Direction indirect
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Summary

Impacts from transport

The transport of people and goods contributes considerably to economic development, welfare and well-being. However, there are also negative impacts on welfare and well-being. Road transport in The Netherlands contributes to the national CO₂ emissions by 16%, to the national NOₓ emissions by 57% and to the national CO emissions by 61%. Air pollution influences health and the feeling of well-being of people, especially within cities. Traffic noise disturbs many people regularly. Traffic accidents lead to high costs for the public health sector.

Freight transport

This thesis deals with the energy requirements and emissions from freight transport for a variety of reasons. First, freight transport can be characterised by specific environmental impacts. About two-third of the national emissions of aerosols and SO₂ are produced by freight transport vehicles and are associated with the use of diesel fuel. Both passenger and freight transport contribute significantly to NOₓ emissions. However, NOₓ emissions expressed per vehicle kilometre are much higher for trucks than for passenger cars. Besides, nuisance is caused more by freight than by passenger cars. Also, the environmental impacts related to the transport of freight will increase faster than environmental impacts related to the transport of people. 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 depending on scenario assumptions (RIVM, 1997).

Second, freight transport also has its specific logistic characteristics. Due to the nature of the production activities between the extraction of raw materials and the consumption of goods, 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. Due to this large variety in characteristics of goods and goods packaging, the freight transport system shows a higher degree of specialisation than passenger transport does. For instance, there are heavy duty and light duty trucks, container trucks, trucks developed for cooling transport etc.

Third, freight transport has its own technical characteristics. For instance, alternatives for the combustion engine are less promising for freight than for passenger transport since the diesel engine predominantly used in freight
transport 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).

**Summary**

This thesis focuses on the indirect energy requirements and emissions from freight transport. 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.

This thesis focuses on energy use and emissions related to the construction and maintenance of vehicles and infrastructure. In environmental transport research until now, only limited attention has been given to the indirect energy requirements and the indirect emissions.

Also, this thesis focuses on the relation between abatement strategies and the large variety in the freight transport system with regard to the vehicles fleets, the goods, the logistic chain, etc. This variety may lead to different conclusions for specified freight flows if compared with conclusions formulated on a larger, e.g. national, scale.

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 energy use and emissions related to driving or sailing.
3. Development of a prototype freight transport impact model 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.)

These research activities lead to the identification of successful abatement strategies aiming at the reduction of the indirect energy requirements and emissions from freight transport.

The main conclusions of the thesis are discussed below.
Conclusion 1

Suitable methodologies are available to calculate the indirect energy requirements and indirect emissions of the freight transport system and similar systems. However, in order to get more reliable emission results, reference emission data sets need to be improved.

Methodologies developed

Process Energy Analysis (PEA) and Input-Output Energy Analysis (IOEA) are suitable methodologies to calculate the indirect energy requirements of transport systems. Process energy analysis (PEA) has been developed based on 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 at 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.

The structure of the emission analysis methodologies PEmA (Process Emission Analysis), IOEmA (Input-Output Energy Emission Analysis) and IOEpPEmA (Input-Output Energy product Process Emission Analysis) is suitable to calculate the indirect emissions of transport systems. PEmA is derived from PEA. IOEmA is derived from IOEA and only takes into account the energy-carrier related emissions CO₂ and SO₂. IOEpPEmA has both process and input-output characteristics. Several methodological principles incorporated in the emission methodologies are similar to those of the energy methodologies.

Methodological issues

Both the input-output and process-based approaches are used in developing methodologies for the calculation of the indirect energy requirements of transport systems. An 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 process analysis point of view can be regarded as a collection of products, and,

• from an input-output analysis 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.

The basic structure of all the energy and emission analysis methodologies for freight transport system analysis in this thesis is the combination of the embodied energy or indirect emissions of the system, the depreciations of the system and the transport performance belonging to the system. This structure is shown by figure S.1.

**Figure S.1** The common structure of the freight transport system analyses.

### Application of the methodologies

The application of the analysis methodologies on transport system analysis leads to satisfying methodologies and reference data sets. Moreover, application of the energy methodologies to rail, road and water freight transport systems leads to estimates of the indirect energy requirements by PEA and IOEA for all transport (sub)systems with a reasonably to good correspondence. This supports the applicability of the methodologies.

However, application of the emission methodologies shows a wide variety in the results for the various methodologies. More detailed analyses of the results show some inconsistencies in the reference data sets. As a result, the absolute values of the indirect emissions are not very reliable. Yet, for CO₂ emissions, one should use the IOEEmA results in cradle-to-grave analyses. They are most reliable due to methodological aspects. For the other emissions, one should use the PEmA results since they are based on calculations including process and material-specific emissions.

Reference data sets, for PEmA and IOEpPEmA in particular, need to be improved in order to get more reliable results for the indirect emissions of transport systems. Improvement of these data bases is highly recommended.
Nevertheless, the emission results presented in this study can be considered rough estimates.

**Advantages of the methodologies**
One of the main advantages of the IOEA and IOEEmA methodology developed in this study is that they are less time consuming than the process-based methodologies, i.e. if sufficient data are available in a right format. However, also PEA and PEmA have some advantages. By use of this methodology not only system averages but also the energy requirements for separate vehicles and kilometres of infrastructure can be calculated. Besides, due to the nature of PEmA, other emissions than the energy-related emissions can be incorporated in PEmA while this extension is not possible for the input-output based methodologies.

**Applicability of the methodologies**
The methodologies developed to calculate the indirect energy requirements and emissions of freight transport systems are not unique for transport systems but can also be used to calculate the energy requirements and emissions of other systems, e.g. the building sector. Besides, the methodologies are not unique for freight transport. They can also be applied to passenger transport. However, reference data sets have to be adapted in order to analyse such systems.

**Conclusion 2**

*The average indirect energy requirements of all transport modes are considerable compared to the direct energy requirements. The indirect impacts of freight transport should be considered in energy policies on the medium-long and long term since they make up a considerable part of the total impacts of transport and since they are likely to increase in future.*

**Description transport systems**
This conclusion is based on analyses of the freight transport by rail, road and over water in The Netherlands in 1990. The transport systems include the infrastructural networks, including the construction works required for infrastructure crossings, and the vehicle fleets and in some cases supporting systems such as industrial and commercial buildings, internal means of transport, etc. Unfortunately, some parts of the system, such as harbours, are too complex to be analysed in any detail. These parts of the system could not be analysed due to the large variety in the (sub)system and due to a lack of data. Figures presented below are based on the infrastructural networks and vehicles fleets only.
The indirect energy requirements and emissions of the various transport modes

The estimate for the indirect energy requirements of both the vehicles and infrastructure in rail transport based on PEA is 0.34 MJ/tonkm; that of road transport is 0.46 MJ/tonkm. Both estimates based on IOEA are 0.25 and 0.48 MJ/tonkm, respectively. For water transport, the estimate of the indirect energy requirements is 0.27 MJ/tonkm; the vehicle’s share of this value is based on PEA, the infrastructure share is based on IOEA.

For rail transport, the indirect energy requirements make up about 45% of the sum of the direct and indirect energy requirements. For road transport and inland waterways transport, they make up about 18% and 60% respectively. In the various transport modes, the share of the vehicles in the total indirect energy requirements varies between 25% and 40%. Thus, the share of the infrastructure is always larger than 50%.

Generally speaking, the share of the indirect emissions in the total emissions is also considerable. The share depends on the compound and the transport mode.

(The percentages presented above depend strongly on the values for the direct impacts. These values differ strongly according to several sources. The values for the direct impacts used to calculate the percentages presented are based on Bouman (1990).)

The total amount of energy embodied in the road infrastructure in The Netherlands is about 3000 PJ, that in the rail infrastructure about 100 PJ and that in the inland waterways about 300 PJ. For comparison: the total primary energy use in The Netherlands in 1997 is about 3000 PJ. The total amount of energy embodied in the road vehicles of the professional freight transport sector in The Netherlands is about 60 PJ, that in the rail vehicles about 6 PJ and that in the inland shipping fleet (consisting of self-propelled barges and pusher craft and pushed barges) about 80 PJ.

All results presented above are valid for The Netherlands in the year 1990. In future, the indirect energy requirements and emissions may increase due to the expansion of the infrastructure (see ‘interpretation of the results’).

Comparison transport modes

Generally, the average indirect impacts of road transport are the largest. Those of rail transport and inland shipping are somewhat lower and more or less equal regarding the energy requirements. The transport modes order from most to less polluting with respect to direct impacts is ‘road, rail, water’. Considering both the direct and indirect energy requirements does not change the order from most to less polluting based on the direct impacts only.

However, for parts of the transport system, this order can be discussed. On the main infrastructure, they is not very clear yet if the overall impacts are in
favour of rail or road transport although they may still favour rail transport. A
detailed analysis is required to determine the overall impacts. This observation
concerning rail and road transport is relevant since real competition between rail
and road transport occurs on this main infrastructure.

**Sensitivity results**
All rail, road and water transport results are sensitive to depreciation rates of
vehicles and infrastructure. Also, most rail, road and water transport results are
sensitive to assumptions with regard to transport performance of the vehicles
and transport performance on the infrastructure.

Besides, rail and road infrastructure results are sensitive to assumptions with
regard to the share of the embodied energy of the rail or road infrastructure
allocated to freight transport. Finally, PEA results for the road vehicles are
sensitive to the materials requirements for spare parts and spare tyres and IOEA
results for road infrastructure transport are rather sensitive to the construction
costs of roads.

**Allocation issues**
One main allocation problem addressed in these analyses is the allocation of the
indirect energy requirements and indirect emissions of infrastructure to
passenger and to freight transport.

In case of rail transport, the energy embodied in the infrastructure is
allocated based on a damage factor which in itself is defined based on wagon
kilometres and axis loads (cf. subsection 3.2). In road transport, construction
and maintenance energy and emissions are dealt with separately. Construction
energy is allocated to passenger and freight transport based on the space the
passenger and freight vehicles use in real traffic. Maintenance energy is
allocated to passenger and freight transport based on the damage caused by the
passenger and freight vehicles. In case of inland waterways transport, allocation
is based on the damage caused by both passenger and freight ships. For the
large waterways investigated in this study, 100% of the indirect energy
requirements and emissions is allocated to freight transport.

**Interpretation of the results**
Cautiousness is due in interpreting the average results for the Dutch transport
system above. Results for the indirect energy requirements and emissions are
annual system averages which incorporate:
• the logistic characteristics of the transport systems,
• the present infrastructure construction and composition of the vehicle fleet
• the state-of-the-art of production technologies,
• the present role of rail, road and water transport, and,
• the present infrastructure use.
These system averages do not represent the indirect energy requirements and emissions of each single transport activity. Besides, the results represent indirect energy requirements of 'stable' transport systems, i.e. transport systems in the medium-long term. In case major shifts in transport systems occur, the results are no longer valid.

Infrastructure results incorporate logistical characteristics of the transport systems. In 1990, about 50% of truck kilometres took place on 2% of the roads, i.e. the motorways. The additional 98% of the network is necessary for the remaining 50% of ton kilometres. The average indirect energy requirements per ton kilometre of road transport, which amount to 0.34 MJ/tonkm, include both the relatively energy-efficient ton kilometres on the highways and the relatively energy-inefficient ton kilometres on the other roads. These energy-inefficient ton kilometres are not a real feature of road transport but a feature of the service provided by road transport. If all roads except the main roads would be replaced by railway tracks, the indirect energy requirements of road transport would decrease and those of rails would increase. If only the motorways and the transport performances on these motorways are considered, the indirect energy requirements are 0.07 MJ/tonkm. For tertiary roads, the indirect energy requirements are relatively high since only few tons are transported over this network.

The transport systems in The Netherlands in 1990 can be regarded as being 'stable'; calculations are based on annual average transport performances and annual average depreciations. Therefore, the results for the transport systems are valid as long as the systems are more or less stable with respect to the logistic characteristics, the manufacturing technologies, etc., i.e. on the medium-long term. As soon as major shifts in the transport systems occur, the results are no longer valid.

In The Netherlands, no major changes are expected to occur with regard to the freight vehicle fleets on the medium-long term. Major changes are more likely with regard to the infrastructural networks. In the next few decades, such infrastructural changes are the construction of huge infrastructural projects (such as the Betuwe rail line en de High Speed rail Line), the construction of new types of infrastructure (such as underground (freight) transport) and a relatively large expansion of the infrastructural networks while the traffic intensity on the short term only increases gradually.
Conclusion 3

The variety the freight transport system should be considered explicitly in studying transport flows and their related energy requirements and emissions and in formulating strategies to reduce the impacts from (freight) transport.

The variety of the freight transport system

An important observation is that the indirect impacts of parts of the transport systems may differ strongly from the system’s averages. E.g., vehicles with a small load capacity have relatively large indirect energy requirements. Similarly, for secondary and tertiary roads, the indirect impacts are much larger than for the main roads. Therefore, variety should be considered explicitly in studying transport flows and their related energy requirements and emissions and in formulating strategies to reduce the impacts from (freight) transport.

A prototype freight transport model has been developed which explicitly takes into account the variety in the freight transport system with regard to the vehicle fleet, the infrastructure and the goods characteristics. With the model, one can analyse the influence of the specific features of the freight transport systems related to specific transport chains, specific use and specific circumstances with regard to time and space. The model was applied in a case study on light and heavy commodities in order to study strategies to reduce impacts from freight transport with regard to both direct and indirect energy requirements and emissions.

Strategies to reduce the environmental impacts from freight transport

Several strategies are available to reduce the direct and indirect impacts of freight transport. Some strategies, such as an increase of the load factor or the use of larger vehicles, are strategies by which both the direct and indirect impacts decrease. However, some other strategies, such as the construction of new infrastructure in order to solve traffic jams and direct energy requirements lead to an increase of the indirect impacts due to the construction activities.

Strategies to reduce the indirect impacts are more related to the infrastructure than to the vehicles. Examples of promising reduction strategies are a better exploitation of the infrastructure, the introduction of main infrastructure suitable for freight transport only (in case freight flows are sufficiently large to utilise the full capacity) and an increase of asphalt recycling. Which strategies are most promising may differ for the different parts of the transport system and for different goods groups. E.g., on the main infrastructure, strategies to reduce the direct impacts are most promising. In case of secondary and tertiary roads and for rail transport, strategies to reduce the direct as well as indirect impacts are relevant.

Impacts of strategies to reduce the impacts of freight transport discussed in
this thesis include technical theoretical potentials. However, the real potential for change does not only depend on the physical potential. Economic, psychological and institutional aspects are relevant too (Noorman et al, 1998).