6 The indirect energy requirements of freight transport

6.1 Introduction

This chapter compares and discusses the results of the chapters 3 till 5 inclusive. Section 6.2 summarises the IOEA and PEA results of rail, road and water transport and discusses similarities and differences\(^1\). All results describe the situation of 1990 in The Netherlands incorporating characteristics of the Dutch transport system in and before 1990. In section 2.7, three categories of characteristics were distinguished. The first one includes those features which are transport-mode specific, such as the composition of the vehicle fleet, the material use in the infrastructure, etc. These characteristics which determine the validity of the results for other countries and in the future were discussed in the discussion sections of the chapters 3 till 5 inclusive. This chapter discusses the two other categories of characteristics, those related to the structure and organisation of the transport system and those related to the technologies applied in manufacturing.

The results for rail, road and water transport as presented in section 6.2 can be used for the comparison of the direct and indirect energy requirements of each transport mode and for the comparison of the present-day transport modes. But, since they represent static and no dynamic results, they are not suitable to answer the question which transport mode uses the least indirect energy under different circumstances. If, for instance, the modal split changes radically, the results also change accordingly. Results are therefore valid within certain limits, also stemming from assumptions in the calculations, basic data sets of the methods and the restrictions related to the used methods used.

Section 6.3 discusses the reliability of the results. The aspects discussed in this section influence the results of all transport modes and, thus, the comparison among the transport modes. First, it discusses the allocation of the construction works. Second, it discusses the energy embodied in 'other equipment' besides vehicles and infrastructure which is included in some calculations and excluded from others. Third, it discusses the state-of-the-art of production technologies implicitly present in the analyses. Fourth, it discusses alternative basic data sets for IOEA. And fifth, this section compares results of the present study to the only other study we are aware of which deals with the indirect energy requirements of freight transport in relation to the transport performance (TFD, 1979).

\(^1\) Only vehicle and infrastructure results are considered. Results regarding 'other equipment' in the transport systems are excluded since they are not available for all transport (sub)systems.
Section 6.4 discusses characteristics with regard to the organisation of the transport system. These characteristics influence the results of all transport modes and the comparison among them. In this section, however, the essential differences of the various transport modes are emphasized more and differences due to the logistics features of the total transport system less.

Finally, section 6.5 integrates results of the previous sections and discusses the transport modes based on both indirect and direct energy requirements.

6.2 Comparison of the indirect rail, road and water transport results

Figure 6.1 summarises the results of the indirect energy requirements for road, rail and water transport. Results of all analyses except those of the IOEA analyses of rail transport are sensitive to assumptions with regard to the depreciation rate of vehicles and infrastructure and the transport performance variable (cf. tables 3.8, 3.16, 3.17, 4.8, 4.9, 4.15, 4.16, 5.4 and 5.8). Figure 6.1 shows both best estimates and the intervals around the best estimates consisting of lower bounds and upper bounds that correspond to changes in the values of the transport performances. (For changes in the depreciation rates, a similar figure can be produced.) For the rail vehicles, the transport performance increases or decreases by 11%. These percentages correspond to changes in the distances over which rail vehicles travel to foreign countries such as France and Germany (cf. section 3.2). For all other means of transport (vehicles and boats) and infrastructure analyses, the transport performance increases and decreases by 15%.

The comparison of the results as shown in figure 6.1 concentrates on the results for the means of transport and the infrastructure. Energy embodied in 'other equipment' is excluded since it has not been calculated for all transport modes. Since PEA and IOEA-1990 are based on 1990 technologies, best estimates based on these methods can be compared. Best estimates based on IOEA-hist were calculated based on historical manufacturing technologies. Therefore, they differ from the other estimates.

Figure 6.1 shows that the energy embodied in the infrastructure is higher than the energy embodied in the means of transport. For rail and water transport, it is about 1.5 times the energy embodied in the means of transport. For road transport, the energy embodied in the infrastructure is about 3 times the energy embodied in the means of transport.

Figure 6.2 shows the PEA and IOEA-1990 results of vehicles and infrastructure separately. For the rail and road vehicles, the intervals resulting from a change in the transport performance overlap. The average IOEA-1990 and PEA rail vehicles result, which is 0.115 MJ/tonkm, and the average road vehicles result, which is 0.126 MJ/tonkm, are not really different. The vehicle
The indirect energy requirements of freight transport results for rail and road transport can be regarded as being equal. The interval around the best estimate of the embodied energy of barges does not overlap with the rail and road vehicles intervals. The intervals corresponding to a change in transport performance on the water and rail infrastructure overlap. The intervals of road transport and the other transport modes do not. From both figures 6.1 and 6.2 it can be concluded that the total indirect energy requirements of rail and water transport do not differ significantly. The indirect energy requirements of road transport and the other transport modes are different. This difference is caused by the differences in the share of the infrastructure.

Figure 6.1 The indirect energy requirements of the different transport modes including intervals that correspond to a change in transport performance (1990).

Figure 6.2 Estimates of the indirect energy requirements of the vehicles and infrastructure for the different transport modes including intervals that correspond to a change in transport performance (1990).
Finally, table 6.1 summarises the embodied energy of the infrastructural networks and vehicle fleets in rail, road and water transport according to the definitions defined in the previous chapters. The embodied energy in the road infrastructure amounts about to the annual primary energy requirements in The Netherlands; in 1990, these were 2721 PJ (CBS-NEH, 1990).

Table 6.1 The embodied energy of the infrastructural networks and vehicle fleets in rail, road and water transport.

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Passenger and freight transport PJ</th>
<th>Vehicle fleet freight transport PJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail IOEA-1990</td>
<td>82</td>
<td>5.9</td>
</tr>
<tr>
<td>Rail PEA</td>
<td>100</td>
<td>6.6</td>
</tr>
<tr>
<td>Road IOEA-1990</td>
<td>3471</td>
<td>54.2&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Road PEA</td>
<td>2638</td>
<td>64.1&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Water IOEA-1990</td>
<td>32&lt;sup&gt;3&lt;/sup&gt;</td>
<td>82&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Water PEA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>*1</sup> The vehicle fleet includes the professional road transport fleet.
<sup>*2</sup> The water infrastructural network includes the inland waterways.
<sup>*3</sup> The vehicle fleet includes the self-propelled barges and the pusher-craft pushed-barges combinations in the inland shipping fleet.

6.3 Reliability of the results

This section discusses the reliability of the results related to those variables which influences the results of all transport modes and thus, the comparison among transport modes.

Construction works

The embodied energy in the construction works required for infrastructure crossings is included in both the IOEA and the PEA results. In these results, the embodied energy in the construction works is allocated to the transport modes based on ownership. This choice for the allocation is forced by the non-availability of data. The results would change in case the embodied energy in all construction works could be calculated and allocated based on, for instance, number of vehicles passages. In the present study, the construction energy embodied in construction works can be estimated based on investment values.
For road transport, the construction works is estimated at 30 to 40 percent, for water transport at 55%. For rail transport, the construction works will probably be lower than for road transport since the rail infrastructure network is less dense than the road infrastructure network and since the rail tracks are generally older than roads and consequently many infrastructure crossings were constructed after the rail tracks were constructed.

‘Other equipment’ and transport supporting systems
The embodied energy in ‘other equipment’ is the energy embodied in industrial and commercial buildings, internal means of transport, computers etc. The embodied energy of these parts of the transport system were calculated in the IOEA of rail and road transport. These energy requirements concern the capital goods owned by the Dutch railways and owned by the professional road transport sector.

Not included in any of the calculations in rail, road or water transport is the energy embodied in

- equipment for transshipment owned by other companies than the Dutch railways and the professional road transport sector,
- industrial and commercial buildings owned by transport-supporting companies, and,
- equipment present in the harbours.

The energy embodied in these parts should be included in a fullscope analysis of the freight transport (sub)systems. Unfortunately, these parts of the system are too complex to analyse in any detail.

Manufacturing technologies
The efficiencies of the technologies as applied in The Netherlands play a role in the GER values of the materials and the energy intensities of the economic sectors. As a consequence, all results comprise the state of the art of the technologies in The Netherlands in and before 1990.

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2 The investment value of the motorways and highways owned by Rijkswaterstaat is Dfl 50 billion (Dekker, i1994); about Dfl 35 billion (70%) of these investments are investments in construction works required for infrastructure crossings (van der Toren, i1994). The investments in construction works of province and municipality roads in The Netherlands are estimated at 25 to 40 % of the total investments (estimate of the author based on Medema, i1994). Of railway tracks under construction these days, the share is estimated at about 50% (estimate of the author based on Railbouw, i1993). However, tracks which were constructed in earlier days consist of less construction works. Therefore, the construction works share of the rail network is estimated to be lower than that of the road network. The construction works share of the inland waterways was already discussed in chapter 5 (cf. subsection 5.4).
The GER values of the materials used in PEA and the energy-intensities of the economic sectors as considered in IOEA-1990 include the manufacturing technologies of 1990. Results based on these values describe the energy embodied in the infrastructure and vehicle park as if they would have been manufactured by means of 1990 technologies. Results of IOEA-hist (based on historical energy-intensities of the economic sectors) describe the energy used in earlier times for the production of vehicles and infrastructure present in 1990. Results based on IOEA-1990 and IOEA-hist should differ much in case many capital goods stocks originate from a long time ago and should not differ much in case the capital goods stocks are relatively young. The differences found between IOEA-1990 and IOEA-hist for rail and road transport correspond to these suppositions.

All energy intensities, in both IOEA-1990 and IOEA-hist, and the GER values used in PEA include manufacturing technologies in The Netherlands. Of course, not all products part of the transport systems are produced in The Netherlands. However, the energy intensities of the Dutch industries are supposed to represent the energy intensities of comparable industries in the other European countries from which for instance the vehicles largely originate. The GER values of the materials used in The Netherlands are supposed to represent the GER values of the materials used in the means of transport and infrastructure of the Dutch transport systems. For some GER values such as that of steel and cast iron, this assumption is undoubtedly valid. The GER value of steel, the most dominant material in terms of weight in the PEA, is a representative value for The Netherlands as well as the rest of Europe (cf. 2.5.3). For the GER values of some other materials this assumption may not be true. In the previous chapters, sensitivity analyses were carried out in order to study the sensitivity of the results for the GER values of materials dominantly present in the transport systems. The main conclusion which can be drawn from the different sensitivity analyses is that vehicles results are not very sensitive for the GER values of steel while the infrastructure results are rather sensitive for the GER values of asphalt.

In general, it is difficult to derive the impacts on the results due to deviations in the GER values of materials or the energy intensities of the economic sectors which are related to other manufacturing technologies.

Other data sets for IOEA
There are a few other data sets which have been derived from energy requirements and investments which could be suitable to use in the IOEA-based methodology for transport system analysis. This section discusses differences between these data sets and the data sets used in this study as well as the suitability of the other data sets as reference IOEA data sets for transport system analysis.
Haanappel (1995) calculated energy intensities for the transport means industry for the period 1973-1990 with the help of both IOEA and PEA. The study focuses on the trends in energy use. The trends reported by Haanappel are similar to the trends of the transport sector as found by Wilting for the period 1969-1988 (Wilting, 1994) and as discussed in chapter 2 (cf. 2.5.2). Since Wilting's trends are similar to the trends in energy intensities of the economic sectors calculated in this study, the trends in Haanappel's study and this study are also alike. The absolute values of the energy intensities of the transport activities calculated by Haanappel are somewhat lower than those calculated by Wilting and somewhat higher than those in this study. These differences between Haanappel's and Wilting's values are explained by the system boundaries which are more narrow in PEA and therefore lead to lower values. Differences among Haanappel's figures and those in this study are explained by both the use of PEA and the same factors which are responsible for the differences between the absolute values of the energy intensities in Wilting's and this study (cf. 2.5.3).

The data sets calculated by Haanappel form no real alternative for the reference data sets in this study since in the first place, the energy intensities series only covers the period 1973-1990 and secondly, only the transport sector has been studied by Haanappel while for this study a consistent data sets covering several sectors is necessary.

An IOEA data set made available by the CBS contains several activity-specific energy requirements (CBS, d1990; cf. section 2.6). A close look at these activity-specific energy requirements and the sector-specific energy intensities calculated by Wilting and used this study show that they differ significantly (cf. the tables 2.4 and 2.14). A study of the methodology developed and used by the CBS to calculate the specific energy requirements of the products offered no reasonable explanation for the differences between the energy requirements per product and the energy requirements per sector calculated by Wilting. The basic data sets of the CBS from which they derived the specific energy requirements of the products do not seem to be the main reason for the differences between their energy requirements per product and Wilting's energy requirements of the economic sector. Namely, if Wilting calculates the energy requirements of the various products by use of the CBS basic data sets and his IOEA analysis methodology, the energy requirements...
of the products are much lower.\textsuperscript{3}

Since the methodologies used by the CBS and Wilting seem to differ, the activity-specific energy requirements can not replace some of the sector-specific energy requirements of Wilting. This would lead to inconsistent data sets. Besides, since the CBS activities do not cover all economic sectors required for transport system analysis, this data set by itself forms no alternative reference data for the IOEA-based methodology for transport system analysis.

Comparison with 'Energy efficiency in passenger and freight transport transportation (TFD, 1979)'.

This section discusses one other study available which contains calculations of the indirect energy requirements of freight transport for various modes. In this study, conducted by the Transport Research Federation (TFD) in 1979, the indirect energy requirements of freight transport in Sweden were calculated based on process energy analysis. Although the TFD results are valid for Sweden specifically, it is interesting to compare them with results in this study.

There is one methodological difference between the TFD study and this study. The TFD results were calculated for separate vehicles and based on the average transport performances of these vehicles. These transport performances are calculated by combining the vehicle’s lifetime in vehicle kilometres and an average load factor. The PEA results in this study are calculated based on the total embodied energy of a vehicle fleet and the total realised transport performance of this fleet.

For rail vehicles, the TFD indirect energy requirements equal 0.126 MJ per tonkm. These energy requirements correspond with the 0.120 MJ per tonkm calculated in this study. However, the TFD considers an electric locomotive and in this study, the vehicle fleet consists of both electric and diesel-electric locomotives.

The embodied energy of the 23-tons truck in the TFD study is 960 GJ, that of a 50-tons truck 1775 GJ. In this study, the embodied energy of a 20-tons truck and 40-tons truck is 735 GJ and 1275 GJ, respectively. The biggest differences between the TFD results and the results in this study are found in the energy required for production and manufacturing and the energy embodied in the

\textsuperscript{3} A data set containing the energy intensities of 247 different economic activities came available very late in this research (Wilting, d1997). This data set can form a new reference data set for the IOEA-based methodology for transport system analysis. Calculations based on these data have not been carried out yet. A comparison among the data in the elaborated detailed list and the data used in this study leads to the conclusion that most estimates derived in the previous chapters 3 till 5 inclusive would be somewhat higher if they would be calculated based on the energy intensities presented in the elaborated list.
The indirect energy requirements of freight transport

spare parts which are both higher in the TFD study. The differences between the TFD and this study with regard to the indirect energy requirements per ton kilometer are even higher since the assumed lifetimes of the trucks in the TFD study are much lower. Based on a lifetime of 200,000 km for a 23-tons and 480,000 km 50-tons truck and a 40% load capacity, the indirect energy requirements of both trucks are 0.37 MJ and 0.22 MJ per tonkm respectively. If in this study, the indirect energy requirements would be estimated based on the lifetime in vehicle kilometres and average load factors, the indirect energy requirements would be 0.10 MJ/tonkm for a 23-tons truck and 0.17 MJ/tonkm for a 40-tons truck.

The indirect energy requirements of a 2000-tons ship according to TFD is 0.05 MJ/tonkm. In this study, the indirect energy requirements of an average ship of the inland shipping fleet is 0.072 MJ/tonkm. The corresponding (weighted) average load capacity is 830 ton. The share of the assembly energy in the total energy requirements is similar in both studies (20% to 25%).

Finally, if the infrastructure results of both studies are compared, it seems that estimates calculated in this study are higher than those in the TFD study. E.g. the embodied energy of rail tracks are 13.9 TJ per kilometre in the TFD study and the average embodied energy of 1 kilometre of tracks in this study is 22.1 TJ. For roads, the estimated embodied energy values seems to differ about a factor 2. However, results can not properly be compared since necessary details for this comparison, such as the width of the road, the thickness of the sand (or stones) layers and asphalt layer etc., are missing.

6.4 The structure and organisation of the transport system

The density of the goods

The commodities transported by trucks differ from those transported by vessels. For instance, in inland transport, the trucks transport almost all agricultural products, foods, raw materials and construction materials. Vessels are more strongly concentrated on the transport of the heavy commodities such as raw materials, fertilizers and fossil fuels. This difference in the density of the goods transported by trucks and by vessels is accounted for in the embodied energy values calculated for water and road transport (expressed in MJ/tonkm). However, this difference is not a real feature of the transport mode but a feature due to the density of the commodity. If fertilizers (with a high density) would be transported by trucks instead of by vessels, the (average) indirect energy

4 These estimates for a 20-tons truck and 40-tons truck are based on the following assumptions: load capacity 26 ton and 13 ton, load factors 0.43 and 0.50 and vehicle’s lifetime in vehicle kilometres 770,000 and 1,000,000, respectively.
requirements of vessels would increase and those of trucks would decrease. Therefore, if one ton of goods needs to be transported, a choice based on the lowest energy use should not be based on the average energy use per ton kilometre for the transport modes. Instead it should be based on a measure which expresses the energy requirements to transport one fictive ton over one kilometre for the different transport modes and various vehicles for each mode.

With regard to the vehicles’ embodied energy value, a suitable measure is the energy use per ton of load capacity. A comparison of the different transport modes based on this measure is possible by means of the process energy analysis results for the different vehicles (cf. table 6.2).

**Infrastructure use**

Other important structure and organisation characteristics dominantly present in the results are logistic characteristics. Most important is the length of the different transport mode networks for the different transport modes in relation to the transport performance on the infrastructure. This is illustrated in the following example. In 1991, the total length of the wide-spread infrastructural network for road transport was 104,831 km; the main infrastructure (freeways and highways) accounted for 4.1 percent of this network (CBS-W, 1992). In 1990 (no data for 1991 are available), the vehicle kilometre performance by trucks on the road network was 6050.10^6 km; that on the main infrastructure was 4079.10^6 km (CBS-VVW, 1992). This means that 67% of vehicle kilometres took place on 4.1% of the roads. If only this main infrastructure is considered, the indirect energy requirements per ton kilometre are much lower than in case the total network is considered. However, road transport serves a large market and the additional 96% of the network is necessary for the remaining 33% of the ton kilometres.

The indirect energy requirements per ton kilometre of road transport as calculated in the best estimate include both the relatively energy-efficient ton kilometres on the main infrastructure and the relatively energy-inefficient ton kilometres on the other roads. If all roads except the main infrastructure would be replaced by tracks, the indirect energy requirements of road transport would decrease enormously and those of rails would increase enormously.

The combined use of the infrastructure by passenger and freight transport is

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5 The 4.1% of the total network’s embodied energy can not simply be related to the 67% of the ton kilometre performance of the truck fleet on the roads. The energy required for construction and maintenance of state roads is higher than 4.1 percent of the energy required for the total network since state roads are wider and since the truck intensity on the state roads is higher than on the other roads. However, without doubt, the energy requirements decrease in case only this part of the system would be considered.
The indirect energy requirements of freight transport

another logistic feature which influences the infrastructure results. Differences between the combined use in rail and road transport influence the results and make them basically incomparable.

Below, results are presented for motorways. In such results, influences of the wide-spread road network are not present but influences of the shared use of the infrastructure by both passenger and rail transport are still present. If one wants to exclude this shared use, one should study non-existing infrastructure serving freight transport only. However, since such an infrastructure does not exist at the moment, such results can only be calculated based on several assumptions.

Vehicles categories
For different vehicles transporting aluminium containers in rail and road transport, table 6.2 shows results (and associated assumptions) based on a comparison of energy requirements per ton of load capacity.

For all transport modes, the results per ton of load capacity differ from the average Dutch energy requirements. They are all lower since in practice, the actual load is often lower than the load capacity. The table shows that the indirect energy requirements per ton of load capacity of the vessels are the lowest. For vessels, these indirect energy requirements range from 39% to 57% of the average Dutch energy requirements. The energy requirements per ton of load capacity of rail and road transport vehicles are higher. In case of rail transport, the indirect energy requirements per ton of load capacity make up 42% to 60% of the average Dutch energy requirements. In case of road transport, the indirect energy requirements per ton of load capacity make up 47% to 72% of the average Dutch energy requirements. Results for the different vehicles in rail and road transport depend on the size of the vehicles and the density of the goods. For road transport they are somewhat higher than for rail transport while the average Dutch energy requirements for both transport modes do not differ.

If one transports containers with a load of 12 tons by a 20-tons trucks, a 40-tons truck suitable for large-volume transport or a train suitable for large-volume transport, the energy requirements are 91, 80 and 69 kJ /km / ton of load capacity respectively. If one transports containers with a load of 24 tons, the energy requirements are 59 and 48 kJ /km / ton of load capacity in rail and road transport respectively. Since the mass of the containers is such that the mass of the load of the vehicles described above approaches the vehicles’ maximum, the energy requirements per ton of load equals the energy requirements per ton of load capacity. Therefore, a switch from road to rail transport means less energy requirements in any of the cases described. However, the energy decrease percentage depends on the density of the goods and the related vehicles.

The maximum load of the vehicles is not reached for all goods transported
in containers. Results of table 6.1 show that the choice for rail or road or a type of rail or road vehicle needs detailed study. For this purpose, the freight transport model discussed in chapter 8 has been developed.

Table 6.2 The indirect energy requirements of vehicles carrying aluminum containers in relation to their load capacity.

<table>
<thead>
<tr>
<th>Vehicle*1</th>
<th>Embodied energy (GJ)</th>
<th>Lifetime x 10^6 (km)</th>
<th>Load capacity (tons)</th>
<th>Indirect energy requirements (kJ/km/ton of load capacity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck 20 ton(^2)</td>
<td>1040</td>
<td>0,9</td>
<td>12.7</td>
<td>91</td>
</tr>
<tr>
<td>Truck 40 ton(^2) mass transport</td>
<td>1461</td>
<td>1</td>
<td>24.9</td>
<td>59</td>
</tr>
<tr>
<td>Truck 40 ton(^2) volume transport</td>
<td>1894</td>
<td>1</td>
<td>23.7</td>
<td>80</td>
</tr>
<tr>
<td>Train 200 m(^3), mass transport</td>
<td>27129</td>
<td>1</td>
<td>563</td>
<td>48</td>
</tr>
<tr>
<td>Train 200 m(^3), volume transport</td>
<td>25191</td>
<td>1</td>
<td>368</td>
<td>69</td>
</tr>
<tr>
<td>SP barge 582t</td>
<td>9640</td>
<td>0,4</td>
<td>582</td>
<td>41</td>
</tr>
<tr>
<td>SP barge 1400t</td>
<td>20100</td>
<td>0,4</td>
<td>1400</td>
<td>35</td>
</tr>
<tr>
<td>SP barge 3000t</td>
<td>34500</td>
<td>0,4</td>
<td>3000</td>
<td>28</td>
</tr>
</tbody>
</table>

*1 All vehicles carry aluminium containers.

*2 The trucks specified in the table are a truck of 20 tons carrying one 20ft container and two trucks of 40 tons, one truck carrying one 40ft container which is suitable for products with low densities and one carrying two 20ft containers which are suitable for products with high densities.

*3 The trains specified here are a train of 200 meters developed for goods with low densities, i.e. a train which contains wagons with 2 axes (which were developed for large-volume transport) and 40ft containers, and a train developed for goods with high densities, i.e. a train which contains container wagons with 4 axes (which were developed for heavy goods transport) and 20ft containers.
Infrastructure categories
An estimate of the construction and maintenance energy of 1 kilometre of motorway over a period of 50 years is about 90 TJ (cf. section 4.4). Taking into account the ton kilometre performance by trucks, trucks and trailers and trucks with semitrailers on these roads\(^6\), the indirect energy use is 0.07 MJ/tonkm. This value differs substantially from the corresponding value for the complete Dutch infrastructure which is 0.34 MJ/tonkm. For other types of roads similar figures can be calculated. For secondary roads, the indirect energy requirements are 0.23 MJ/tonkm; for tertiary roads, they are 0.98 MJ/tonkm.

6.5 A comparison of the transport modes including both direct and indirect energy requirements

The best estimates for the total indirect energy requirements of road transport, i.e. the energy requirements embodied in both the vehicles and the infrastructure, are larger than those of rail and water transport. Those of rail and water transport are more or less equal. Differences between road transport and the other modes are mainly found in the infrastructure values.

The results of rail, road and water transport incorporate many system characteristics, such as the state-of-the-art of transport manufacturing technologies and logistic features of the entire transport system. The results are suitable for a comparison of the direct and indirect energy requirements of the different transport modes and for a comparison among the present-day transport modes.

In the previous chapters dealing with the separate transport modes, it was already concluded that the indirect energy requirements make up a considerable part of the sum of the direct and indirect impacts. Next, if one compares the various transport modes, one can draw the following conclusions. The transport modes order from most to less polluting with respect to direct impacts is 'road, rail, water'. The indirect impacts of road transport are higher than those of rail transport and water transport. Therefore, considering both the direct and indirect energy requirements does not change the order from most to less polluting based on the direct impacts only.

\(^6\) From these values, also the share of the construction energy allocated to freight transport is derived. The ton kilometre performance of all freight trucks is about 24 billion ton kilometres.
As indicated, both the results for the indirect impacts and the direct impacts include system characteristics which are not all specific for the transport mode itself but for the service provided by the transport modes. Logistic characteristics can partly be excluded from the results. This leads to results (cf. section 6.4) which stress the essential differences of the various transport modes more and emphasize differences due to logistics features of the total transport system less.

If only the main infrastructure is considered, results with regard to the indirect impacts show that road transport may not be more or even less polluting than rail transport. With regard to the direct energy requirements, on the main infrastructure, trucks are still more polluting than trains. However, here, the differences with rail transport are considerably smaller than in case Dutch averages for rail and road transport are considered. Real competition between rail and road transport occurs on the main infrastructure only. Taking into account the direct and indirect energy requirements and emissions and the total distances over which transport takes place in case goods are transported by trucks only or by both trains and trucks, one can conclude that intermodal transport is not always as attractive as it seems on the first sight.

Unfortunately, also the results presented in section 6.4 still incorporate several system characteristics. A way to study differences among rail, road and water transport without the influence of logistics characteristics is to define hypothetical freight flows by specifying the density of the goods, the types of vehicles transported by, the type of infrastructure transported on, the distance transported over etc. and to calculate the corresponding direct and indirect energy requirements. Chapter 8 deals with a model which is built to study such hypothetical freight flows.