport modes and their technological features which in turn depend largely on speed and the driving characteristics. Second, the transport systems in these areas differ with respect to the logistic concepts. Consequently, the emission characteristics differ for urban and non-urban areas. Besides, not only traffic characteristics in these areas are different but also the population density. In cities, per square meter, more people are affected by emissions and noise from traffic than in the countryside.

It can be concluded that transport in urban and non-urban areas differs with regard to the air pollution characteristics, the concentration of the various compounds and the number of people effected by air pollution. Consequently,
strategies to reduce emissions or noise, or the nuisance as experienced by people, also differ for urban and non-urban areas.

**Indirect environmental impacts**

Another important factor in studying in environmental impacts of transport is the distinction between the so-called direct environmental impacts and indirect environmental impacts. Direct impacts are environmental impacts due to driving, sailing or flying. Indirect impacts are derived impacts such as the disappearance of nature due to the construction of infrastructure and the emissions caused by the production of asphalt or vehicles.

The indirect impacts of transport have been studied from a cost point of view. E.g. consciousness of the high social costs associated with traffic accidents stimulated research in the field of the external costs during the last ten years. Janse (1994) estimated the external costs of freight transport in The Netherlands in 1990 using two different methodologies. The estimates amount to Dfl 673 and 2708 millions respectively. The huge difference between both estimates originates from the costs due to the use of fossil fuels and costs due to air pollution which are included in the latter methodology but excluded from the former. For Germany in the year 1990, Planco (1990) estimated the external costs of motorised passenger transport between 0.51 and 0.67 Deutschmark per litre of fuel and those of freight road transport between Deutschmark 0.70 and 0.83 per litre of fuel. In road transport, high costs are associated with air pollution and accidents. In rail transport, a relatively large share of the costs is associated with noise (Planco, 1990; Hansson, 1992).

The indirect environmental impacts of transport in a physical sense received little attention in both research and policies until now. For The Netherlands, an exception is the waste problem from cars wrecks and tyres. Obviously, this problem drew attention since it is related to the high population density of The Netherlands, the high waste production and the lack of space. Another exception is the attention given to noise, in particular noise related to air transport.

In foreign countries, two studies carried out in the seventies (TFD, 1979; Boustead, 1979) paid attention to the indirect energy requirements of the various transport modes. For road, rail and water transport, these studies consider the energy requirements for vehicle and infrastructure construction and maintenance. Results from these studies show that the indirect energy requirements and emissions, compared to the direct energy requirements, are considerable (cf. box 1.1).

In order to estimate the indirect energy requirements of a current 40-tons truck

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1 ton kilometre is the transport of 1 ton over a distance of 1 kilometre.
in The Netherlands, one can apply the straightforward and simple methodology of Makhijani and Lichtenberg as presented in Boustead (1979). This leads to an estimate of the indirect energy requirements of 0.53 MJ per vehicle kilometre (cf. box 1.2). Such an estimate can be regarded as a lower bound.

The indirect energy requirements according to TFD (1979):

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Indirect Energy Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck, gross vehicle weight 10 tons</td>
<td>1.13 MJ/(load) ton kilometre</td>
</tr>
<tr>
<td>Truck, gross vehicle weight 50 tons</td>
<td>0.22 MJ/(load) ton kilometre</td>
</tr>
<tr>
<td>Train (32 wagons)</td>
<td>0.13 MJ/(load) ton kilometre</td>
</tr>
</tbody>
</table>

The indirect energy requirements according to Boustead (1979):

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Indirect Energy Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck, gross vehicle weight 20 tons</td>
<td>0.65 MJ/(load) ton kilometre</td>
</tr>
<tr>
<td>Truck, gross vehicle weight 30 tons</td>
<td>1.29 MJ/(load) ton kilometre</td>
</tr>
<tr>
<td>Train</td>
<td>indirect energy requirements are estimated at 45% of the direct energy requirements.</td>
</tr>
</tbody>
</table>

Sea transport: indirect energy requirements are estimated at 12% of the direct energy requirements.

Box 1.1 Early estimates for the indirect energy requirements of freight transport.

Assume:
- a truck to consist of steel only
- the production energy of steel to be 30 MJ/kg (van Heijningen, 1992a)
- the lifetime of a truck to be 800,000 kilometres

Then, the indirect energy of:
- a 40-tons truck with a mass of 14000 kg is estimated at 0.53 MJ/km

Box 1.2 Rough estimate for the indirect energy requirements of a truck based on a methodology suggested by Makhijani and Lichtenberg (Boustead, 1979).

5 The energy required to produce steel (plates) is lower than that of materials such as aluminium and plastics (Heijningen, 1992a). However, in the Makhijani and Lichtenberg’s methodology, these materials are treated as steel. Besides, Makhijani’s methodology disregards assembly energy and the energy requirements for the production of tyres, many of which a truck uses during its lifetime. Therefore, estimates based on Makhijani and Lichtenberg’s methodology are assumed to be underestimates of the real energy requirements to produce trucks.
The direct energy requirements of trucks according to several sources range from 7 to 17 MJ a vehicle kilometre (Mensinga, 1995) which means that the indirect energy requirements can not be neglected beforehand.

TFD (1979) also shows some results for the indirect energy requirements of the infrastructure. However, due to the manner the results are presented, they are difficult to interpret and besides, the energy requirements are difficult to allocate to the vehicles which use this infrastructure. However, as observed in the case of the vehicles, the energy required to construct and maintain infrastructure can not be neglected beforehand.

Summary

This section showed that:

- Transport activities in The Netherlands contribute considerably to national emissions.
- The contributions of passenger transport and freight transport to atmospheric emissions differ with respect to various compounds.
- The impacts of the transport emissions on nature and human beings depend on the amounts of emissions, on the location of the emissions (urban or non-urban) and on the sensitivity of individuals.
- In environmental transport studies and transport policy planning, most attention has been given to direct environmental impacts, while rough estimates of the indirect energy requirements lead to presume that indirect environmental impacts from transport may be important.
- Strategies to reduce emissions from transport should be studied in relation to transport type, i.e. passenger or freight transport, the location, i.e. urban or non-urban, and the type of emission, i.e. direct or indirect.

Focus of the thesis

This thesis focuses on freight transport for two main reasons. First, the developments in passenger transport differ from developments in freight transport. Environmental impacts related to the transport of freight will increase faster than environmental impacts related to the transport of people. Second, the environmental impacts of freight transport are much less addressed than those of passenger transport.

Also, this thesis focuses on the indirect environmental impacts since limited information is available on indirect environmental impacts while preliminary results indicate that they are important and should be included in studies dealing with the environmental impacts due to the transport of people and goods.
1.3 Freight transport

Direct environmental impacts

Environmental impacts predominantly connected with freight transport are the emissions of SO₂, NOₓ, aerosols and noise (cf. section 1.1). Specific impacts ask for specific solutions taking into account the characteristics of the freight transport system. Therefore, this section discusses the freight transport sector in The Netherlands in more detail. First, the share of the various transport modes in total freight transport and the contribution of the various transport modes to the environmental problems are discussed. Second, expected future developments in freight transport are outlined. Third, strategies to diminish impacts from freight transport are categorised and discussed.

Figure 1.3 shows the share of the different transport modes in the total direct emissions from freight transport. It can be concluded that most emissions in The Netherlands originate from road transport. The contribution of rail transport is negligible while that of inland waterways transport varies between 0% in case of the CₓHᵧ and 20% in case of the NOₓ emissions.

Subsequently, focusing on road transport, one should distinguish trucks and vans. Figure 1.4 shows the contribution of both vehicle fleets to the emissions of freight road transport. The relative high contributions to CO and CₓHᵧ by vans stem from the use of gasoline in this fleet. For other emissions, the largest shares stem from trucks. Finally, figure 1.5 shows where the emissions of the trucks and vans actually take place. From the figure, it can be concluded that CO and CₓHᵧ emissions are emitted in the built-up area mainly; they stem from vans mainly. However, also a considerable share of NOₓ, aerosols, and SO₂ emissions is emitted in the built-up area. Stop-and-go traffic in urban areas results in higher emissions per vehicle kilometre than traffic in rural areas.

Road transport plays a dominant role in the emission figures 1.3 till 1.5. Obviously, road transport also plays a dominant role if the numbers of tons transported or the ton kilometre performance for the various transport modes are compared. Figure 1.6 shows the shares of the various transport modes in inland goods transport⁶, further on also indicated as national transport. Road transport counts for more than 75% in both the ton and ton kilometre performance. The somewhat smaller share in the ton kilometre performance indicates that the average haul length of trucks (on Dutch territory) is somewhat shorter than the

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⁶ Inland goods transport is the transport of goods on Dutch territory of which starting point and final destination are in The Netherlands.
average haul length of trains and boats.

Such a large share of road transport in the total transport performance is also found on a European level. However, on a European level rail transport plays a larger role and inland waterways transport a smaller role than in The Netherlands (Group transport 2000, 1990).

Finally, figure 1.7 shows the shares of the different transport modes with regard to the tons transported in inland transport and the tons transported in international transport, both on Dutch territory. In national transport, road transport is dominant. In international transport, inland waterways transport and road transport have a more or less equal share.

**Summary**

For freight transport, based on the above, one can conclude that:

- Inland road transport is responsible for a large share of the overall transport emissions in The Netherlands.
- A significant part of the emissions occur in the built-up area. About 69% of the transport-related CO emissions, 26% of the NO \(_x\) emissions and between 40 and 60% of the other emissions (C\(_x\)H\(_y\), SO\(_2\) and aerosols) originate in built-up areas.
- Vans contribute to a relatively large extent to the CO and C\(_x\)H\(_y\) emissions and trucks to the NO\(_x\), aerosols and SO\(_2\) emissions.

**Future**

In the future, the environmental impacts due to the transport of goods will increase. In two scenarios published by AVV (1997), the increase of the national and international ton kilometres on Dutch territory range from 9.4% to 22.2% over the period 1996-2002. In three scenarios considered by the RIVM, the increase of vehicle kilometres in freight road transport ranges from 80% to 300% over the period 1990-2020 (RIVM, 1997). Also worldwide, projections show large increases with regard to the vehicle kilometres of freight transport. One expects a 50% increase of the ton kilometres performance in the ECMT countries over the years 1990-2010 (Group transport 2000, 1990). Indicators for the vehicle kilometres of heavy vehicles in both OECD and non-OECD countries and over the period 1990-2030 (OECD, 1997) show:

- a 100% increase in the OECD countries, and,
- an almost 300% increase in the non-OECD countries, which leads to,
- a worldwide increase of almost 200%.
Figure 1.3 The shares of the various transport modes in the freight transport emissions in The Netherlands’ (1993) (Klein, 1993).

Figure 1.4 The shares of ‘trucks and trailers’ and ‘vans’ in the road freight transport emissions in The Netherlands’ (1993) (Klein, 1993).

* In this figure, aer = aerosols.
The emissions from professional transport vehicles related to the spatial characteristics in The Netherlands’ (1993) (Klein, 1993).


* In this figure, aer = aerosols.
Strategies to diminish the environmental impacts

Measures can be taken to diminish the environmental problems related to the transport of goods. Below, several strategies, each consisting of a group of measures with specific characteristics, are discussed. Strategies can be divided into strategies with the explicit goal to reduce transport demand and strategies which consider transport demand as a fact. To reduce the transport demand, either the numbers of tons to be transported should be reduced, by changing consumption and production patterns, or the ton kilometre performance should be decreased, by changing the spatial organisation of production and consumption. These strategies have enormous impacts on today’s society and are not further discussed here. Strategies starting from an unrestricted growth are divided into strategies to reduce emissions and strategies to reduce disturbance.

Strategies to reduce emissions

Following a comprehensive Dutch study into a non-traditional scenario for freight transport (Peeters, 1993), three groups of emission reduction strategies are discussed below: 'green-transport strategies', 'green-logistic strategies' and 'green-technology strategies'.

![Figure 1.7](image-url) The modal split of tons transported on Dutch territory (1993) (CBS-AAD, 1993).
Chapter 1

Green transport strategies

In ‘green transport strategies’, tons to be transported are no longer transported by relatively polluting transport modes but by transport modes which are relatively environmentally friendly. The introduction of intermodal transport under certain circumstances is a typical ‘green transport strategy’.

Table 1.1 shows the energy requirements and emissions for the various transport modes according to some sources. For some compounds, the data in table 1.1 vary strongly. However, they give an impression of the emissions and energy requirements per ton kilometre for each transport mode. (A more comprehensive descriptions of the direct energy use and emissions from freight transport is found in Appendix A.) Table 1.1 shows that road transport vehicles use most energy and emit most chemical compounds per unit transport performance.

One should be careful in interpreting the average figures shown of table 1.1. The figures in table 1.1 are averages which means that they do not represent each separate transport activity at any place. E.g., the Dutch averages for road transport do not represent traffic on the main routes (with average driving speeds of 80 to 90 kilometres per hour). Many vehicle and transport system characteristics are incorporated in the average emission figures. Examples of vehicle characteristics are the (average) speed and the size of the vehicles. Traffic dynamics is an example of transport system characteristics. Urban transport is relatively energy inefficient due to the dynamic driving patterns in urban areas. This feature of urban transport is incorporated in the averages presented for road transport in table 1.1 since it is mainly road transport which serves urban transport. However, the relatively energy inefficiency is characteristic for the service fulfilled by road transport and not for road transport itself. For instance, if trains instead of vans and trucks would transport the goods in the urban areas, the averages for road transport would decrease while those of rail transport would increase. (Appendix A presents some energy and emission figures related to some specific system characteristics.)

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The name ‘Intermodal’ is used when more than two modes are used to transport the goods.
### Table 1.1: Energy requirements and emissions for various transport modes according to a few authors.

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Energy MJ/tkm&lt;sup&gt;*1&lt;/sup&gt;</th>
<th>NO&lt;sub&gt;x&lt;/sub&gt; gr/tkm</th>
<th>C&lt;sub&gt;H&lt;/sub&gt;&lt;sub&gt;y&lt;/sub&gt; gr/tkm</th>
<th>CO gr/tkm</th>
<th>SO&lt;sub&gt;2&lt;/sub&gt; gr/tkm</th>
<th>Part gr/tkm</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>^&lt;sup&gt;*3&lt;/sup&gt;4.06 1.40</td>
<td>2.97</td>
<td>0.68</td>
<td>0.9</td>
<td>0.20</td>
<td>0.39</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>^&lt;sup&gt;*1&lt;/sup&gt;1.20 1.68</td>
<td>1.21</td>
<td>0.29</td>
<td>0.36</td>
<td>0.11</td>
<td>0.05</td>
<td>2</td>
</tr>
<tr>
<td>Rail</td>
<td>0.66</td>
<td>1.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.07</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>Inland shipping</td>
<td>0.45</td>
<td>0.26</td>
<td>0.05</td>
<td>0.11</td>
<td>0.04</td>
<td>0.02</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>0.79</td>
<td>0.04</td>
<td>0.04</td>
<td>0.06</td>
<td>0.05</td>
<td>2</td>
</tr>
</tbody>
</table>

<sup>*1</sup> tkm = payload ton kilometre.


<sup>*3</sup> 4.06 MJ/tonkm are the energy requirements for a truck, 1.40 MJ/tonkm are the energy requirements for a tractor with semi-trailer.

### Green logistic strategies

In 'green logistic strategies', the logistics of the transport network are improved which leads to lower energy use and lower emissions. Examples of logistic improvements are an increase of the load factors<sup>8</sup> of vehicles and trains.

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<sup>8</sup> The load factor is defined as the payload (the actual load) divided by the load capacity with both payload and load capacity considered in tons. However, figures presented as load factor or figures presented as being based on average load factor may or may not include empty rides. In order to distinguish clearly among different interpretations for a load factor, one should preferably divide among (Bus, 1996):

A load factor (LF) related to the load capacity (C), the CLF, defined as the payload in tons divided by the load capacity expressed in tons;

A load factor (LF) related to the distance (D), the DLF, defined as the loaded vehicle kilometres divided by the total vehicle kilometres;

A load factor (LF) related to utilisation (U), the ULF, which is defined as the transport performance in ton kilometres divided by the actual number of vehicle kilometres times the load capacity (= the load capacity ton kilometres).

According to these definitions $ULF = CLF \times DLF$. 
Figure 1.8 shows the basic structure of a simplified logistic chain for goods production. Due to the nature of the production activities between the extraction of raw materials and consumption, the characteristics of the products to be transported, e.g. their shape, density and the composition or packaging of the goods, may change. Also, at all stages in between extraction and consumption, storage of products may be necessary. Besides, in between production and consumption, many intermediaries, such as retailers and wholesalers, are involved in the logistic processes. Storage and the change of the characteristics of the goods as well as the interferences of various intermediaries make the logistic network of freight transport much more complicated than the logistic network of passenger transport.

Due to the large variety in characteristics of the goods and the packaging of the goods, in a freight transport system there is a higher degree of specialisation than in passenger transport. For instance, there are heavy duty and light duty trucks, trucks developed for the transport of containers, trucks developed for cooling transport etc.

![Diagram of a simplified logistic chain of freight transport](image)

Figure 1.8 A simplified scheme of the logistic chain of freight transport.

Green technology strategies

'Green technology strategies' focus on the decrease of energy use and emissions based on technological improvements. Possibilities in this field are numerous but they may not be sufficient to achieve substantial reductions, especially not if demand increases simultaneously. Besides, the technological abatement of certain compounds may lead to an increase of the emissions of other compounds as is e.g. the case by using a catalyst. CO₂ emissions increase by

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9 In practice, several production activities may take place in between the extraction of raw materials and the production of goods. These activities are the production of the semi-manufactured articles. Next, several activities, so-called retail activities, may take place between production and consumption.
10% if NO₃ emissions are reduced by 75% (Waters, 1990). And N₂O emissions from traffic increase by 50% over the years 1995-2000 as a result of the high penetration of the three-way catalyst in various scenarios for The Netherlands considered in RIVM (1997).

Strategies to reduce disturbance

In strategies to reduce disturbance, place and time of the emissions instead of the total amount of emissions are most important. Besides, in these strategies, the focus is on the receiver and not on the source. Solutions to decrease disturbance should therefore be found in preventing the emissions to be emitted where they cause nuisance. First, one can think of other logistic concepts which lead to another spatial distribution of the emissions. Second, one can think of infrastructural changes such as the construction of tunnels. Third, one can think of new driving technologies such as electric vehicles. The introduction of such vehicles in urban areas leads to zero emissions in the urban area (locally) and to an increase of other emissions outside the built-up area (by power plants). In studying disturbance-reducing strategies, one should be aware of the fact that place-bounded and time-bounded local impacts may be shifted on to regional or global impacts.

Studies dealing with strategies to diminish environmental impacts

Future developments are influenced to some extent by the strategies to reduce emissions and disturbance from freight transport. For the Netherlands, two studies deal with this question. They consider the total freight transport system. The first study is a very comprehensive study for The Netherlands in which a so-called Trendbreuk (Trend interruption) scenario, a freight transport system is developed and described which fits in a sustainable development (Peeters, 1993). Sustainable development in this study is characterised by severe limits on energy use, CO₂ emissions and NOₓ emissions, varying between 20% to 50% compared to 1990, and by claims with regard to the environmental issues 'disturbance' and 'fragmentation'. Based on a base scenario deduced from the European Renaissance scenario of the Dutch Central Planning Bureau (CPB), the study describes the contribution of 'green transport', 'green logistic' and 'green technology' strategies to a sustainable freight transport system. The main conclusion of the study is that the development towards a transport system which is sustainable according to the definitions is possible for the year 2015. However, since all options of the green transport and green logistic strategies have to be mobilised to reach the emission reduction goals of 2015, it is extremely doubtful that the transport system will be able to develop further within the borders of sustainability after 2015.
However, in an essay by Van Witsen (1990; in CLTM) which also deals with a sustainable transport system in The Netherlands in the next century, the conclusion is drawn that a sustainable transport system can be achieved by 2050 in case many drastic societal changes occur. Van Witsen discusses elements of an environmentally friendly transport scenario for 2050. In this scenario, passenger and freight mobility in terms of passenger and ton kilometres increase by less than 20%. Vehicle kilometres on the other hand decrease strongly. Compared to the Trendbreuk scenario, the essay includes more far-reaching measures such as the construction of compact cities and a stabilisation of the Dutch population.

In both studies, measures are discussed which diminish the energy use and emissions from the total freight transport system. However, the variety in the freight transport system is large. Therefore, the impacts of abatement measures may differ for the separate freight flows. Policy makers are also interested in the consequences of the measures with regard to these separate flows. After all, they are often willing to implement measures on a scale smaller than the total freight transport system and prefer to implement measures with the highest yield first.

Finally, the indirect impacts of the transport of goods are considered neither in the studies discussed nor in the overview of the strategies. If these impacts are taken into account, additional strategies to decrease the emissions can be formulated in all three areas green transport, green logistic and green technology. However, one should be aware of the fact that energy strategies which lead to a decrease of the indirect impacts may lead to an increase of the direct impacts, and the other way around.

### 1.4 The scope of the thesis

#### 1.4.1 The aim and research activities of the thesis

As indicated before, this thesis focuses on freight transport. Arguments put forward to focus on freight transport are the faster increase of the environmental impacts related to the transport of freight and the fact that environmental problems by freight transport are less well addressed than those of passenger transport.

Second, this thesis focuses on the indirect impacts from freight transport. Indirect impacts are derived impacts such as the disappearance of nature due to the construction of infrastructure and the emissions caused by the production of asphalt or vehicles. From the preceding sections, it became clear that in environmental transport research until now, only limited attention has been
given to the indirect energy requirements and the indirect emissions. Besides the fact that in environmental issues, the focus is predominantly on the direct impacts, there are several other reasons for the generally observed negligence of the indirect impacts:

- To calculate the indirect impacts of transport is a very complicated process.
- Methodologies which are potentially suited to calculate indirect energy requirements have become available only recently.
- The political interest for the indirect impacts of transport is limited due to the fact that the political influence on construction works is limited. Most infrastructure was constructed in earlier times and yet, only the use of the infrastructure can be influenced.
- The construction of huge infrastructural projects such as the High Speed rail Line (the HSL) and the Betuwe rail line (the Betuwelijn) are only discussed from an investments point of view. The financial returns do not even play a crucial role let alone the environmental impacts related to these infrastructural projects.

However, preliminary results indicate that the indirect impacts are important and should be included in studies dealing with the environmental impacts caused by the transport of people and goods. This necessity is even more urgent in times that society discusses the expansion of infrastructural networks and transport systems by large infrastructural construction project as is the case in The Netherlands in these years. The increase of the indirect impacts due to these expansions may exceed the decrease of the direct impacts due to the expansion of the road capacity and therefore, a decrease of traffic jams and the direct impacts.

Third, this thesis focuses on the relation between abatement strategies and the large variety in the freight transport system since this variety may lead to different conclusions for specified freight flows if compared with conclusions formulated on a larger, e.g. national, scale.

The aim of this thesis is to perform an integral assessment of freight transport systems, to design a prototype model based upon this integral approach and the large variety in the transport system and to assess options for medium and long term abatement strategies.

The thesis covers the following research activities:

1. Development of methodologies to calculate indirect energy requirements and indirect emissions of transport activities (and similar activities) and the collection of basic data sets.

2. Calculation of the indirect energy requirements and indirect emissions for freight transport by rail, road and over inland waterways in The Netherlands. These indirect impacts of transport are compared with the direct impacts related to driving or sailing.
3 Development of a prototype freight transport impact model\(^{10}\) embodying the variety in the freight transport system regarding vehicle fleet and goods characteristics explicitly and that can be applied to study future strategies to reduce the direct and indirect energy requirements and emissions from freight transport. (Basic data sets derived from the research activity 1 and results from research activity 2 are incorporated in this model.)

As a result from the research activities, strategies can be formulated to reduce the indirect energy requirements and emissions from freight transport.

As indicated the second research activity, this thesis focuses mainly on The Netherlands. There are three main reasons for this:

• In The Netherlands, the transport demand has increased during the past 5 to 10 years and will continue to increase in the future. The Netherlands is a goods distribution country; the general trend is not to discuss the necessity and desirability of the expansion of the infrastructural network. However, the decisions to construct huge infrastructural projects such as the High Speed rail Line (HSL) and the Betuwe rail line (Betuwelijn) should require research with regard to the indirect energy requirements and emissions from infrastructure constructions in The Netherlands. Such indirect impacts are assumed to be even more important for The Netherlands than for other countries since The Dutch infrastructural network is very dense and therefore, new infrastructure incorporates many elements such as tunnels, etc.

• The indirect energy requirements and emissions of infrastructure are dependent on specific geographic characteristics (soil, slopes, altitudes). Therefore, in calculating the indirect energy requirements and emissions, regional aspects should always be taken into account. However, from a methodological point of view, it makes sense first to focus on one geographic region, in this case that of The Netherlands.

• Lots of data are required in order to calculate the indirect impacts and to build a freight transport model. For The Netherlands, these data are relatively easy to collect from the Dutch Central Bureau of Statistics (CBS) and many other sources such as the Dutch Railways, road builders and vehicle constructors, etc. (Thus, in this case, the reason to focus on The Netherlands is a more pragmatic one.)

The second research activity also indicates that overseas transport, transport by pipelines and other forms of underground transport are not included in this

\(^{10}\) In transport studies, three types of models can be distinguished: transport economic models (calculating (future) goods flows), transport traffic models (calculating (future) traffic flows) and transport impact models (calculating (future) energy use and emissions given a certain traffic flow).
study. The two main reasons for this exclusion are:

- The exclusivity of the goods markets these modes serve. There is no reasonable alternative for the transport of bulk products and containers by sea-going vessels. This also holds for the transport of drinking water and waste water which are the main products transported by pipelines (EIB, 1991). On the other hand, rail, road and inland waterways transport compete with regard to the goods they transport.

- A lack of data for (parts of) the transport systems. This in mainly the case for data regarding harbours and data regarding underground transport other than transport by pipelines.

1.4.2 Some methodological remarks

As indicated in subsection 1.4.1, the methodologies potentially suited for the calculation of the energy required for construction, manufacturing and maintenance of capital goods stocks present in transport systems, have become available only recently. Two fundamentally different methodologies exist. Process Energy Analysis (PEA) has been developed based on the physical sciences (IFIAS, 1974; Nieuwlaar, 1988). It combines analysis of material flows with analysis of the related energy contents and flows. Input-Output Energy Analysis (IOEA) has been derived from standard economic input-output analysis (Wilting, 1996) and Natural Capital Accounting (NCA; Noorman, 1995). In this methodology, energy inputs into production sectors are distributed over the final consumption sectors according to the pattern of intermediate deliveries described by input-output matrices. In essence, process energy analysis is applied on a process or product level while the input-output energy analysis based methodology is applied at a higher aggregation level, i.e. on the level of economic sectors or the economy as a whole.

In this study, both approaches are used in developing methodologies for the calculation of the indirect energy requirements of transport systems, i.e. the energy requirements related to the construction, manufacturing and maintenance of vehicles, infrastructure and other parts of transport system. A very important methodological issue is that transport systems can neither be regarded as a product level nor as an economic sector (according to the definition in the Dutch economic input-output tables). In fact, a transport system is a system at an intermedium level which:

- from a PEA point of view can be regarded as a collection of products, and,
- from an IOEA point of view can be regarded as a collection of capital goods which are produced by a few economic sectors, such as the construction section, only.
Based on these observations and the general concepts of PEA and IOEA, new methodologies are developed to analyse the energy requirements of transport systems on a PEA or IOEA basis\textsuperscript{11}.

The energy required for construction, manufacturing and maintenance of the various freight transport modes is calculated based on the methodologies developed. For each transport mode, the following parameters are calculated:
- the energy requirements for the separate vehicles and kilometres of infrastructure, as well as,
- the energy requirements of the total freight vehicle fleets and the total infrastructural networks.

The separate vehicle and infrastructure results are the necessary input for the model to be constructed. Results on the total freight vehicle and infrastructure level are used to calculate the (average) indirect energy requirements for rail, road and water transport. For both the vehicle \textit{fleets} and the infrastructural \textit{network} of each transport mode, the indirect energy requirements are calculated by combining:
- the annual depreciations and replacement investments respectively (in both systems) from an energy perspective, and,
- the annual transport performances by the fleets and on the infrastructure, expressed in ton kilometres.

In this study, one of the major methodological problems is the allocation of indirect energy requirements and emissions of the infrastructural networks and other capital goods to passenger and freight transport. After all, passenger and freight transport often use the same facilities, such as railway stations, and generally both passenger and freight vehicles make use of the same infrastructural network. Another complicated allocation problem concerns the allocation of the indirect energy requirements and emissions of infrastructure elements such as a bridge crossing the railway tracks. Such a bridge cannot be assumed having been built for use by the rail or road transport infrastructural network only.

In the life cycle analysis (LCA) approach (van den Berg, 1995), allocation problems often occur. In this methodology, guidelines have been developed to deal with allocation problems. These guidelines and experiences in LCA studies are helpful in developing allocation guidelines for transport system analyses.

\textsuperscript{11} Such approaches for transport system analysis are in fact not unique for this system. Methodologies suitable for transport system analysis, should, with some restrictions, be suitable to calculate the indirect energy requirements for other systems on an intermediate level.
The methodological approaches described above result in data which are annual averages and which incorporate:

- the logistic characteristics of the transport systems (e.g. average load factors),
- the present infrastructure construction and composition of the vehicle fleet,
- the state-of-the-art of production technologies (e.g. the production efficiency of iron production),
- the present role of rail, road and water transport, and,
- the present infrastructure use (e.g. the use by passenger and freight transport).

Therefore, the outcomes show insight in the average indirect energy requirements of freight transport modes but they do not represent the indirect energy requirements of each single transport activity (as is the case for the average direct energy requirements). Besides, results represent the indirect energy requirements of 'stable' transport systems, i.e. transport systems on the medium-long term. As soon as major shifts in the transport systems occur, the outcomes are no longer valid. However, the methodological approach does not change and can be applied to changed stable transport systems.

1.5 The structure of the thesis

This thesis consists of three parts: a methodological part, a part dealing with the calculation of the indirect energy requirements and emissions and a part dealing with the construction and application of a freight transport impact model.

Chapter 2 discusses the basic energy and emission methodologies and the application of these methodologies for transport system analysis. The chapter concludes with reference data sets for energy and emission analyses for (freight) transport systems.

The chapters 3 till 5 inclusive deal with the derivation and calculation of the indirect energy requirements of rail, road and water transport respectively. Next, chapter 6 summarises, compares and discusses the results of the chapters 3 till 5 inclusive. In chapter 7, basic emissions data sets of chapter 2 are combined with intermediate results concerning the capital goods stocks presented in the chapters 3 till 5 inclusive. This results in the presentation and discussion of the indirect emissions of freight transport.

Next, chapter 8 discusses the structure of the EEFT model (EEFT = Energy requirements and Emissions from Freight Transport) and applications of the model on some cases.

Finally, in chapter 9, general conclusions are drawn and the results are discussed.
Figure 1.9 The structure of the thesis related to the chapter numbers.