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ENVIRONMENTAL ASSESSMENT OF FREIGHT TRANSPORTATION

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ABSTRACT (AIM, METHOD, RESULTS)

This report is a short version in English of two reports in Swedish: KFB report 1994:6 "Environmental Effects of Change of Transport Mode for Goods Transportation"" and "Combining of Transport Modes" which was performed as a commission for the Swedish Environmental Protection Agency.

The aim of both studies is to investigate the environmental effects of political measures to transfer goods from one transport mode to another.

To be able to calculate the environmental effects a method to follow the transport chains has been developed. By defining the transport chains with a main transport mode it has been possible to relate the emissions to the different modes.

The main results are that the transferable volumes are limited and even if a maximum volume is transferred, the positive environmental effects are small compared to the effects of measures to reduce the emissions from the vehicles.

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FOREWORD

During 1990-1994 MariTerm AB and The Department of Human and Economic Geography, Göteborg University carried out an investigation on the environmental effects from Swedish goods transportation. The investigation was based on a new methodology for mapping of goods flows in transport chains and allocating emissions and energy consumption to them. The project was requested and financed by the Swedish Transport Research Board, KFB (formerly TFB). The results of the project were reported as a KFB-report:

> Miljöeffekter av transportmedelsval för godstransporter, (Environmental effect of choice of transport mode for goods transportation), G Demker, E Flodström, A Sjöbris, M Williamson, KFB-rapport 1994:6, ISBN 91-88370-65-8, Sept. 1994.

In 1995 MariTerm AB undertook a separate investigation for the Swedish Environmental Protection Agency, SNV, based on the same models as the previous work. In that work the maximum potential for transfer of goods flows from road traffic to mainly railway was investigated. The results were reported to SNV but the report was not published at the time.

This report consists of a condensed version in English of KFB-report 1994:6 together with an English translation of the report of 1995 to SNV.

The main aim of the condensed report is to present to international decision makers and experts the methodology and the conclusions regarding effects of transfer. No attempt has been made to update any of the figures or conditions to later developments.

Gothenburg March 1998

MariTerm AB

Eje Flodström

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I Environmental Assessment Of Freight Transportation

I.1 Introduction

In the ongoing debate regarding the environmental effects from traffic, the possibility of political measures to affect the transfer of goods to other, environmentally friendly, alternatives are often discussed. The primary alternative has been transfer of goods from long haulage trucks to railways. However the effects of such a transfer have been difficult to evaluate. It is well known that the long haulage (more than 300 km) truck traffic in Sweden constitutes only 4 per cent of the total tons transported by truck. These 4 per cent are about the same goods quantity as is transported by railway annually.

However there are no records on how the goods are transported in reality from shipper to consignee. Depending on the geographical situation (as for example location of manufacturing in relation to railway stations or harbours) the transport is in many cases undertaken in a transport chain, for example truck-train-truck, truck-ship-truck, etc. In these transport chains the trucking acts as a distribution feeder service to the mode that performs the long haulage.

As the issue is of great interest for the traffic and environmental political debate, the Swedish Transport and Communications Research Board, KFB (formerly TFB), has initiated a research study to develop a generally applicable methodology and use it to quantify the effects of transfer of goods between transport modes.

Statistics on the Swedish domestic haulage is compiled by SCB - Statistics Sweden. This is neither detailed nor extensive enough to give information on the haulage, transport chains and environmental effects of the different modes. For truck transportation a random selection of trucks is followed by SCB and the processed results are considered to be fairly reliable. The railway traffic is only reported as national totals in order not to reveal the competitive situation of the sole national operator. For waterborne transport the statistics only refer to port activities and this is not detailed enough.

Thus the available information forming the statistics is based on the individual haulage for each mode of transportation. As the goods flows normally are assembled for different modes of transportation, there will be a double counting of some flows. Different modes of transportation within a transport chain will add the same goods quantity to their total. This leads to an overestimate of the actual goods quantities.

In this research project the approach is instead to start with the connections available to the charterer when choosing transport arrangements. The methodology developed is based on following the transport chain (combination of transport modes) from shipper to consignee. The method has included considerable work with the collection of statistics and validation of the results.

The new information forms the basis for creating different scenarios covering the development until the year 2015. Through assumptions on the transfer of goods quantities, mainly from road to rail, the changes in energy consumption and emissions are quantified.

1.2 Method

The chosen method is to build a model of national goods transport split between transport chains. The following definitions and assumptions have been used:

- Every goods movement is allocated to a transport chain.
- Each transport chain has a Main Transport Mode.
- The Main Transport Mode is the mode that undertakes the largest share of the haulage in the transport chain.
- The transport chains are sorted under the Main Transport Mode.
- All energy used and emissions produced, in order to undertake the transport, are assigned to the transport chain.
- Transfer of goods in the scenarios is done from one transport chain to another.

The simplest description of the viewpoint is to see the emissions as related to goods movements instead of related to the transport mode. Thus a direct truck transport is assigned to the truck transport mode. In the more complex chains all the emissions that are produced during the full transport are assigned to the main mode. Distribution at both ends as well as handling emissions are included in the model. One example is a railway transport to the continent that will include train ferry and distribution transport with truck at both ends: This transport chain will be assigned the following emission quantities:

- Truck transport to railway terminal.
- Handling from truck to railway.
- Total train operation including shifting operations.
- Domestic part of ferry emissions (up to territorial border)

The generalised transport chains used in the goods flow investigation and the emission calculations are listed in the following table:

TRANSPORT CHAINS

Short haul truck
Long haul truck
Short haul truck - Long haul truck
Long haul truck - Short haul truck
Short haul truck - Long haul truck - Short haul truck
Railway
Railway - Truck
Truck - Railway
Truck - Railway - Truck
Ship
Ship - Railway
Railway - Ship
Ship - Railway - Ship
Ship - Truck
Truck - Ship
Truck - Ship - Truck

Other, more complex, transport chains exist but are of little importance to the overall picture.

Figure I-1 shows the principal flow of the of computation.

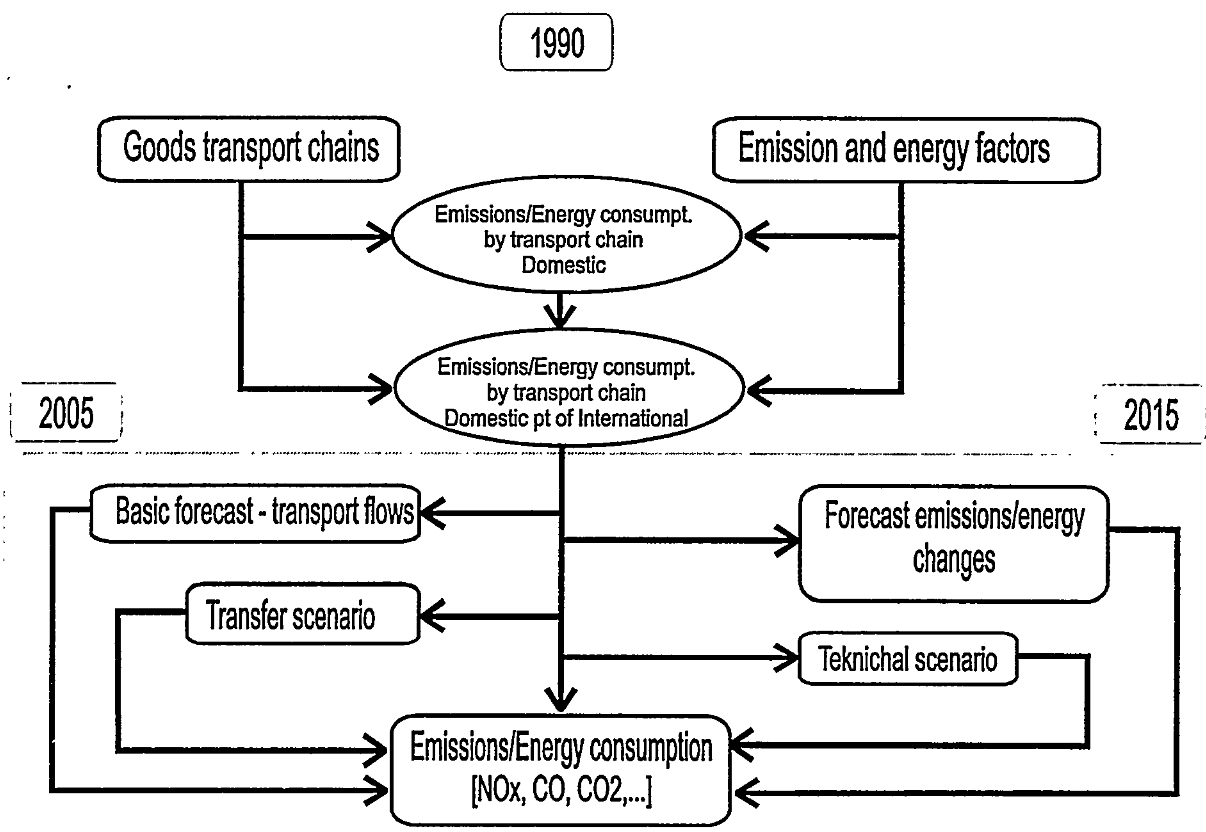


Figure I-1 Schematic view of the method for assembling the total emissions for the Main Transport Modes.

With the knowledge of goods flows and haulage for different transport chains and the emissions and energy consumptions for different modes, it is possible to calculate the total emissions and energy consumption for Swedish goods transportation.

The situations in the years 2005 and 2015 are computed by adding a baseline scenario for transportation and emission/energy consumption development. The results will give a basis for the comparisons with alternative scenarios.

By assuming alternative developments for the transports, for example in the transfer of goods between chains or other different technical developments, different scenarios are created. These scenarios can be considered and used as a sensitivity analysis of the baseline scenario.

To summarise, the transport chains are identified and the haulage is assigned to the transport chains. The links of the transport chains are assigned energy and emission factors. This allows the computation of the total emissions split by transport chain or by Main Transport Mode.
The assumptions on future developments affect both the goods flows and the emission factors and lead to new results. Changes can then be made through transfer of goods between chains and alternative technical scenario's. This gives new results that can be compared with the baseline scenario.

I.2.1 The available statistics

The Swedish statistics on goods transportation are reported by SCB and both collection and reporting are connected to each mode of transportation. The environmental statistics are reported by the mode administrations to the environmental administration who combines the information. This project is concerned with the modes road, rail and sea. The haulage by air is not included as it is marginal compared with the other modes. Domestic trucking of air freight is included in the national road transport statistics.

The regular statistics of goods transportation are built up by different data for different modes:

Trucks — SCB makes a random selection of 4 000 trucks each quarter. The driver of the truck are requested to keepp book on the operation for one week. These are the base data for the statistics. Goods quantities and haulage are reported with splits after types of goods, transported distances and vehicle capacities.

In the future the environmental statistics may be based on direct measurement of vehicle passages by the road transport administration. This registers the number of axle passages and the axle loads. From this the traffic flow, fleet composition and road load can be derived. No information is available on the transported goods or the load factors from these measurements.

Railway — Railway statistics are published by SCB from material collected by the national rail operator SJ. The statistics are split by goods type but no geographical information is available.

SJ is keeping extensive statistics for internal use. Some rationalisation has resulted in the loss of some information. Due to SJ's special status as a state owned operator and former state administration, the operator has no obligation to report to the national statistics. A few research projects have been allowed access to the internal statistics to some extent. No statistics are reported that touch on the competitive situation. The published statistics are adapted to the marketing of SJ. For example the total haulage reported includes the train ferry traffic.

The environmental statistics are collected separately by the Railroad Administration from figures provided by SJ and other small operators.

Sea transport

The statistics on sea transportation are based on the information given by the ships to the port authorities. This includes the size of the ship as Gross Tonnage that is an international rule for volume measurement. This does not give enough information on the cargo capacity of the ship and no information on the actual goods quantities on board.

The haulage of sea transportation is calculated by SCB from information collected by the ports on the loaded and unloaded goods quantities. This information stems from the ship declarations. As long as the quantities are correctly reported this information should enable a fairly good estimation of the haulage performed on goods destined between Swedish ports. However, no information is available on the goods quantities that are transiting a Swedish port onboard ships.

The information from the ports is not sufficient to enable calculation of the haulage performed by the ships, as the ships may carry additional goods in transit to or from foreign ports. The same goes for goods from Sweden to a foreign destination with an intermediate stop at a Swedish port. Thus it is not possible to relate the haulage to the emissions and energy consumption of the ship.

There is no generalised information available or collected on the energy consumption of the ships. An effort has previously been made to estimate this from the bunkered quantities in Sweden. This gives a totally erroneous picture as most ships are trading internationally and take their fuel where the required quality can be acquired at the lowest price.

Environmental statistics for waterborne transportation are reported by the Swedish National Maritime Administration. This has so far been based on the gross tonnage of the ships that is converted into energy consumption and cargo capacity through empirical models and functions. The National Maritime Administration has under preparation a new program for statistics where the parameters are chosen to better represent the environmental issues.

I.2.2 New statistics based on transport chains

The official statistic on different modes of transportation is not sufficient to carry out research on transport chains. Thus further research has been necessary. However, the mode based statistics have been used to correlate the total quantities and haulage for Sweden. The baseline year 1990 has been chosen for the statistics.

A large part of this research project has consisted of building a database of goods flows in transport chains. In order to achieve this the statistical material has been collected for five major groups:

- Import
- Domestic trade
- Manufacturing industry
- Raw materials
- Transit traffic

It was not possible within the economical limits of this project to make an investigation on the total transportation. Instead an enquiry was made on the transports from the manufacturing industry. About 3 000 companies, consisting of all manufacturers with more than 50 employees were questioned about their outgoing goods flows. The answers to the enquiry gave a very detailed picture of these flows. The answering frequency was 63,5 % implying that the results are statistically assured. This information has been processed by analysing different subgroups and then extrapolated to cover all of the manufacturing sector.

The resulting statistics were then projected onto the trade volumes and combined with raw material flows that have been put together from trade specific statistics. The transit traffic has been supplied by SCB. It should be recognised that the sea transportation uses SCB's definition of domestic share of foreign transport, that is the part of the transport performed within Swedish territorial waters.

Table I-1 shows the resulting haulage in Sweden when the ferry traffic has been allocated to the corresponding transportation mode. A comparison is also made to the modal statistics reported by SCB.

Table I-1 Total haulage in Sweden 1990. Billion tonkms.

Transport mode	Haulage			SCB
	Domestic	Domestic share of foreign	Total	
Short haul truck, direct	5,69	0,00	5,69	
Short haul truck, via terminal	0,40	0,61	1,01	
Short haul truck, total	**6,09**	**0,61**	**6,70**	7,7
Long haul truck, direct	18,45	5,62	24,07	
Long haul truck, via terminal	1,30	0,14	1,44	
Truck goods on ferries	0,04	0,40	0,44	
Long haul truck, total	**19,79**	**6,16**	**25,95**	**23,5**
Railway, direct	6,2	3,91	10,11	
Railway, intermodal	2,24	4,54	6,78	
Railway goods on ferries	0,00	0,16	0,16	
Railway, total	**8,44**	**8,61**	**17,05**	**19,0**
Ship, direct	4,94	13,96	18,90	
Ship, intermodal	2,09	4,00	6,09	
Ship total	7,03	17,96	24,99	27,6
Total	**41,35**	**33,34**	**74,69**	**77,8**

The major differences with SCB can be traced to uncertainties in the used figures for transportation distance. Many raw material transports have been calculated using the Swedish average transportation distance which may give large deviation in the haulage. Another source of deviation can be in the inclusion or exclusion of load carriers in the reporting.

One result of the used method is that it is possible to identify the domestic part of foreign transportation for the land transport modes. These flows have previously only been reported up to the border passage or port as part of the total domestic haulage. The share of the domestic haulage that actually is a part of a foreign transport is shown in Table I-2

Table I-2 Share of domestic haulage that is part of a foreign transport.

	Domestic haulage in a foreign transport chain [billion tonkms]	Share of domestic haulage
Long haulage truck	6,2	24 %
Railway	8,4	50 %

The distribution of haulage and transport quantities between the major groups mapped is shown in Table I-3:

Table I-3 Distribution of goods quantities and haulage. Year 1990.

Group	million tons/yr	billion tonkms/yr
Manufacturing industry	112	39
Raw material	194	13
Import	53	12
Trade	44	8
Transit	6	3
Total	409	93

I.2.3 Development of goods flow

The obtained haulage figures are to the year 1990. The haulage for the years 2005 and 2015 have been calculated using a prognosis model. This calculation uses the relationship between economic development and haulage where the change in total haulage during the last decades has trailed the changes in GNP on a slightly lower level. This is used as a precondition for the whole duration of the scenarios. For the time period up to the year 2000 the haulage increase is assumed to be 0,7 per cent lower than the GNP growth. For the time period 2000-2010 it is 0,8 per cent and for years 2010-2015 it is 0,9 per cent lower. This mirrors the development towards more processed goods and increased efficiency in the transport system. The scenario base includes Swedish membership in the EU and a fixed link between Sweden and Denmark.[1].

The estimate on the development of transportation in Sweden is presented in Table I-4. Comparison is also made with the last prognosis presented by Transportrådet, TPR and a prognosis by VTI 1992. Both prognoses give more than one growth figure and the version presented here is the middle version. VTI also give a lower alternative that corresponds better with both this study and the one from TPR.

Table I-4 Different prognoses on domestic haulage in Sweden.

Billion tonkms	1990		2005			2015		
	new	SCB	new	TPR	VTI	new	TPR	VTI
Sea	25,0	27,6	29,0	27,5	34,6	31,1	30,1	48,5
Rail	17,0	19,0	20,3	24,1	25,1	21,4	25,2	29,0
Long haul road	26,0	24,0	24,1	28,3	29,8	26,1	30,7	35,8
Short haul road	6,7	7,2	7,4	8,1	9,2	7,6	8,7	11,2
Total	74,7	77,8	80,8	88,0	98,7	86,2	94,7	124,5

[1] None of these were decided at the time of the study. The membership is now reality and the fixed link is under construction.

1.2.4 Energy consumption and emissions

The total emissions of the transport system are obtained by combining emission factors for the transport vessels with the haulage on the separate legs of the transport chains. The emission factors include the average load factors for the modes. This means that the used emission factors will be higher than the, more often presented, full load figures for the vessels.

An important difference with this type of model compared to the traditional, mode specific environmental models, is that the statistics relate to the goods flows and not the movements of vessels. This means that some knowledge is lost considering the details of the vessels. The emission factors have to be generalised and statistically derived for the different modes. This should as far as possible include size distribution, age distribution, load factors, etc.

At the same time it has to be emphasised that the used emission factors are solely applicable to larger sets of statistical goods flows. Calculations on separate goods categories or trade areas must be based on the normal loads achieved for that type of transport.

The emission.factors used have different backgrounds:

Trucks — The available data and references for truck transportation are judged to be fairly well assured. Emission measurements for different vehicles are readily available. There are alternative ways to check the accuracy of energy consumption figures and emission factors. The figures used in this project are a compilation deriving mainly from reports from VTI and Scania. Load factors are derived from the truck transport statistics reported by SCB.

Railway — No good reports on the environmental effects of railways have been available. The emissions officially reported by the railways are based on the electricity consumption of electrical trains. The emissions are only those that stem from Swedish electricity production, meaning a very low share of combustion based emissions. In this project a statistical material from 1989 has been utilised. This gives a realistic picture of the load factors and diesel engine usage with the operation of train used 1990. The activities needed for the total railway transport are included, such as shifting, assistance, etc. The emissions and energy consumptions for diesel engines were based on measurements in Sweden (SJ) and Denmark (DSB).

Sea transport — Within the waterborne transport measurements of emissions have just started. The modelling problems are often larger for waterborne transport due to the heterogeneous characteristics of the fleet. This goes for unit size, technical solutions, choice of fuel, etc. The statistics kept within waterborne transport are very incomplete for environmental research and information is lacking especially on load factors. There are individual ships and routes that are well known and for which the emission factors can be calculated. However the generalised information is lacking. The factors used are based on previous research on emissions from ships [1] and estimated load factors.

The energy consumption is compared within the same type of energy to assure the comparability between the modes. For vessels that burn fuel internally the energy is counted as the energy content of the fuel. For units that use electricity the energy is counted as if the electricity is generated through combustion processes as the energy content of the fuel. This is achieved through multiplication of the electrical energy with 2,6 which is an internationally accepted conversion factor between electricity and fuel energy.

For combustion engines the emissions are counted as produced by the vessel. This goes for all modes. Emissions from electrical energy are counted after the Swedish situation. This means that emissions to air are virtually zero for hydropower and nuclear power. Production of electricity by combustion is very small in Sweden at about 2-5 per cent. For the calculations 4 per cent is used combined with emission data from the largest Swedish electricity producer: Vattenfall. As the electricity is generated away from the usage transfer losses of 4 per cent are included. (Energy consumption for distribution of fuel is included in the model as they add to the total haulage)

For the trucks the energy- and emission factors from several sources (VTI, Scania, SNV, TFD) have been collected and judged. These sources also include field measurements. The emission profiles for each year of calculation include the age distribution of the trucks (VTI).

Table I-5 Specific emission and energy factors for trucks 1990

	Fuel energy	NO_x	VOC	CO	Part	CO_2[1]	S[1]
	[MJ/ tonkm]	[g/tonkm]					
Long haul truck 52 t	1,0	1,5	0,08	0,23	0,10	76	0,041
Long haul truck 38 t	1,1	1,7	0,10	0,30	0,13	83	0,045
Short haul truck 14 t	2,7	3,7	0,41	1,21	0,38	200	0,11

[1] Calculated from fuel consumption and with sulphur content 0,17 %.

The emission factors and energy consumption for the railway transport are a combination of direct emissions from diesel engines and indirect from electricity production. The split between diesel and electrical trains is based on the real distribution 1989. The energy consumption and emissions represent the national average for all freight trains in Sweden. The average train weight and load factor refer to the national average and thus the factors should only be used for national calculations. Train operation and load factors vary a lot for different transports and other traffic populations differ in diesel share. One Swedish train system, the Malmbanan, is treated separately. The main reason for this is that the freight volumes are large and the necessary information is readily available as it is separately reported in the statistics.

Table I-6 summarises the specific emissions averaged over the total haulage for Swedish rail transportation during 1990.

Table I-6 Specific direct and indirect emissions and energy factors for Swedish railways except Malmbanan.

Freight trains direct and indirect emissions	Fuel energy	NO_x	VOC	CO	Part	CO_2	S
	[MJ/ tonkm]	[g/tonkm]					
Specific emissions	0,46	0,13	0,003	0,012	0,002	7,5	0,007

The emissions from the use of diesel engines are being scrutinised by SJ. The ambition is to minimise the use of diesel and to only use fuel with low sulphur content.

The emissions from waterborne transportation have been investigated in recent years. Regulations for the reduction of emissions from ships are under development within IMO - International Maritime Organisation. The Swedish database on exhaust emissions from ships is relatively comprehensive on an international level [Alexandersson e. a. 1993]. Emission factors for waterborne transport are based on this previous work and some later measurements. It should be added that the figures refer to average coastal and short sea shipping and does not include transocean vessels.

The statistical data on ships are incomplete and hard to assemble into subgroups as each ship is distinctive. This holds especially for information on load factors. The model to create energy and emission factors necessarily becomes very approximate and the resulting figures should only be used for calculations on Swedish national averages.

Table I-7 Specific energy and emission factors for type ships.

Coastal and short sea ships	Fuel Energy	NO_x	VOC	CO	PM	CO_2	S
	[MJ/ tonkm]	[g/tonkm]					
Specific Emissions	0,24	0,43	0,013	0,019	0,016	18,3	0,11

Ferries are treated separately as they appear as links in the transport chains for truck and railway transportation. One problem with ferries is how to split the total emissions between passenger and cargo traffic. In this study the cargo is assigned the same emissions as if it had been transported with pure Cargo Ro/Ro-ships with the same deadweight as the ferries.

Table I-8 Specific emission and energy factors for goods traffic on ferries.

Ferries	Fuel Energy	NO_x	VOC	CO	PM	CO_2	S
	[MJ/ tonkm]	[g/tonkm]					
Specific emissions	0,83	1,4	0,022	0,082	0,040	62	0,16

The train ferry lines on Sweden are known in detail and the emissions and energy consumption can be established.

Table I-9 Specific emission and energy factors for railborne goods traffic on ferries.

Train Ferries	Fuel Energy	NO_x	VOC	CO	PM	CO_2	S
	[MJ/ tonkm]	[g/tonkm]					
Specific emissions	3,4	6,2	0,10	0,42	0,18	290	0,71

To complete the energy and emission factors for the transport chain the transfer operation between the modes has to be included. These energy and emission factors include the majority of handling types averaged from the transport chain mapping. The energy consumption is handled in the same way as for the railway with manual handling set as zero. The final results showed that the contributions from the transfer is negligible to marginal compared to the total emissions. The biggest contribution is for the sea transport chains.

Table I-10 Specific energy and emission factors for the transfer between modes.

	Fuel energy	NOx	HC	CO	Part	CO2	S
	[MJ/ton]	[g/ton]					
Truck-Truck	2,6	0,65	0,09	0,22	0,08	50	0,03
Truck-Railway	2,9	1,7	0,21	0,55	0,18	87	0,06
Truck/ Railway-Ship	9,0	6,6	0,80	2,1	0,67	340	0,22

I.2.5 The future development of the emission factors in the baseline scenario.

In the baseline scenario two factors affect the development of the average load on the trucks. On one hand there is a slow and continuous development of the load capacity through adaptation and specialisation of the vessels while improvements in communication and logistics allow higher load factors. On the other hand the Swedish situation is very much affected by the future legislation and integration with the rest of Europe.

The baseline scenario in this investigation was that the negotiations for EU entry would result in the reduction of the Swedish gross weight limit of 60 ton but with a long gestation period. This is achieved in the model by keeping the 24 m, 60 ton trucks for domestic traffic in the year 2005 but replacing them with European sized units in the scenario year 2015. In the scenario it is assumed that the 24 m units to a large extent are replaced with 18 m units but other combinations, especially 15 m semitrailer units will increase their share of Swedish domestic traffic.

These assumptions were made as the negotiations with EU was not finalised at the time of the investigation. The actual outcome was that the 60 ton limit was allowed to continue. This results in a slight overestimation of the truck emissions in 2015 in the baseline scenario but it is thought that with other insecurities this difference is of little importance.

As regards specific energy consumption and emissions there is very little difference between the 18 m units and the 15 m semitrailer as the higher load capacity of the former is matched by the lower aerodynamic and rolling resistance of the latter. They are therefore given the same factors in the model.

The average loads of similar truck units are assumed to increase by 3 per cent until 2005 and by 8 per cent until 2015. This is a combined effect of reduced empty weights and increased load factors. Between 1990 and 2005 there is an increase in max gross weight from 52 ton to 60 ton carried through in 1993. A large majority of the trucks is built towards the legislation limits but for technical reasons not all 24 m units can use the full weight. A 56 ton unit is chosen as type truck for the domestic long haul transport.

Note that the average load refer to the actual load including possible load carriers. The effects of load carriers, such as containers and swapbodies, and their increasing share of the transportation is treated in another part of the model.

Table I-11 Average loads for type truck units.

Type	Average load yr 2005 [ton]	Average load yr 2015 [ton]
Long haul truck 56 ton	19,3	(20,2)[1]
Long haul truck 38 ton	13,4	14,0
Short haul truck 14 ton	3,7	3,9

[1] Not included in the baseline scenario.

In all cases it is assumed that the truck combinations have had time to adapt to the gross weight limits, that is the lowered gross weight in the year 2015 have been followed by smaller engines and lighter chassis, and the energy consumption is optimised to the new conditions.

The energy and emission factors for each year of calculation include the mix of yearmodels as per the model used by VTI.

The assumed scenarios for the emission development of the trucks mainly follow the scenarios used by VTI [Hammarström 1990]. Figure I-2 shows the different scenarios for nitrogen oxides.

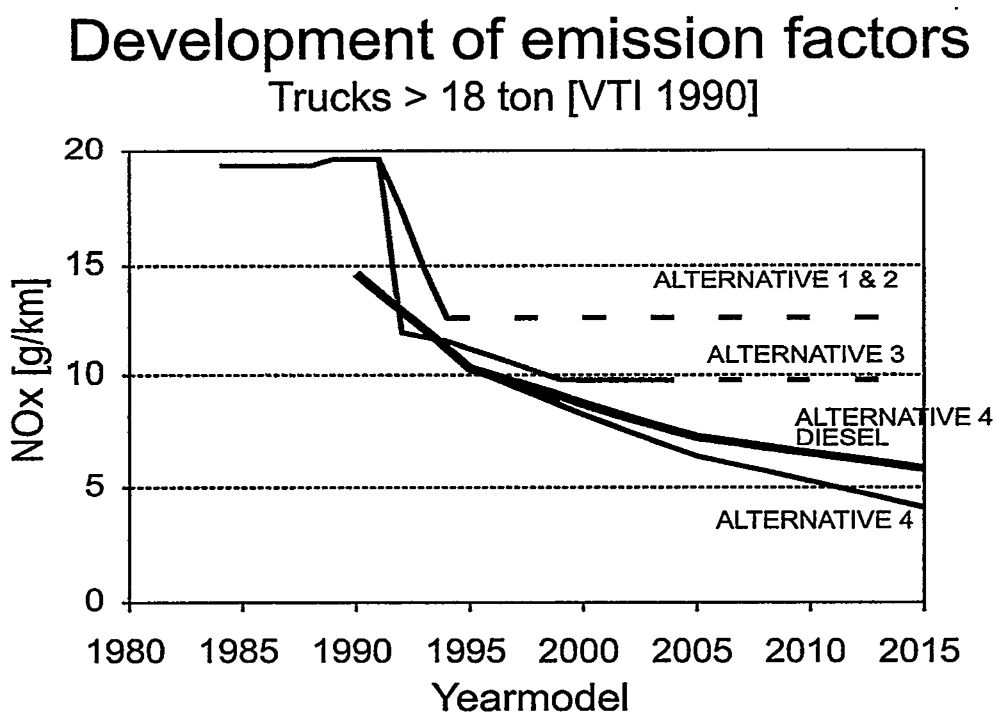


Figure I-2 Development of emission factor for nitrous oxides for heavy truck units. [Hammarström 1990]

The different alternatives are:

Alternatives 1 & 2	The truck emissions develop only as per decided legislation. This means that no development of the heavy trucks take place after yearmodel 1994.
Alternative 3	Environmental classes with tax reduction as per a Swedish proposal are introduced from model 1992. This leads to a gradual introduction of first environmental class 2 and later class 1 units. For the heavy trucks the changeover, that is 100 per cent class 1 trucks, is finalised by model 2004. (The environmental classes were decided at the time of this investigation but the introduction was postponed until 1994.)
Alternative 4	Introduction of best available technology combined with alternative fuels. The heavy traffic is assumed to change to alcohol fuel, a process that is finalised by the year 2025. The technical development refers to Thörnblom & Kindbom 1990. Only nitrogen oxides and carbon dioxide have been considered.

The baseline scenario uses alternative 4 modified with the more conservative view of assuming that a large scale change to alcoholic fuel is not to be. This switch of fuel is less probable considering the capacity limitations in making alcoholic fuels from biomass. The alternative of producing alcoholic fuels from fossile fuel is of course possible although unlikely due to the energy loss. The baseline scenario used is the development proposed by Hammarström for diesel fuelled units in alternative 4.

Using these assumptions the trucks will have the following energy and emission factors in the scenarios:

Table I-12 Energy and emission factors for NO_x and CO_2 from trucks in the baseline scenario.

	Fuel energy [MJ/tonkm]		NO_x [g/tonkm]		CO_2 [g/tonkm]	
	2005	2015	2005	2015	2005	2015
Long haul truck 56 ton	0,80	0,76	0,62	0,44	59	52
Long haul truck 38 ton	0,91	0,87	0,75	0,54	68	59
Short haul truck 14 ton	2,2	2,0	2,0	1,4	167	141

Table I-13 Emission factors for VOC, CO and particles from trucks in the baseline scenario.

	VOC [g/tonkm]		CO [g/tonkm]		Part [g/tonkm]	
	2005	2015	2005	2015	2005	2015
Long haul truck 56 ton	0,007	0,004	0,020	0,012	0,009	0,005
Long haul truck 38 ton	0,010	0,006	0,029	0,017	0,013	0,007
Short haul truck 14 ton	0,040	0,024	0,121	0,073	0,036	0,021

For sulphur it is assumed that in the year 2005 all fuel will be of at least environmental class 1. This demands a sulphur content of less than 0,001 per cent. A sulphur content of 0,0008 per cent is used in the baseline scenario. By the year 2015 zero sulphur content is used in the calculation.

Table I-14 Emission factors for sulphur from trucks in the baseline scenario.

	S [g/tonkm]	
	2005	2015
Long haul truck 56 ton	0,0002	0
Long haul truck 38 ton	0,0002	0
Short haul truck 14 ton	0,0004	0

For the railway the axle load will in the future increase to 25 ton on the larger lines. In the base scenario we assume that 60 per cent of the haulage is undertaken on lines with 25 ton axle load.

The future average freight train most certainly is composed of more railcars than today. Due to the introduction of fast passenger trains the freight trains has to become fewer and longer. Rationalisation will move some of today's smaller and shorter train transports to truck transportation. In the scenario model it is assumed that the trains as an average is made up of the equivalent of 40 two-axle cars in the year 2005 and 42 two-axle cars in 2015. The relatively small increase from 2005 to 2015 is due to the assumption of increased axle loads which means that the gross weight of the trains nevertheless will increase significantly.

Any large changes in the load factors are not probable for trains. Much of the activities on railways consist of positioning of empty railcars. The system trains that constitute a large part of the railway haulage, normally run full in one direction and empty return resulting in a load factor of nearly 50 per cent. For the wagon loads the increasing demands on regularity and service level will not be beneficial for the load factor. The average loads will still increase due to the higher axle loads. Unit load and piggyback system traffic will have the same level of return loads as of today.

Any general decrease in tare weights is not expected. Every new railcar type will of course be optimised towards less tare weight but increased axle loads and speed will demand stronger structures. The share of covered railcars that weigh more will also increase.

Using the same load factor as of today and 25 ton axle load on 60 per cent of the traffic will result in an average freight load of about 7,4 ton per axle by the year 2015. The average gross axle load is estimated to 13,4 ton. For 2005 the freight load is estimated to be 7,0 ton per axle while the gross weight is estimated to 13 ton per axle. With these estimates, the average freight train will have an average weight of 1120 ton in the year 2005 and 1200 ton year 2015 including the weight of the locomotives. These weights are used in the calculation of average energy and emission factors.

SJ expects to increase the average speed for freight trains. Increased speed will be a necessity to enable long hauls overnight and to enable the mixing of fast passenger trains and freight trains on the lines were the traffic cannot be separated.

Increased speed results in increased energy consumption. Air resistance and energy consumption for acceleration increases by the square of the velocity while the rolling resistance increase is approximately linear. Running in 160 km/h, as proposed by SJ for some unit load trains, probably demands an improvement of the aerodynamics. For the scenarios we assume that freight trains for 160 km/h will have 15 per cent less air resistance coefficient than today. These trains accomplish only 5 per cent of the total freight haulage year 2015. We also assume that 20 per cent of the haulage year 2005 and 50 per cent year 2015 is undertaken with trains running at a max speed of 120 km/h. These trains will not get any large improvements in aerodynamics compared to the trains of today.

Energy feedback from braking is realised on modern trains and will probably be specified for all new acquisitions of locomotives and train sets. The present Rc-class will however dominate freight traffic for a long time yet. According to the builder, ABB, they can not be equipped with brake energy feedback. In addition, this technology demands investments in the overhead line system which means that few of the smaller lines will receive it due to the small traffic volumes.

For the baseline scenario it is assumed that 20 per cent of the rail haulage in the year 2015 is performed by a new generation of freight trains with brake energy feedback. This results in a 30 per cent recovery of the energy used to accelerate the trains.

To enable the calculation of the future electricity consumption from trains in the scenarios the traffic has been split into a few different types of train representing expected features of the technical development. The energy consumption calculation is done on the base of today's average freight train which in itself includes several train types. However the actual types and split of these is not very well known.

The weighted averaging between these different train types gives the following energy consumption for future freight trains in Sweden:

Table I-15 Energy consumption for future trains.

Year	Electrical energy [kWh/tonkm]	Incl. transfer losses
2005	0,053	0,058
2015	0,062	0,068

The increase in energy consumption is entirely due to the assumptions on increased speeds for some trains.

As regards emissions from train traffic in the baseline scenario it is assumed that the use of diesel locomotives has decreased. In the year 2005 the use of diesel locomotives is half that of 1989, and by 2015 the use of diesel is down to one fifth of the 1989 activity. This is also due to the introduction of hybrid locomotives using both electricity and fuel.

Until the year 2005 no new diesel locomotives have to be added to the fleet due to a surplus of T44 class locomotives. Some of the diesel engines are assumed to be modified giving less emissions. The modified locomotives are assumed to do 30 per cent of the total diesel haulage while the rest is done by locomotives of today's standard.

By the year 2015 it is assumed that 30 per cent of diesel locomotive haulage is done by a new generation heavy locomotives were low emissions have been an important target. They can also be run from overhead lines as mentioned above in connection with total diesel use. Developed engines with exhaust aftertreatment give lower emissions and fuel consumption than the locomotive of today. The relative reductions are shown in table X

Table I-16 Reduction of emission for new diesel locomotives

New diesel locomotives	NO_x	VOC	CO	Part
Emission reduction	90%	80%	80%	50%

The remaining old heavy diesel locomotives in 2015 have all undergone the modifications that was on the way in 2005.

In the scenarios the railway is expected to use the same type of diesel fuels as the road traffic. All diesel correspond to environmental class 1 by the year 2005 with a 2 per cent share of biofuel. In 2015 the share of biofuel is about 10 per cent.

The following table gives direct emissions from diesel trains divided by the total haulage for all trains.

Table I-17 Future average emissions from Swedish trains.

Freight trains Direct emissions	NO_x	HC	VOC	Part	CO_2	S
	[g/tonkm]					
2005	0,061	0,0012	0,0047	0,0008	2,95	0,00001
2015	0,014	0,0002	0,0008	0,0002	1,08	0

The indirect emissions are depending on how the national energy is produced after the closing of the nuclear power generation plants. Depending on the economical growth, electricity saving measures and success in introducing renewable energy sources it is very likely that 20 to 40 per cent of the Swedish electrical energy has to be produced from fossile burning power plants. In order not to compromise CO2-targets to much it is estimated that most of this is from natural gas. The baseline scenario uses 30 per cent fossile energy with the assumption that the total electricity use stays at approximately today's level.

In an alternative scenario where the nuclear power generation is utilised at the same level as today, the fossile fuel is only used as reserve power. The share of energy that is fossile based is then estimated to 2 per cent in 2005 and zero in 2015 at which time biofuels are available for peak production.

While the present efficiency for power generation from fossile sources is about 35-40 per cent the theoretical efficiency in the future can be expected to be up to 55 per cent.

The reasoning above leads to an emission factor for the indirect emissions from rail transportation in the year 2015 of 195 g CO_2/kWh electricity or 10,1 g CO_2/tonkm. Together with the direct emissions the resulting emission factor is 11,2 g CO2/tonkm. In 2005 the peak production of electricity is covered by power generation from biofuel with extensive exhaust gas cleaning and thus the indirect emissions are practically zero.

For waterborne transportation, as for the railway, the renewal of the fleet is very slow. The baseline scenario uses a newbuilding rate of 4 per cent per year. New built ships are assumed to have 10 per cent lower specific fuel consumption than the fleet average at every time. There is also a slow improvement in older ships through rebuilds. This rate is set at 0,1 per cent improvement in energy consumption per year.

The present interest in high speed ships will lead to the establishment of some new traffic, most probably within the ferry field. This fast ferry traffic will have a very marginal effect on the overall haulage and emissions. This effect is probably compensated by increased efficiency of other new built ships. The overall trend is presently hard to evaluate but most probably the cost of energy will increase and the energy consumption reductions as per above will dominate.

From a technical point of view the potential is very good to reduce the emissions from ships. The technology to clean diesel exhaust emissions is already developed for land based stationary applications. All technology available for truck diesel engines is also applicable to ships' machinery. The sulphur oxides are best reduced by the introduction of fuels with lower sulphur content while the reduction of nitrogen oxides needs either changes to the combustion process or aftertreatment of the exhaust. The presently most developed aftertreatment is Selective Catalytic Reduction - SCR that allows reductions in NO_x of around 95 per cent.

The following assumptions are made on the development of the exhaust emissions from ships in the model:

Economical measures are introduced in the late 90ies that reward SCR and similar cleaning methods. The effects begin to show around year 2000. From the start 10 per cent of all newbuildings are assumed to have exhaust aftertreatment and this increases linearly to 40 per cent by year 2015. Older ships are introducing cleaning at a rate of 1 per cent year 2002 increasing to 2 per cent year 2015.

The following reduction factors are used for the exhaust aftertreatment. These are achievable with presently available technology.

Table I-18 Reduction factors for exhaust aftertreatment

	NOx	VOC	CO	Part
Reduction of emissions	90%	70%	70%	10%

Figure I-3 shows the resulting development of the emission factors with the assumptions above.

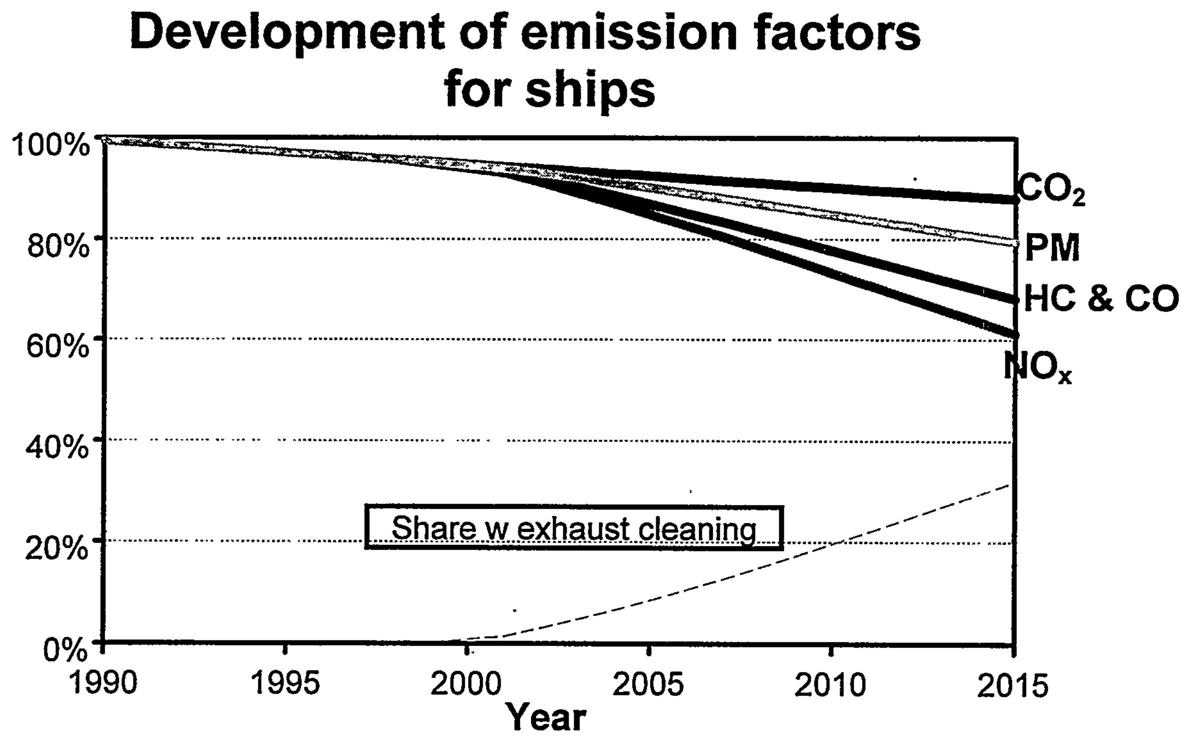


Figure I-3 Development of emissions from ships with economical control measures.

One of the most urgent items as regards measures against air pollution is a limitation of the sulphur content in ships' fuels. MARPOL annexe 6 contains an upper limit that could only result in a small change from today's situation. Acting on pressure from port and environmental authorities, a large part of the ferry traffic in Sweden have reduced the sulphur content in their fuel. The sulphur emissions from ferries on Sweden have been reduced by half between 1987 and 1991. The trend will continue either through the establishment of bilateral agreements between Sweden and surrounding countries or through economical control measures applied on Swedish port calls. The model assumes a continued reduction in fuel sulphur content from 1996. The sulphur reduction can take place without fleet renewal and this means a faster development than for other emissions. In 1990 the average sulphur content for ships other than ferries around Sweden was 2,6 per cent. This is reduced to 1,2 per cent in 2005 and 0,8 per cent in 2015. The resulting emission factors are shown in Table I-19

Table I-19 Future specific emission and energy factors for type ship.

	Fuel energy	NO_x	VOC	CO	Part	CO_2	S
Year	[MJ/tonkm]	[g/tonkm]					
2005	0,22	0,37	0,011	0,016	0,014	16,8	0,05
2015	0,21	0,26	0,009	0,013	0,013	16,1	0,03

For ferries a faster development of the emission factors is expected due to local demands and bilateral agreements. The conditions in the scenario is that installation of exhaust cleaning starts on a larger scale by 1999. From the beginning the rate is 20 per cent of all newbuildings and 2 per cent per year rebuild of older ferries. The rates increase to 100 per cent of the newbuildings and 8 per cent rebuilding by the year 2015. The ensuing development of the emission factors is shown in Figure I-4.

The sulphur content in the fuel is also decreased at a faster rate for ferries. The average sulphur content changes from 0,8 per cent 1990 to 0,4 per cent 2005 and 0,1 per cent in the year 2015.

Car ferries and train ferries are assumed to undergo the same relative development. The result in the form of future specific emission and energy factors is shown in Table I-20.

Table I-20 Future specific emission and energy factors for ferries.

	Fuel energy	NO_x	VOC	CO	Part	CO_2	S
Year	[MJ/tonkm]	[g/tonkm]					
Ferries 2005	0,80	1,0	0,017	0,063	0,035	59	0,08
Ferries 2015	0,76	0,39	0,010	0,037	0,028	56	0,02
Train ferries 2005	3,3	4,4	0,0088	0,032	0,015	278	0,34
Train ferries 2015	3,1	1,7	0,005	0,019	0,013	264	0,08

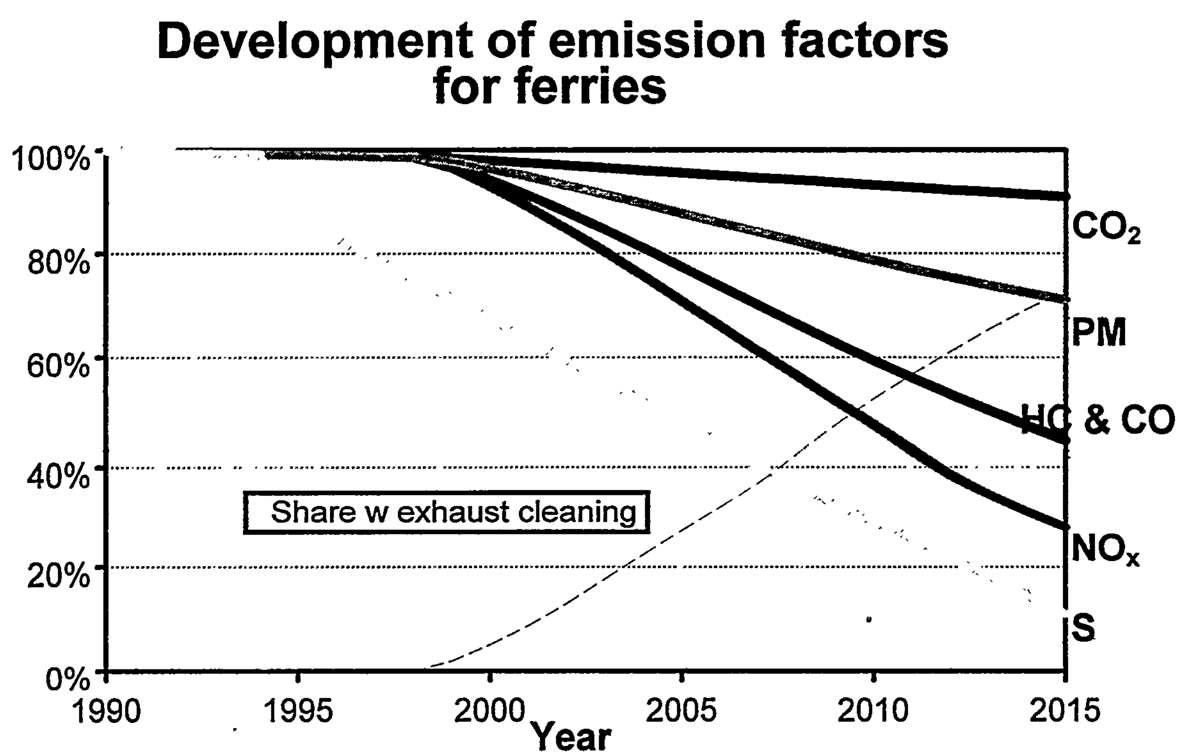


Figure I-4 Development of emissions from ferries.

I.2.6 Scenario Calculations

The total figures for energy consumption and emissions from transportation are arrived at for the year 1990, by combining the specific emission and energy factors för different transport modes with the identified haulage. This is summarised in Table I-21 in the traditional way for the individual modes of transportation.

Table I-21 Emissions and energy consumption by transport mode year 1990.

BY TRANSPORTATION MODE							
	NO_x	VOC	CO	CO_2	Part	S	Fuel energy
	[ton]						[TJ]
Truck	63 000	4 700	14 000	3 300 000	5 200	1 800	44 000
Railway	2 000	47	190	120 000	32	130	7 900
Waterborne	13 000	370	600	550 000	460	3 000	7 300
Handling	110	13	35	5 600	11	4	160
TOTAL	78 000	5 100	15 000	4 000 000	5 700	4 900	59 000

The results can also be sorted in and summed up after the Main Transport Mode based on the previously described transport chain model where all activities in the transport chain are assigned to the mode defined as Main Transport Mode.

Table I-22 Emissions and energy consumption by Main Transport Mode year 1990

TRANSPORT CHAINS BY MAIN TRANSPORT MODE							
	NO_x	VOC	CO	CO_2	Part	S	Fuel Energy
	[ton]						[TJ]
Truck	61 000	4 500	13 000	3 200 000	5 000	1 800	43 000
Railway	4 000	160	550	220 000	160	290	8 500
Waterborne	13 000	450	800	550 000	520	2 800	8 000
TOTAL	78 000	5 100	15 000	4 000 000	5 700	4 900	59 000

In this table, handling, distribution transports and ferries are distributed under the long distance transport mode they serve, as exemplified earlier.

By introducing the future development in haulage, energy and emission factors, scenarios can be built for the years 2005 and 2015. First a baseline scenario is calculated and to this the lower and higher assumptions on traffic development are added. The results are shown in Figures 5 and 6 for nitrogen oxides and carbon dioxide. These results showed that the political targets at the time of the research may be fulfilled if the preconditions are met.

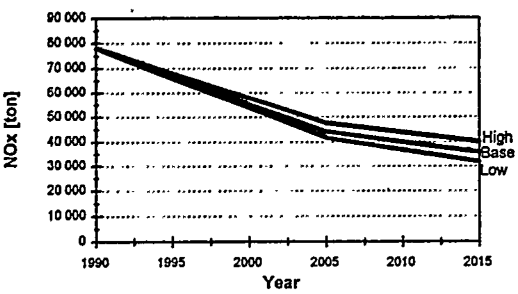


Figure I-5 Development of nitrogen oxide emissions for different transport growth.

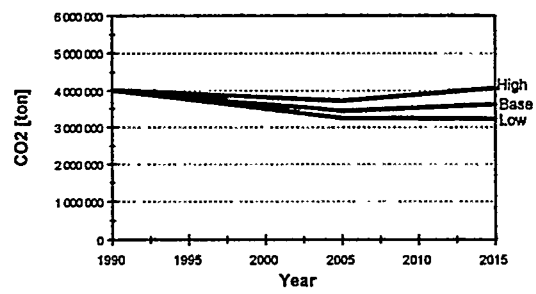


Figure I-6 Development of carbon dioxide emissions for different transport growth.

It should be noted that at this time no nitrogen oxide target exists which corresponds with the period discussed. It should also be noted that it will be difficult to meet the target of no increase in carbon dioxide if the traffic will increase according to the higher growth level. The increase in carbon dioxide emission after 2005 is due to the closedown of nuclear power plants and the adaptation of truck transport to EU standard.

The following tables give the results for the baseline scenarios sorted by type of transport chain.

Table I-23 Emissions and energy consumption per transport chain year 1990

TRANSPORT CHAINS							
	NO_x	VOC	CO	CO_2	Part	S	Energy
	[ton]						[TJ]
Short haul truck	21 000	2 300	7 000	1 200 000	2 200	640	16 000
Long haul truck direct	38 000	2 000	6 000	1 900 000	2 600	1 100	26 000
Long haul truck via terminal	2 500	150	440	130 000	180	70	1 700
Rail direct	2 400	49	200	130 000	51	210	6 200
Rail intermod	1 600	120	360	88 000	110	86	2 300
Waterb direct	8 300	260	360	350 000	310	2 100	4 700
Waterb intermod	4 300	190	440	200 000	220	730	3 400
TOTAL	78 000	5 100	15 000	4 000 000	5 700	4 900	59 000

Table I-23 gives the starting point of the emissions and energy consumption for year 1990. Based on the middle growth alternative the emissions for 2005 and 2015 are calculated as shown in Table I-24 and Table I-25:

Table I-24 Emissions and energy consumption as per the baseline scenario year 2005

TRANSPORT CHAINS							
	NO_x	VOC	CO	CO_2	Part	S	Energy
	[ton]						[TJ]
Short haul truck	12 000	230	700	980 000	210	2	13 000
Long haul truck direct	18 000	220	630	1 700 000	290	36	23 000
Long haul truck via terminal	1 200	16	46	120 000	19	1	1 500
Rail direct	910	18	69	47 000	17	15	5 700
Rail intermod	840	18	59	60 000	16	5	2 200
Waterb direct	8 000	250	350	370 000	310	1 000	4 900
Waterb intermod	3 300	100	170	180 000	120	320	3 200
TOTAL	44 000	850	2 000	3 400 000	980	1 400	53 000

Table I-25 Emissions and energy consumption as per the baseline scenario year 2015.

TRANSPORT CHAINS							
	NOx [ton]	HC	CO	CO2	Part	S	Energy [TJ]
Short haul truck	8 100	140	430	830 000	120	0	12 000
Long haul truck direct	16 600	190	530	1 800 000	220	8	27 000
Long haul truck via terminal	1 100	14	40	120 000	15	0	1 800
Rail direct	270	5	19	170 000	9	4	6 300
Rail intermod	500	10	32	88 000	10	2	2 300
Waterb direct	6 300	220	300	390 000	300	700	5 100
Waterb intermod	2 700	88	150	210 000	110	220	3 600
TOTAL	36 000	660	1 500	3 600 000	800	940	58 000

The relevance of the assumptions in the baseline scenario are of course open for discussion. However the model enables the testing of the sensitivity of the assumptions through alternative scenario that highlights individual components and development paths.

Twelve different alternative scenarios have been tested in the investigation. Eight are of a political or legislative kind (P) while four refer to transfer of goods between Main Transport Modes (T).

P1 Truck scenario with retained 24 m limit truck units instead of EU limit.

P2 Continued nuclear power electricity generation.

P3 Development of emission reduction for truck stops at the level of decided legislation.

P4 Change to alcohol fuels for trucks.

P5 Change to Otto engines in trucks.

P6 Increased load factor for trucks.

P7 Electricity generation for transportation calculated as marginal production.

P8 Decreased speed for sea transportation.

T1 Transfer of half of the truck traffic between Sweden and the Continent to rail and sea.

T2 Train haulage increases according to SJ's development scenario.

T3 All domestic transport by train transferred to trucks.

T4 30% of long haul truck haulage transferred to rail (doubling of rail haulage).

The result of the investigation show that technical development and legislation enables a reduction of the total emissions despite an increase in the total haulage. The present (1994) political targets can be met through sharpened legislation and introduction of available or likely technology. However the combined case of larger haulage growth, smaller EU truck units and the dropping of nuclear power generation will give a small increase in carbon dioxide emissions.

The transfer scenarios show that generally the effects of transferring goods between modes are rather small compared to the effects of technical measures. For example, a large scale transfer of 30 per cent of the long distance truck haulage to rail (a doubling of rail haulage) leads to a decrease of only 17 per cent of the total nitrogen oxide emissions in the year 2015. This can be compared to a reduction of 55 per cent due to the technical development in spite of a simultaneous increase of 19 per cent in the haulage.

The largest emissions of carbon dioxide and nitrogen oxides come from truck traffic. There are no obvious technical obstacles for a continued reduction of these emission given the right demand. A transfer of truck goods to other modes has a small effect on the national scale even given very large transfer volumes. The largest effect is achieved through continued sharpening of emission demands to motivate the introduction of new technology at a reasonable rate.

II THE ENVIRONMENTAL EFFECT OF INCREASED INTERMODALITY

In the previous chapter certain assumptions were made for the transfer of goods from one transport mode to another during the period to 2015. The assumptions does not reflect a true transfer potential but the transferred volumes were done deliberately large as a sensitivity test. This was done with certain assumptions regarding technical development, political measures etc. As transfer of goods from trucks mainly to rail transportation has been discussed as one of the main alternatives to reduce the emissions from transport, it is however of interest to investigate the total potential for this transfer in relation to reasonable physical, logistical and cost restraints.

Recent studies have shown that the selection of transportation by a company depends on the transported quantities. This results in different ranking of the transport cost between companies. Companies with relatively small transported quantities are not as sensitive to the transport cost as companies with larger flows. The result is that the price elasticity is larger for a smaller company that values secondary factors more than the actual service cost. These factors may be shipment size, transport time, service level etc. The price incitement for a transfer from truck transport to a mode with lower service level has to be about 20 percent for companies with large transport volumes while smaller companies demand up to 50 percent savings to be interested in a transfer.

The significance also differs substantially between transports to warehouses and transports integrated in a series production. The latter are largely controlled by the JIT-process where the product is supposed to enter the production directly without intermediate storage. The value of the JIT-function is governed by the company and its policy. In many cases this value by far surpasses the capital value of products in storage, transit or production. This is indicated by the large savings demanded for changing to another transport system. The capital value of the goods is then of secondary importance.

The same goes for the relationship between railway and truck transport. A normal figure is that the railway has a 10 to 15 percent lower rate for the same transport (abt 1000 km) in order to attract goods. In many cases truck and railway are used in parallel for the same flow with this price difference.

At present there is an observable restructuring going on for the transport flows in northern Sweden. The traditional flows have been northbound with trucks and southbound with sea and rail. This has led to an overcapacity of southbound trucks at the same time that ships and rail cars are continuously being repositioned northbound.

The present restructuring is partly a transfer from rail to truck transportation. This is one part of the development during the last decade where the trucks have been taking a increasing proportion of the transported quantities.

Other factors that govern the potential transfer of goods between transport modes is unbalanced flows, transports demanding special solutions, unit load systems and restructuring costs. These factors make the transfer potential between modes very hard to evaluate and it can not be derived from transport statistics only.

The first step is to identify the quantities that have any possibility at all of being transferred. This work uses the breakdown of the Swedish goods flows described in KFB report 1994:6. The database from the project is used to analyse the potential transfer within each category.

II.1 Different categories of goods transfer.

The transfer between modes that is noticeable in the statistics is, on one hand, the share of each mode of the total quantities, on the other hand, the total quantities for each mode. The trends indicate how the goods quantities develop and what the demands are on the transportation. In the TFB-report "Skogsindustrins systemtransporter" [2], "System Transport of the Forest Industry" the shares of the different modes are analysed. One interesting example of the different usage of the modes is that truck transportation increased it's share during both low and high growth periods in the economy for different reasons. During high growth, the demand is high and the customer needs quick temporary transports to fill their needs. During low growth periods the industry is demanding a high service level to show it's ability to give good service.

Both rail and sea transportation are characterised by long term contracted transportation which means that short term changes in the flows normally only effect the truck transportation. The service level is illustrated by the following figure:

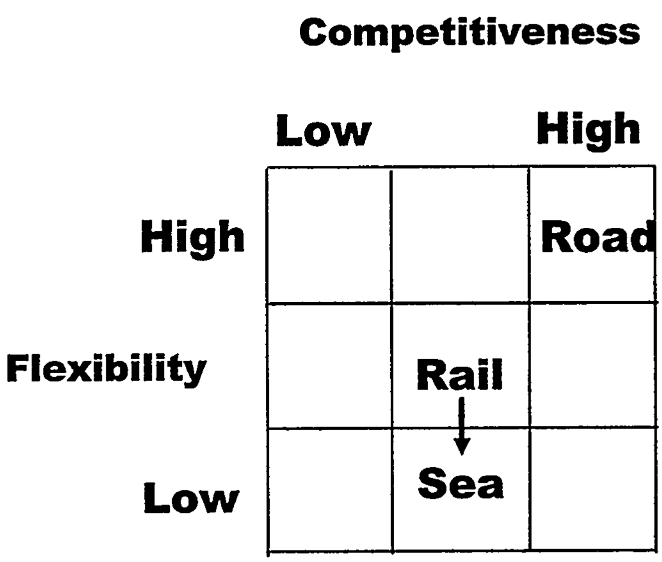


Figure II-1 Schematic figure of the competitiveness between transport modes.

Of course the competitive situation governs the potential for transfer between modes and this is highly dependent of the price of the transport. A comparison of long distance domestic transport gives the following price situation:

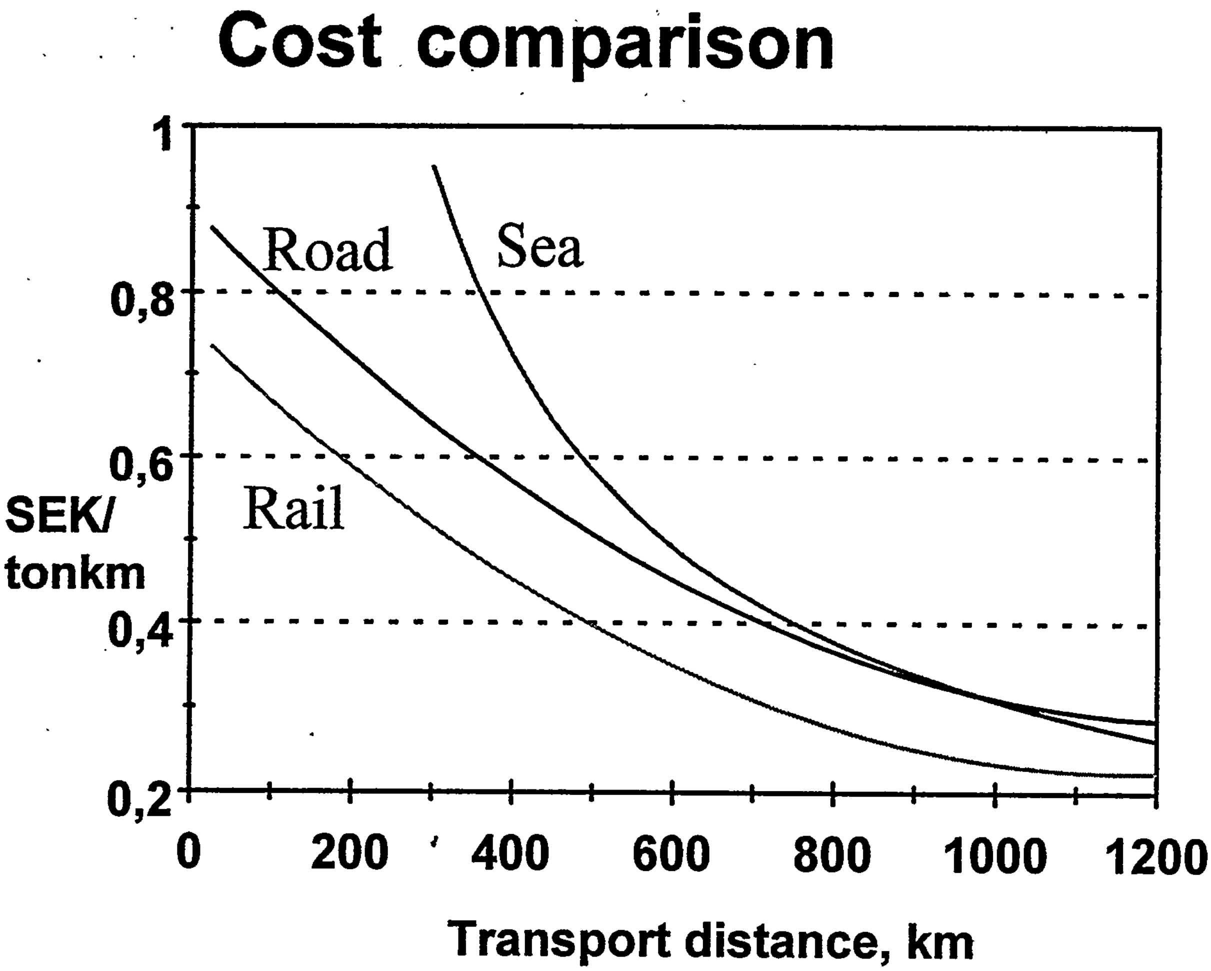


Figure II-2 Cost difference between transport modes in domestic transport.

Figure II-2 gives a good description of the cost competition between different transport modes. The picture is largely drawn from the transport costs specified in applications for regional transport subsidies. For sea transportation a road transport of 50 kms is added at both ends and a fixed cost of 180 SEK to transfer between ship and road transport. This is of course a very simplified picture but nevertheless it illustrates the price differences.

It should be noted that these figures are based on information from consignees that have made their choice of transport mode. This choice may have many motives. The marginal cost for choosing another mode (in this case other than truck) may be much higher than the cost difference to rail in the diagram. The transports going by train generally have rail connections at both ends. If a truck transport is needed at one or both ends the situation becomes entirely different. The competitiveness for the rail transport then becomes more like the sea transport where the relatively expensive short truck legs and the handling operation has to be compensated for by a very low underway cost.

As the marginal cost for changing transport mode is unknown for the individual case it is not possible to determine the level of financial control measures to achieve a desired result.

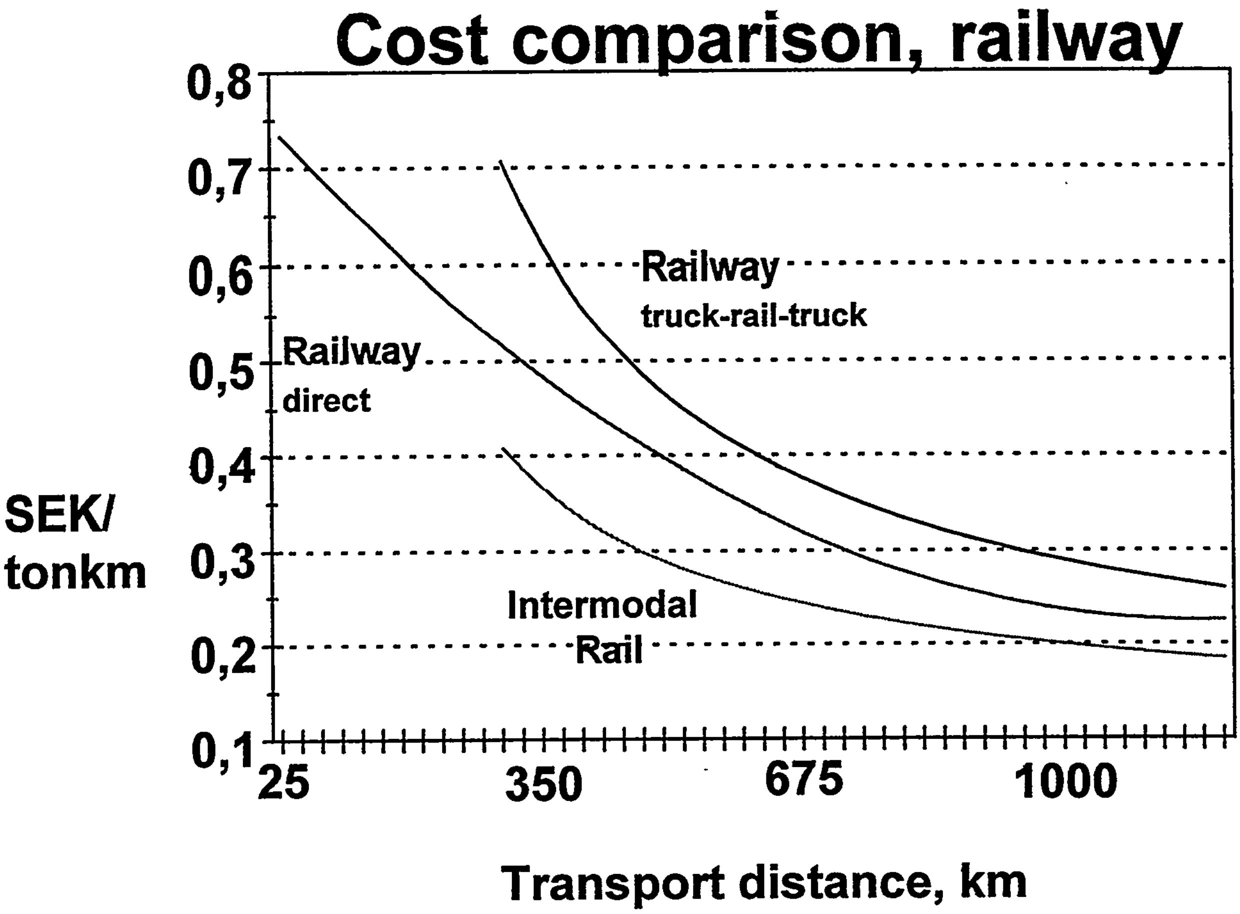


Figure II-3 Comparison between different railway chains.

By transporting goods or unit loads to terminals and load whole trains, the railway can decrease the production costs and thereby the underway costs. This socalled combined or intermodal transports mean that the trains only operate between terminals. Figure 3 shows the cost difference between direct rail transport and rail transport with truck transport in one or the other end. In the example for intermodal transport the underway cost of the train is as low as 0,11 SEK/tonkm while the truck transport is assumed to be 50 kms and the reloading at the terminal is assumed to cost 45 SEK/ton. Provided that the production cost can be kept that low (which only works for long distances, over 1000 km) the combined system are advantageous compared with long distance trucks. However this demands large goods flows between two terminals. Such a system is the basis for cooperation between the transport modes. Conclusively this demands that the long leg is performed very effectively and at a low cost to be competitive.

These estimates are only examples of the cost difference between transport systems and does not show the real cost level. They illustrate the cost components involved and the consequence of different techniques.

II.2 Effect of transfer between transport systems

The shares of the transport modes for different types of goods also give a picture of the market situation for the modes. Figure 1 shows that the flexibility of a transport system not only decides its competitiveness but also its cost situation. The flexibility is a measure of how small a change a system can take up. For truck transportation one truck is the unit. This means a flexibility in the order of 30 ton. For the railway the unit is a full train or 400-800 ton. For sea transportation the practical level of flexibility, depending on frequency requirements, is about 3 000 ton and upwards.

The availability of the transport modes is also important. The trucks have the highest availability and truck transportation can offer a wide range of services from door to door.

Forwarding services and terminals for co-loading are very strongly connected to truck services. For intermodal railway traffic as well as for sea transportation the connecting transports have to be arranged utilising truck transportation.

There is a difference between small and large companies in the availability of different transport modes. This is illustrated in the following diagram that shows the shipment size distribution of the total quantities.

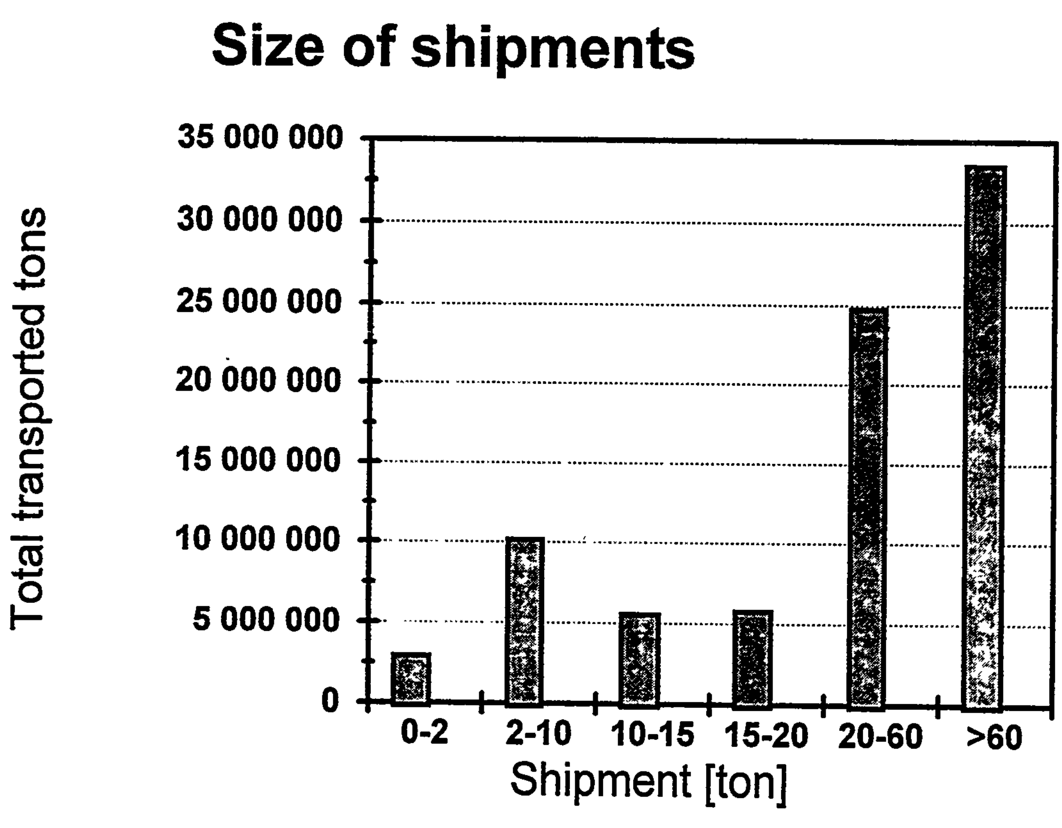


Figure II-4 Freight quantity by shipment size

The large consignees have the possibility to pick between transport modes due to their size. Forest and steel industry pick the transport system that fits their flow and optimises the total cost. Large transfer effects normally only take place when changing the transport system.

The demands from the industry as regards service level and transit times are to a high degree governed by what is offered. The flexibility and individual capacity of the trucks have a large role in this and the arguments that are advantageous to truck transportation tend to become the demands on the transport. The internal competition within truck transportation is much larger than the competition with other modes.

Small shipments and goods over terminals are only shipped by trucks today. Some of these transports make use of rail combi traffic that transport unit loads, mostly semitrailers but also swap bodies, between the large terminals. However, goods over terminals is the smaller part of the truck goods. The transfer potential beyond what is already in this traffic today is probably very small and marginal compared with the total flows.

II.3 Basis for estimates

The information on the total transportation is based on the transport statistics of year 1990 with the distribution and organisation compiled in the KFB-report 1994:6 [1]. To this is added information from Swedish industry as well as a further breakdown of different types of transport within each individual type of goods. This gives a quantification of the share of the different modes a transport chains for:

Raw materials
Trade
Manufacturing industry for domestic and foreign markets
Import
Transit

From this information, the transfer potential for types of goods between transports chains is estimated for all categories except trade and transit.

II.3.1 Principles for estimating transfer potential

Based on today's transportation an estimate is made of the potentially transferable goods quantities. The principle is to estimate different levels of transferable quantities by reasoning around known conditions.

The basis is today's transportation split by chains and types of goods within the categories: manufacturing industry, raw materials and import. The underlying information is illustrated in the enclosures where the information can be read as shown in Figure 5.

The information gives an idea of what is possible to transport in different transport chains and also the share of each transport chain of the total transportation which is shown in a separate figure.

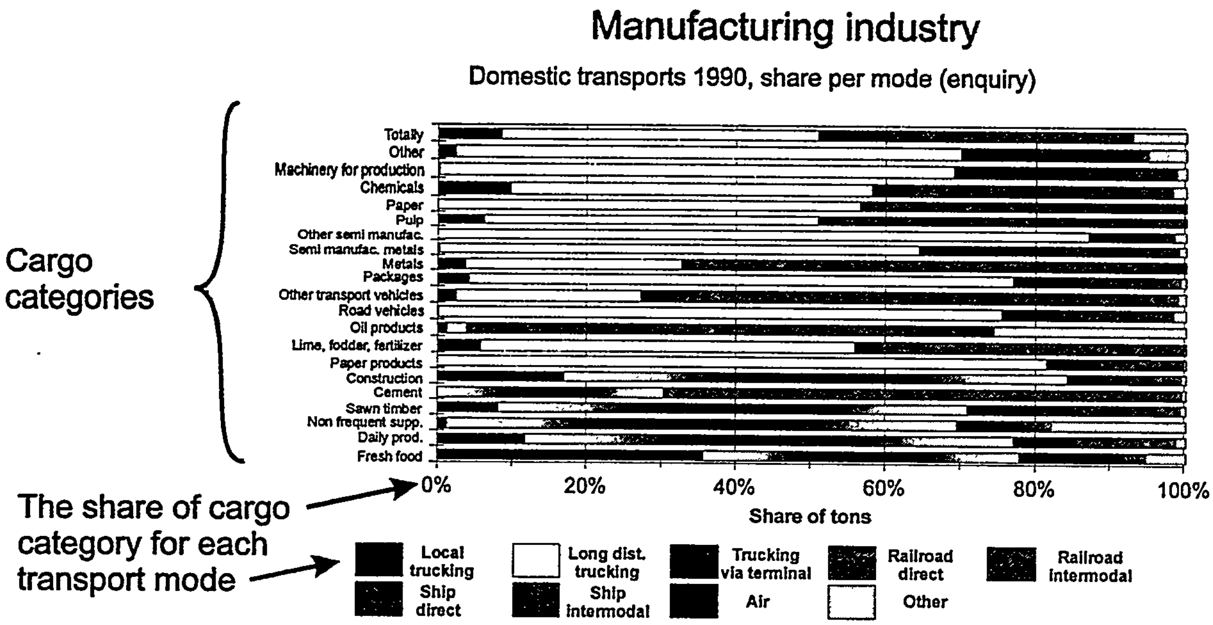


Figure II-5 Example of transport chains split by types of goods for the manufacturing industry.

By studying the following properties:

- Types of goods
- Distribution of transport chains within each type of goods
- Distribution of shipment sizes within each type of goods
- Distribution of transport distance within each type of goods
- Distribution of goods flow sizes
- Goods category

and by evaluation the common trends, an estimate can be made of the maximum transferable quantities from today's situation. In many cases the traffic has to be performed with unit loads in intermodal transport systems instead of direct long distance trucking. For export and import the modelling can be done by assuming that the transportation is done with semitrailers that can be carried by train or pulled along the roads.

The transfer model is based on an estimate of the transferable quantities for each type of goods. For domestic transport the transfer is assumed to be only from truck to railway and then mostly intermodal railway. For foreign transport the transfer is estimated to be partly intermodal to railway, partly to sea transportation. No special effort is made to analyse the transfer potential for sea transportation as this is of secondary importance in an environmental scenario. In addition the competition for sea transportation is more towards railway traffic than towards trucks.

The data for estimates is fairly weak and mainly based on what is reasonable from a transportation point of view. There are very large uncertainties in the collected information. One uncertainty is the information collected from the consignee on the transport mode used for the transport. This does not always correspond with the real conditions. Compared with what can be gathered from the official transport statistics, the used information is unique and very detailed.

Neither can the estimation foresee the technical developments nor their effect. Fairly often technical development lies behind increases in market share for different transport systems.

Within some types of goods there are temporary large quantities upsetting the statistical picture. During 1990 type of goods 15 (other mineralic substances) had an unusually high imported quantity by truck transportation. It is reported as 1 million ton per year compared to the normal of about 250 000 ton. A probable reason is that a flow of building material for some special project has led to the high truck quantities. This is not the normal condition and the type of goods is excluded from the estimates for this reason. If an estimate should be done, the type of goods has to be specially analysed from SCB primary data.

The choice of an alternative transport chain is based on the following reasoning. The statistics for 1990 show a lot of direct transportation by railway. If direct rail transportation can supply the capacity and service level then the transport is already a direct railway transport. This means that a truck transport that is transferred to railway will become an intermodal railway transport.

The cost of direct rail transportation, with today's technique, is too high to be cost effective for SJ. This is shown by large price increases during later years for transports with a direct rail connection and small shipments. SJ has instead referred to intermodal traffic over a large railway terminal. Intermodal rail transport, with a few exceptions, results in a lower service level. Intermodal railway also means that the goods quantity is counted once or twice as additional truck transported within the present system for transport statistics.

The transported quantities (tons) by truck change very little through the transfer from direct long distance truck to intermodal rail transportation. The net result is more probably an increase as the intermodal transport often includes two truck transports. The transferred goods quantity increases the railway quantities and thereby the total transported quantities according to the same model. The large change is in the transfer of the haulage from truck to rail transports.

The previously described transformation of rail transportation from wagon loads to combined traffic has been going on for some years in order to increase the efficiency and minimise the costs for producing railway services. The effect of this transfer can not yet be estimated. Other factors that cannot be evaluated are the effects of lack of capacity in the railway network and of increasing speed differences between train types.

II.4 Transfer model

The enclosures show the type of goods and the distribution of the transport chains for the following categories:

- Manufacturing industry for domestic use
- Manufacturing industry for foreign use
- Import

The delivery transportation from the manufacturing industry is put together through a questionnaire that is described in KFB 1994:6 [1]. The other information is mostly derived from SCB statistics.

Transferable quantities have been estimated as follows:

Table II-1

Manufacturing industry, domestic transports			
Type of goods	**from**	**to**	**motivation**
Fresh food and daily papers	-	-	Special transports that are hard to transfer. Small shipments.
Daily products	long dist truck 10%	interm rail 100%	To some extent transported between stores and can be transported by alternative modes.
Non frequent supplies	-	-	Small quantities with high value and varying character.
Sawn timber	-	-	Very varied market, concealed selection of transport mode
Cement etc.	-	-	Not representative for the group
Construction material	-	-	Often fast deliveries with high JIT demands. Truck to destination.
Paper products	long dist truck 50%	interm rail 100%	Often transports between stores. Suitable for rail transportation.
Lime, fodder, fertiliser	long dist truck 50%	interm rail 100%	Often transports between stores. Suitable for rail transportation.
Oil products	-	-	Very small quantities with truck or rail
Road vehicles	-	-	Small quantities of varying character
Other transport vehicles	-	-	Small quantities of varying character
Packages	long dist truck 30%	interm rail 100%	Often transports between stores. Suitable for rail transportation.
Metals	-	-	Small quantities of varying character
Semi manufac. metals	long dist truck 20%	interm rail 100%	JIT product that partly are transport cost sensitive.
Semi manufac. other	long dist truck 20%	interm rail 100%	JIT product that partly are transport cost sensitive.
Pulp	long dist truck 50%	interm rail 100%	Suitable for rail transportation. Very dependent on transport cost.
Paper	long dist truck 20%	interm rail 100%	Often transports between stores. Suitable for rail transportation.

Chemicals	-	-	Special transports that are difficult to transfer
Machinery for production	-	-	Project connected transportation, small quantities
Other	long dist truck 30%	interm rail 100%	The transport often governed by cost, some groups physically transferable.

Table II-2

Manufacturing industry, exports			
Type of goods	**from**	**to**	**motivation**
Fresh food and daily papers	-	-	Special transports that are hard to transfer. Small shipments.
Daily products	long dist truck 20%	interm rail 100%	To some extent transported between stores and can be transported by alternative modes.
Non frequent supplies	long dist truck 50%	interm rail 100%	Small quantities with high value and varying character. Can be co-loaded for longer distances.
Sawn timber	75%	ship 50% rail 50%	Large share of foreign transpiration by truck due to subvention. Lower costs give railway possibility.
Cement etc.	-	-	Not representative for group
Construction material	-	-	Often fast deliveries with high JIT demands. Truck to destination.
Paper products	long dist truck 50%	interm rail 100%	Often transports between stores. Suitable for rail transportation.
Lime, fodder, fertiliser	-	-	Small truck quantities
Oil products	-	-	Very small quantities with truck or rail
Road vehicles	long dist truck 50%	interm rail 100%	Small quantities with high value and varying character. Can be co-loaded for longer distances.
Other transport vehicles	-	-	Small quantities of varying character.
Packages	long dist truck 30%	interm rail 100%	Often transports between stores. Suitable for rail transportation.
Metals	-	-	Small quantities of varying character.
Semi manufac. metals	long dist truck 30%	interm rail 100%	JIT product that partly are transport cost sensitive.
Semi manufac. other	long dist truck 30%	interm rail 100%	JIT product that partly are transport cost sensitive.
Pulp	-	-	Today only special transports by trucks

Paper	long dist truck 30%	interm rail 100%	Often transports between stores. Suitable for rail transportation.
Chemicals	-	-	Special transports that are difficult to transfer
Machinery for production	-	-	Project connected transportation, small quantities
Other	long dist truck 30%	interm rail 100%	The transport often governed by cost, some groups physically transferable.

Table II-3

Raw materials			
Type of goods	**from**	**to**	**motivation**
Fodder	-	-	Tractor transports, very short
Lumber, pulpwood	long dist truck 10%	interm rail 100%	Increased terminal handling gives transfer to rail.
Grain	-	-	Short transport from fields
Fruit & vegetables	-	-	Special transports
Sugar beets	-	-	Tractor transports, short
Livestock	-	-	Special transports
Milk	-	-	Special transports
Egg & fowl	-	-	Special transports
Sea fish	-	-	Special transports
Earth, sand, stones	-	-	Only short truck transports
Sulphur pyrite	-	-	Only short truck transports
Iron ore	-	-	1990 mostly railway
Turf	-	-	Only short truck transports
Other ores	-	-	1990 mostly railway

Table II-4

Import			
Type of goods	**from**	**to**	**motivation**
Grain	long dist truck 30%	interm rail 100%	Distribution between terminals
Fruit & vegetables	long dist truck 30%	interm rail 100%	Distribution between terminals
Other foods	long dist truck 30%	interm rail 100%	Distribution between terminals
Table oil, margarine	-	-	Very small share truck transportation
Wood, pulpwood, lumber	-	-	Small quantities
Fertiliser	-	-	No change
Minerals	-	-	No change
Iron ore & scrap	-	-	No change
Other ore & scrap	-	-	No change
Other raw materials	long dist truck 25%	interm rail 100%	Large truck transport share, small quantities
Coal & Coke	-	-	No change
Mineral oils & oil products	-	-	No change
Mineral tar	-	-	No change
Chemical products and concrete	long dist truck 30%	interm rail 100%	Increasing share of special transports by rail.
Cement & Lime stone	-	-	Not representative quantities
Metals	long dist truck 30%	interm rail 100%	Increased return transports from the continent
Metal products	long dist truck 50%	interm rail 100%	Increased return transports from the continent
Machines	long dist truck 30%	interm rail 100%	Increased return transports from the continent
Other products	long dist truck 30%	interm rail 100%	Increased return transports from the continent
Other materials	long dist truck 30%	interm rail 100%	Increased return transports from the continent

The transit goods can be considered as 100 percent transferable from trucks to train, consisting of about 3 million ton per year. However this would require a total abolishment of all throughpassing truck traffic in Sweden. For the Norwegian domestic transports through Sweden, for example, this is a totally unrealistic requirement. The whole of the transit traffic is excluded from the modelling as it cannot be considered as a part of Swedish transport politics.

Trade and **trade import** is judged to have special character and being of such extent that no changes are realistic.

As outlined in KFB 1994:9 [3] the transport distance is adjusted to include the difference between different systems. This means that a transfer from truck to intermodal rail gives a 13 percent increase in the rail distance plus two distribution truck legs of 30 km each.

The total quantity thus transferred (added to rail transportation) is abt 13 million ton. The reduction in truck goods quantity is marginal but the transfer affects on haulage.

II.5 Practical potential of transfer

Of course there are reasons why the identified quantities does not already go by railway. The primary reason probably is the total cost of the alternative rail transport. The outlined transfer scenario requires a technical/economical development of intermodal train transport to achieve more competitiveness.

The transfer scenario gives a total increase of rail cargo quantities of about 16-17 percent. This increase will largely take place in Southern Sweden. In this area there is a lack of capacity to achieve the desired service level at all hours. One condition to cover for this volume is a capacity increase, for example through added infrastructure. To what extent this expansion is feasible can not be judged in this project.

One alternative to infrastructure expansion is that goods from the highest utilised lines could be transferred to sea transportation. Forest products and other heavy long distance dry bulk and break bulk goods are suitable for transfer to sea transportation. The railways need to increase its competitiveness towards truck transportation and concentrate their resources towards that purpose.

II.6 Results and conclusions

The conditions for a transfer of goods from truck to rail are a technical/economical development of the intermodal rail transport and that transport capacity is available at the right hours of day.

To be able to estimate the potential of transfer between modes, a very detailed knowledge of the transportation is necessary. The Swedish transportation statistics are based on individual information from the modes. This means that there is no connection between the modes that shows the way of the goods in transport chains. There is also very little geographical information about the transportation routes, where from and where to. There is some regional information of exported goods as information is available on where the goods leaves Sweden and in what way. The individual shipments are not followed through the transport chain.

The handled information does not add much to the official statistics in the geographical content as there is information on where from but not where to. This means that capacity calculations cannot be done from the information. This has to be judged from the overall results.

The transfer scenarios have been done using statistical figures. The transferred haulage is based on the statistical average transportation distance for each category. The major difference between this work and previous research based on official statistics is that this work analyses the transfer potential based on the known transport chains for each type of goods.

Through the transfer from simple transport chains (long distance truck to intermodal rail) the transported quantities by truck change very little or rather increase as the domestic intermodal transport chain contains two truck legs. The goods quantities transferred to rail becomes additional rail quantities. The significant change is in the transfer of haulage. The changes are summarised in the following table:

Table II-5

	From			To	
	ton	tonkm	type	tonkm	type
Domestic transportation	3 563 129	1 133 576 965	Truck	1 494 729 734	Intermodal rail
Foreign transportation	4 177 579	967 925 466	Truck	1 116 226 641	Intermodal rail
				80 843 754	Intermodal sea
Total	**7 740 710**	**2 101 502 431**		**2 691 797 130**	

The transferred share of the total transportation is 1,9 percent of the transported quantity (ton) and 2,7 percent of the haulage (tonkm). This results in a decrease for truck transport chains of 2,8 percent of the quantity and 6,6 percent of the haulage. For long haul trucking alone the decrease is 9,0 percent and 8,1 percent respectively.

For the railway chains the results are a 16,3 percent increase in goods quantity and a 16,6 percent increase in haulage.

The transfer to a combined transport chain means a total increase in haulage of 28 percent for the effected traffic and an increase of 0,8 percent of the total national haulage.

The environmental effects of the transfer are determined with the emission model that was developed for KFB1994:6 [1]. The emission factors used are tabled in the previous chapter.

The generalised emission factors include average utilisation rates for the transport modes. For the railway a combination of direct and indirect emissions are used. The direct emissions are from use of diesel engines and the indirect emissions are from the average Swedish electricity production including the small fraction generated from combustion based plants.

The energy is compared in the same form and for that reason translated into oil equivalent energy. The electrical energy for the railway is converted into the fuel energy necessary for an oil based electricity production. For fuel burning vessels, the fuel energy content is used.

Table II-6 Total emissions and energy consumption per transport chain year 1990

TRANSPORT CHAIN							
	NO_x	HC	CO	CO_2	Part	S	Energy
	[ton]						[TJ]
Short dist truck	21 000	2 300	7 000	1 200 000	2 200	640	16 000
Long dist truck direct	38 000	2 000	6 000	1 900 000	2 600	1 100	26 000
Long distance truck via terminal	2 500	150	440	130 000	180	70	1 700
Railway direct	2 400	49	200	130 000	51	210	6 200
Railway intermodal	1 600	120	360	88 000	110	86	2 300
Sea transport direct	8 300	260	360	350 000	310	2 100	4 700
Sea transport intermodal	4 300	190	440	200 000	220	730	3 400
TOTAL	78 000	5 100	15 000	4 000 000	5 700	4 900	59 000

The following tables sum up the results of the theoretical transfer operations as regards energy consumption and emissions to air:

Table II-7 Changes in emissions and energy consumption after transfer scenario.

CHANGES AFTER TRANSFER							
	NO_x	HC	CO	CO_2	Part	S	Energy
	[ton]						[TJ]
Short dist truck	0	0	0	0	0	0	0
Long dist truck direct	-3 400	-190	-570	-170 000	-250	-100	-2 300
Long distance truck via terminal	0	0	0	0	0	0	0
Railway direct	0	0	0	0	0	0	0
Railway intermodal	1 900	150	460	100 000	140	90	2 200
Sea transport direct	0	0	0	0	0	0	0
Sea transport intermodal	50	2	5	2 500	3	8	34
TOTAL	-1 500	-33	-100	-71 000	-100	-4	-70

Table II-8 Relative changes in emissions and energy consumption after transfer scenario.

RELATIVE CHANGES							
	NO_x	HC	CO	CO_2	Part	S	Energy
Short dist truck	0	0	0	0	0	0	0
Long dist truck direct	-9,1 %	-9,4 %	-9,4 %	-9,0 %	-9,4 %	-9,4 %	-9,0 %
Long distance truck via terminal	0	0	0	0	0	0	0
Railway direct	0	0	0	0	0	0	0
Railway intermodal	+115 %	+132 %	+130 %	+115 %	+132 %	+105 %	+95 %
Sea transport direct	0	0	0	0	0	0	0
Sea transport intermodal	+1,2 %	+1,2 %	+1,2 %	+1,2 %	+1,3 %	+1,1 %	+1,0 %
Changes for effected transports	-44 %	-18 %	-17 %	-41 %	-41 %	-3,9 %	-3,1 %
Changes for all freight transport	-2,0 %	-0,6 %	-0,6 %	-1,8 %	-1,8 %	-0,1 %	-0,1 %

The estimation of transfer potential in this work assumes a development of transport concepts that is hard to quantify, both as regards price and service level, but nevertheless remains a qualified estimate of a reasonable transfer on a detailed level.

The resulting effects of a transfer from a simple truck transport chain to a combined transport chain with railway as the main mode can be summarised as follows:

Table II-9 Summary of results

	Unit	%	Unit	%
Transfer from truck, total	ton	-2,8	tonkm	-6,6
Transfer from long-distance truck	ton	-9,0	tonkm	-8,1
Transfer to railway	ton	+16	tonkm	17
Effected transfer of all goods transport	**ton**	**+1,9**	**tonkm**	**2,7**
Change in effected haulage			tonkm	28
Change of the national haulage			**tonkm**	**0,8**
Change in nitrogen oxide emissions	effected transports	-44	national	-2,0
Change in greenhouse gas emissions	effected transports	-41	national	-1,8
Change in energy consumption	effected transports	-3,1	national	-0,1

If one looks at the reduction in emissions for the effected transports there is an expected large reduction. However from the national perspective the transferable quantities are marginal.

The transfer should be seen in the national perspective. So should the environmental effects and the actions and resources needed to make the transfer possible.

II.7 References

[1] Miljöeffekter av transportmedelsval för godstransporter, (Environmental effect of choice of transport mode for goods transportation), G Demker, E Flodström, A Sjöbris, M Williamson, KFB-rapport 1994:6, ISBN 91-88370-65-8, Sept. 1994

[2] Skogsindustrins systemtransporter, (System transports for the forest industry), A. Sjöbris, M. Koch, TFB-rapport 1988:12, ISBN 91-87246-35-x, nov.1988

[3] Emissions- och energivärderingsprinciper för transportsystem, (Emission and energy evaluation principles for goods transportation), E Flodström, A Sjöbris, KFB-rapport 1994:9, ISBN 91-88370-67-4, sept.1994.

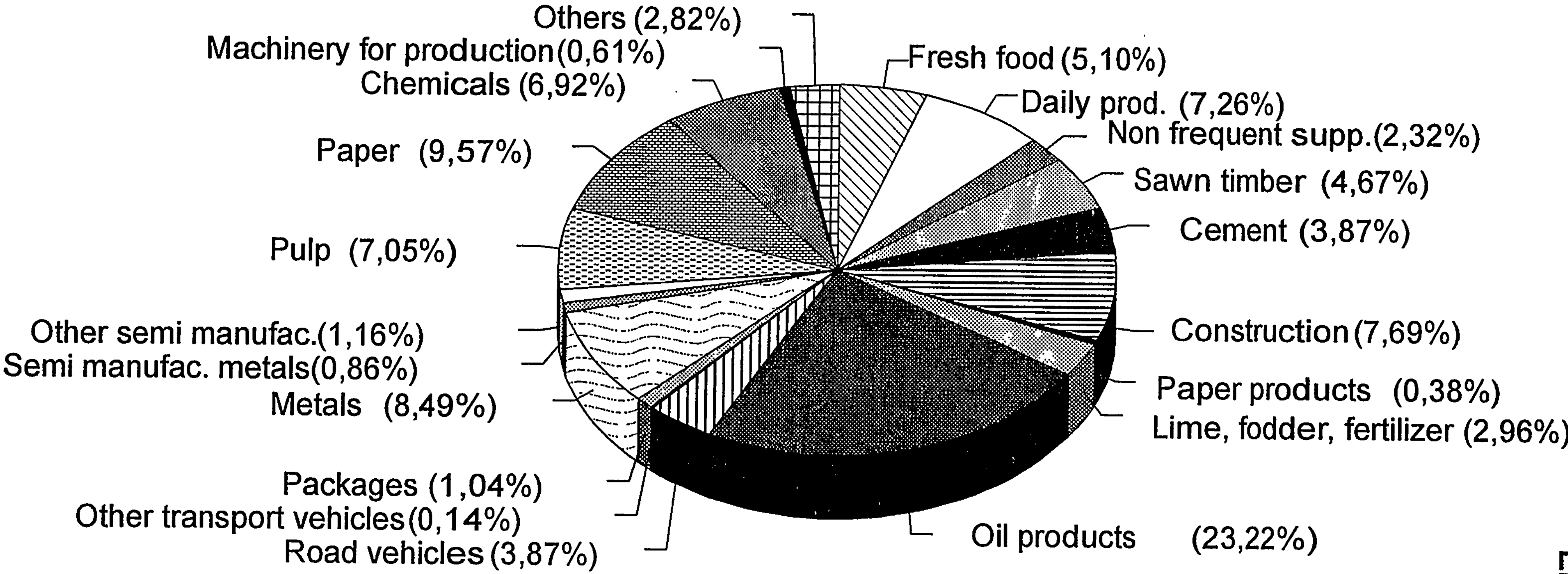
II.8 Enclosures

I	Deliveries from manufacturing industry 1990, split by type of goods.
II	Domestic deliveries from manufacturing industry 1990, split by type of goods and transport chain.
III	Domestic deliveries from manufacturing industry 1990, split by transport chain after type of goods.
IV	Export deliveries from manufacturing industry 1990, split by type of goods and transport chain.
V	Export deliveries from manufacturing industry 1990, split by transport chain after type of goods.
VI	Deliveries from manufacturing industry 1990, split by transport distance after type of goods.
VII	Deliveries from manufacturing industry 1990, split by shipment size after type of goods.
VIII	Deliveries from manufacturing industry 1990, split by goods density after type of goods.
IX	Deliveries from manufacturing industry 1990, split by unit type after type of goods.
X	Import 1990 split by type of goods.
XI	Import 1990 split by transport mode after type of goods.

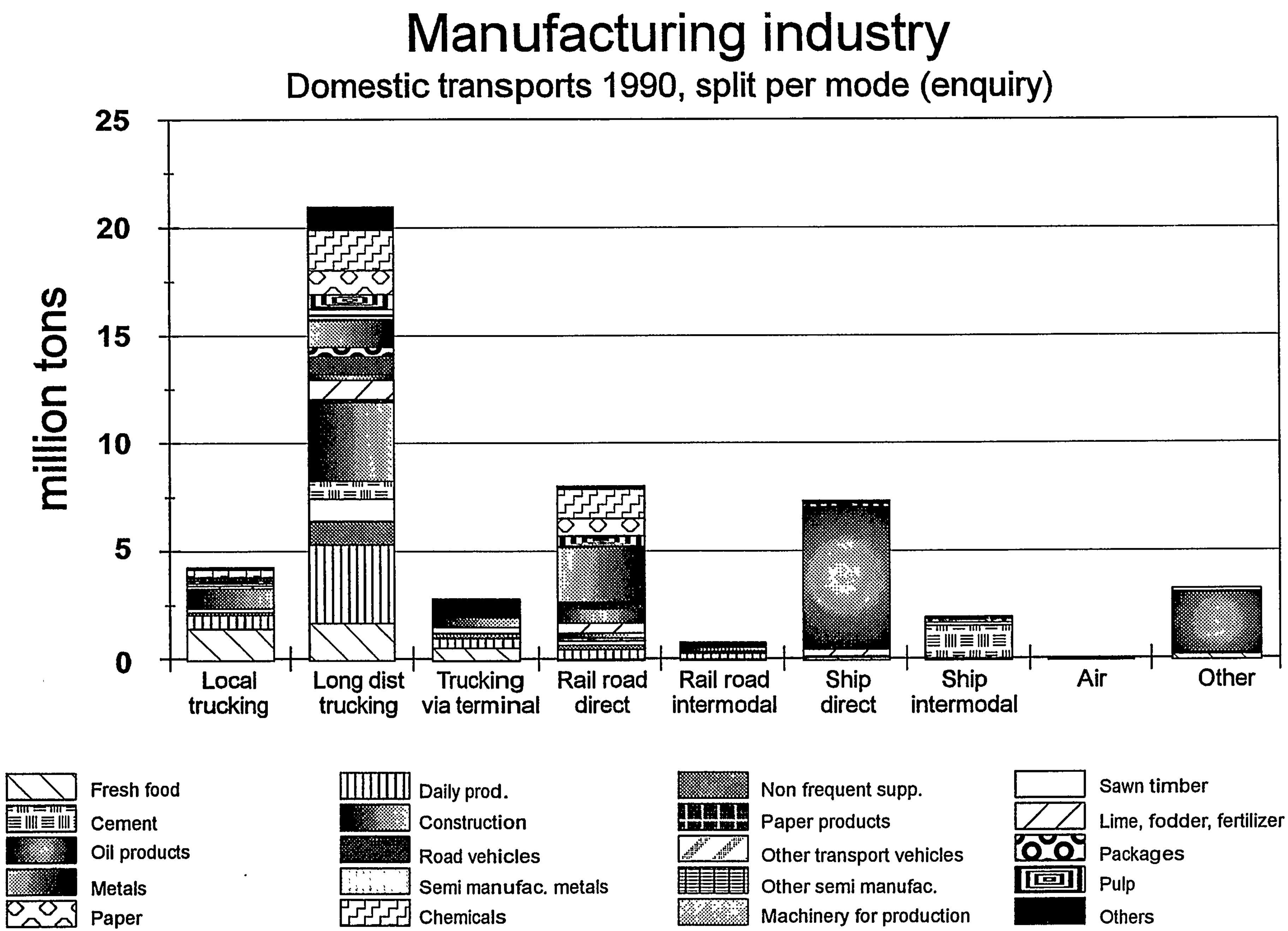
Enclosure I

Manufacturing industry

Deliveries 1990

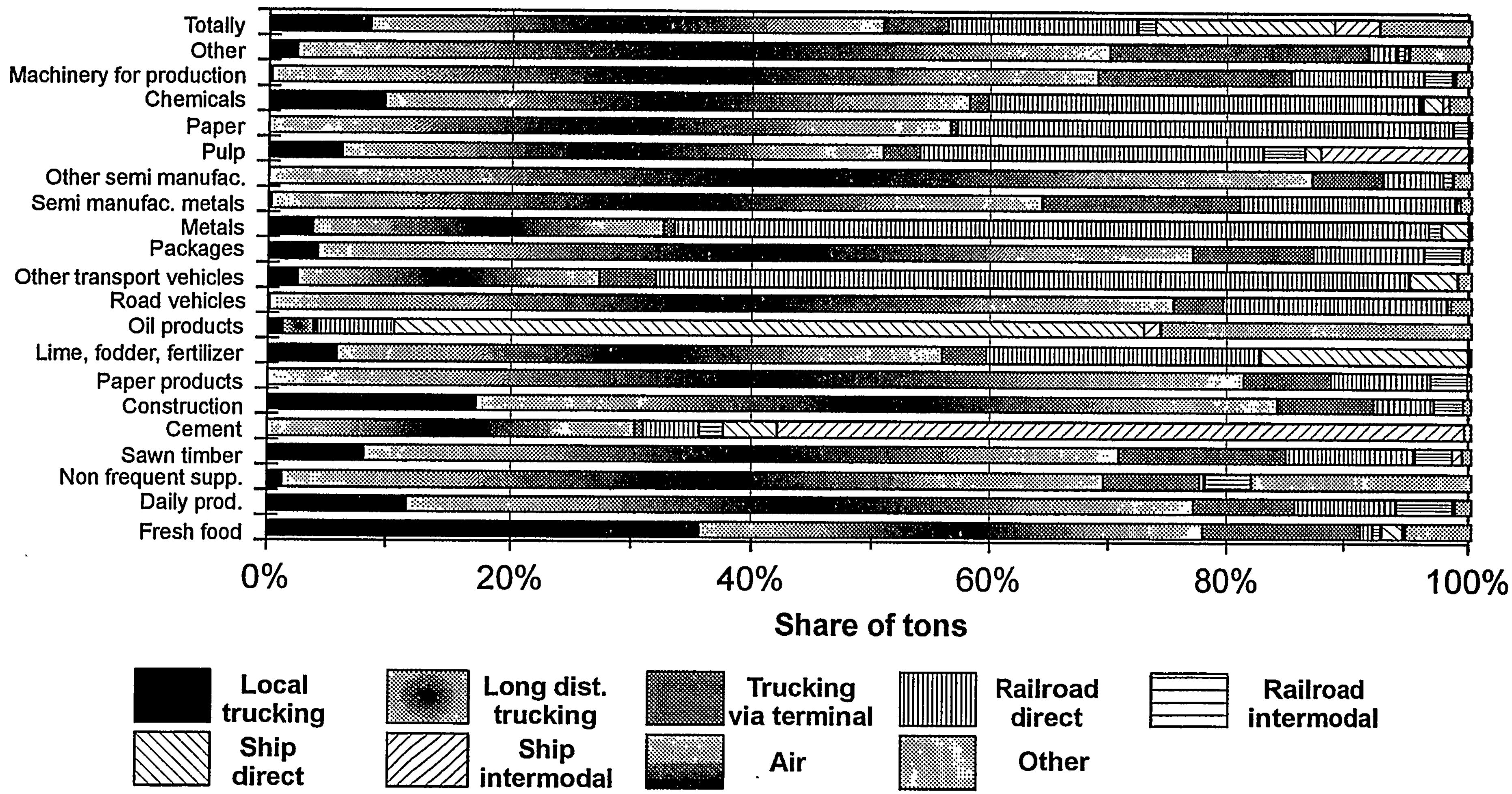


Enclosure II



Manufacturing industry

Domestic transports 1990, share per mode (enquiry)

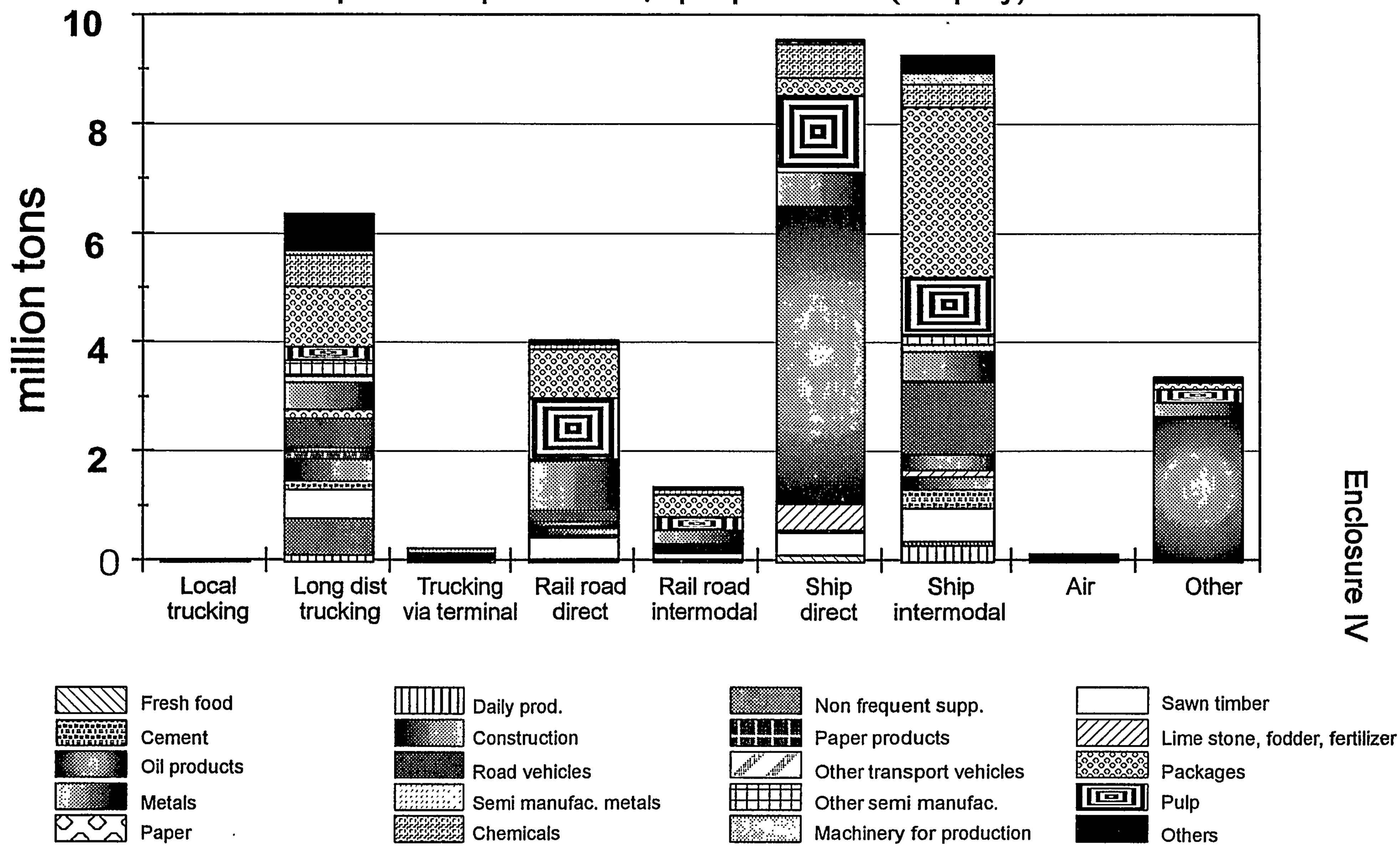


Enclosure III

Enclosure IV

Manufacturing industry

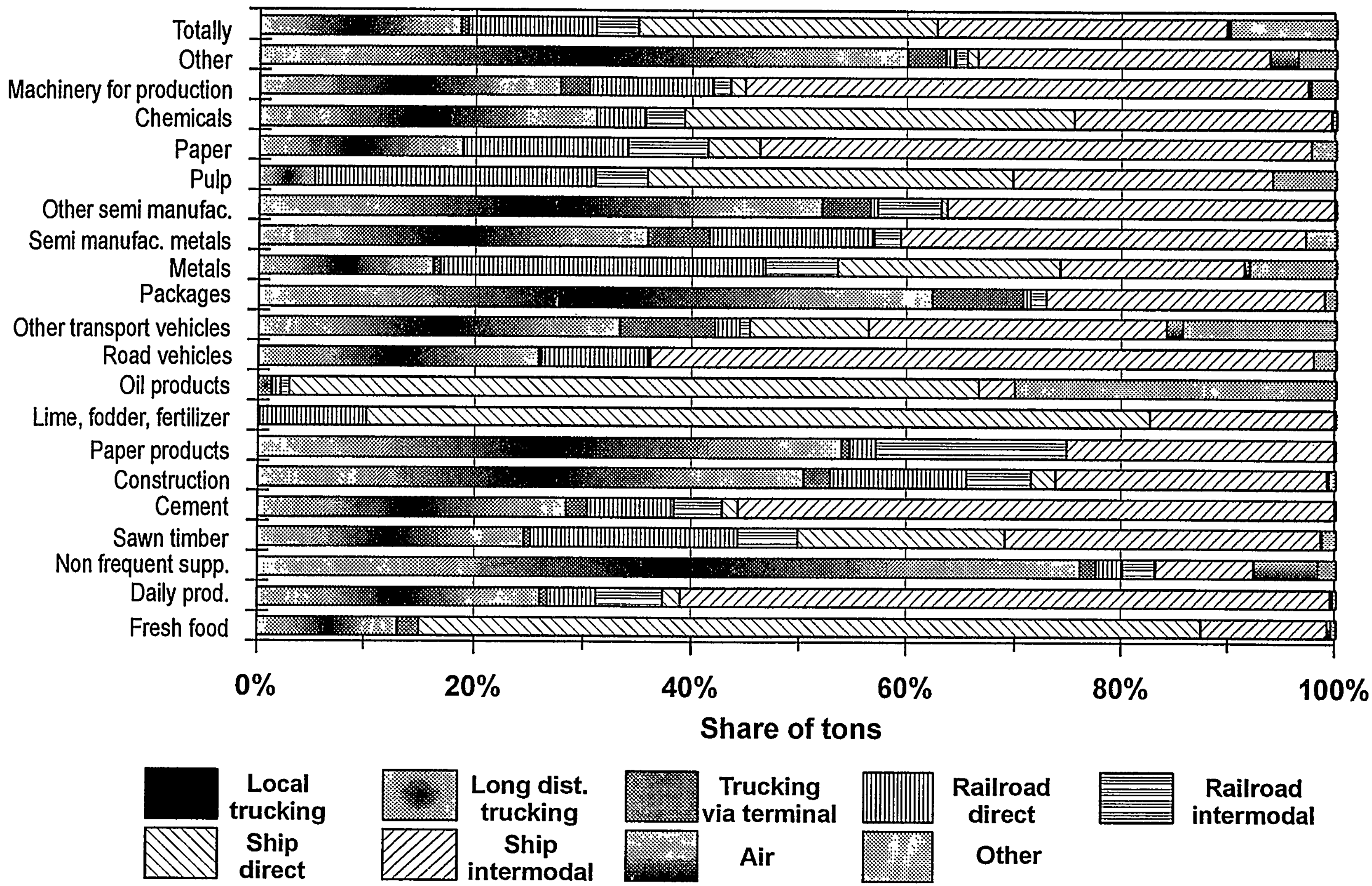
Export transports 1990, split per mode (enquiry)



Enclosure V

Manufacturing industry

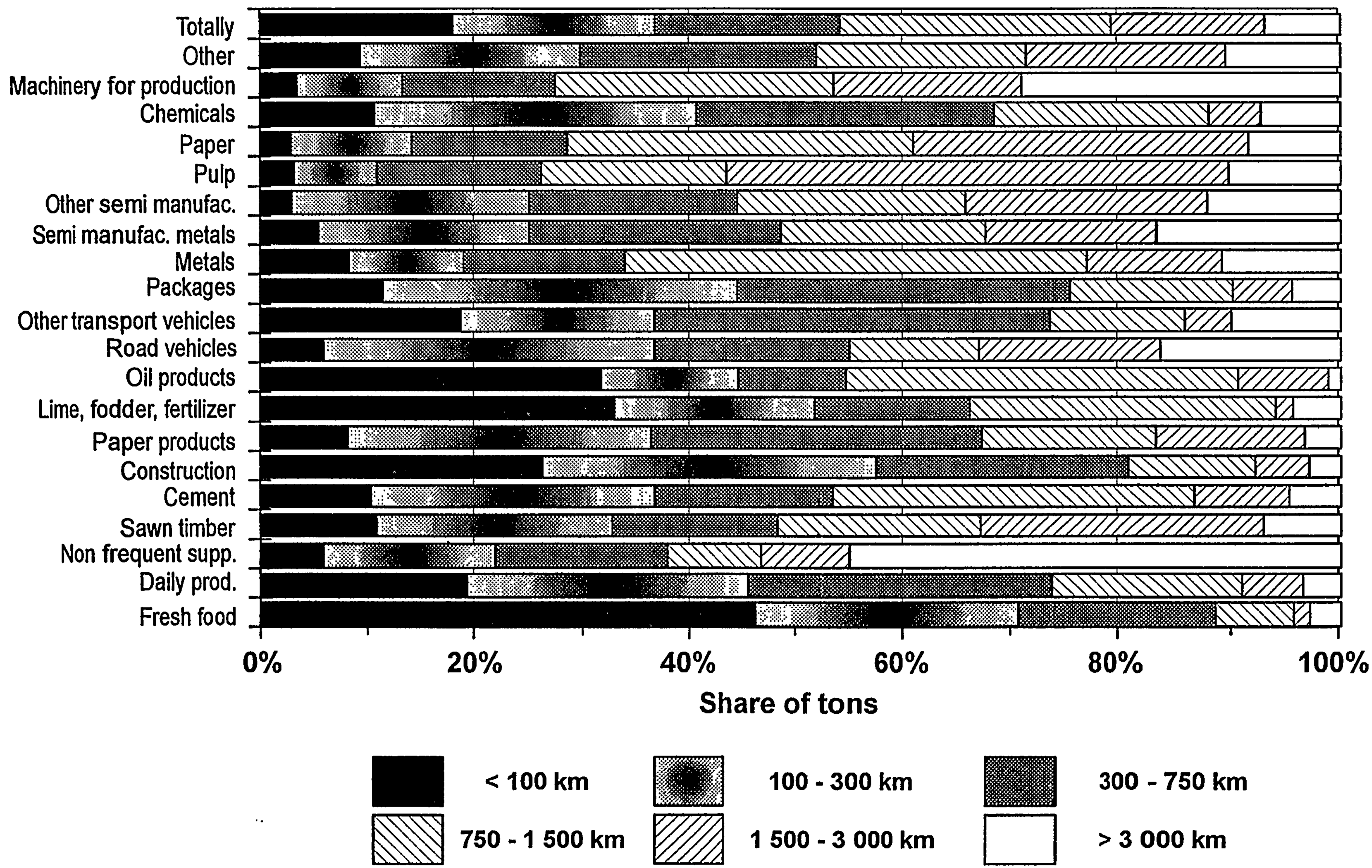
Export transports 1990, share per mode (enquiry)



Enclosure VI

Manufacturing industry

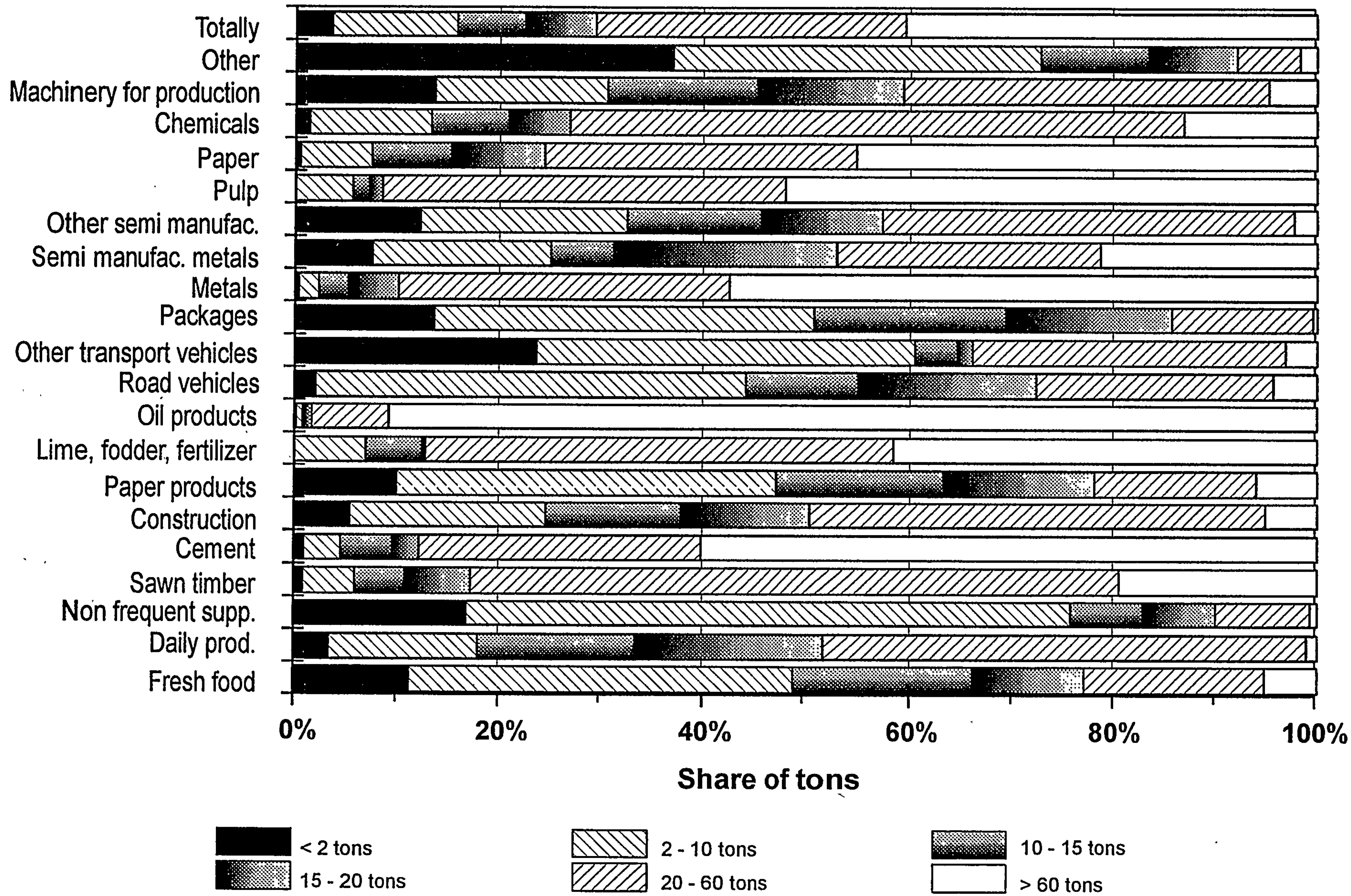
Delivery transports 1990, share per mode (enquiry)



Enclosure VII

Manufacturing industry

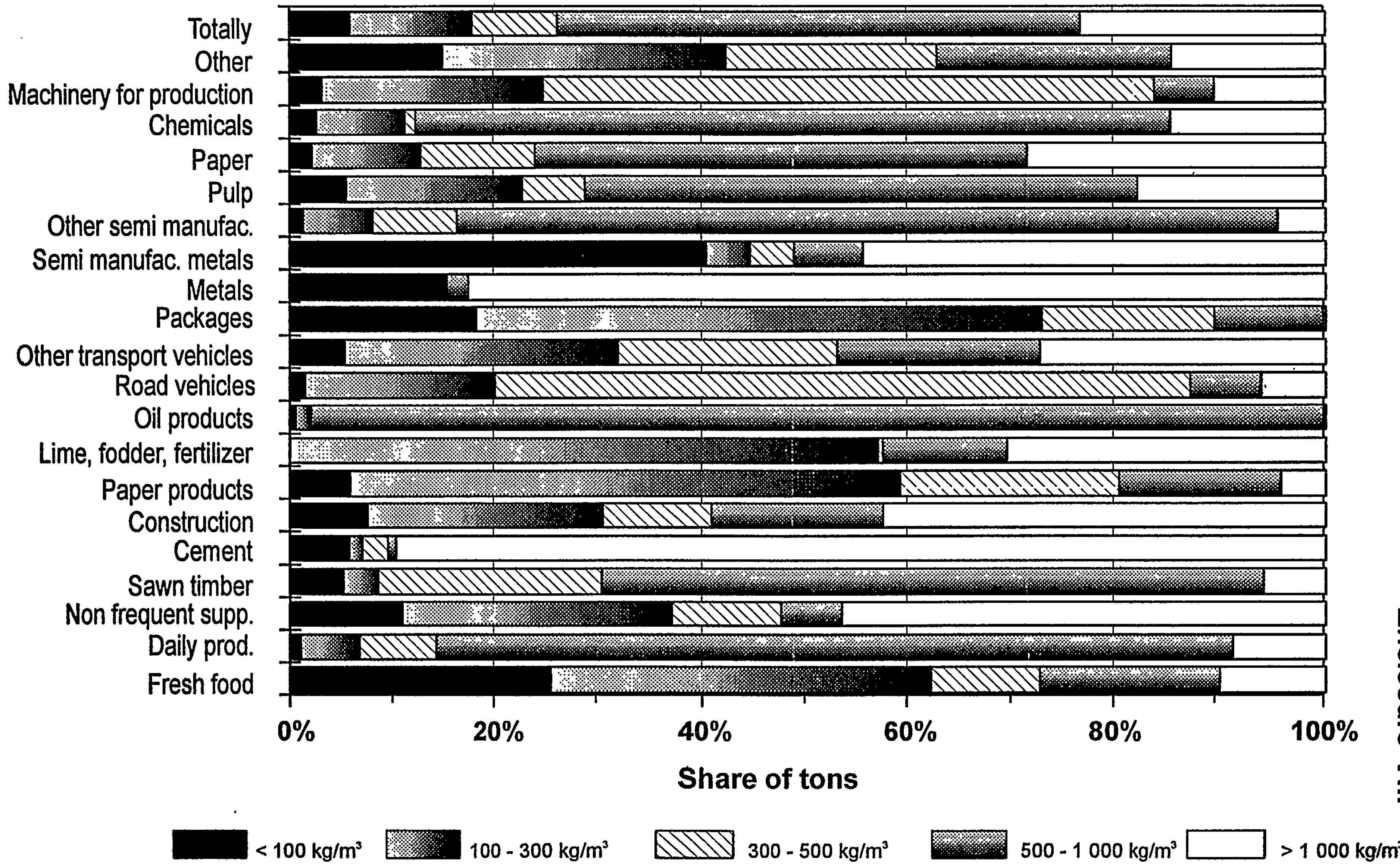
Delivery transports 1990, Size of shipment



Enclosure VIII

Manufacturing industry

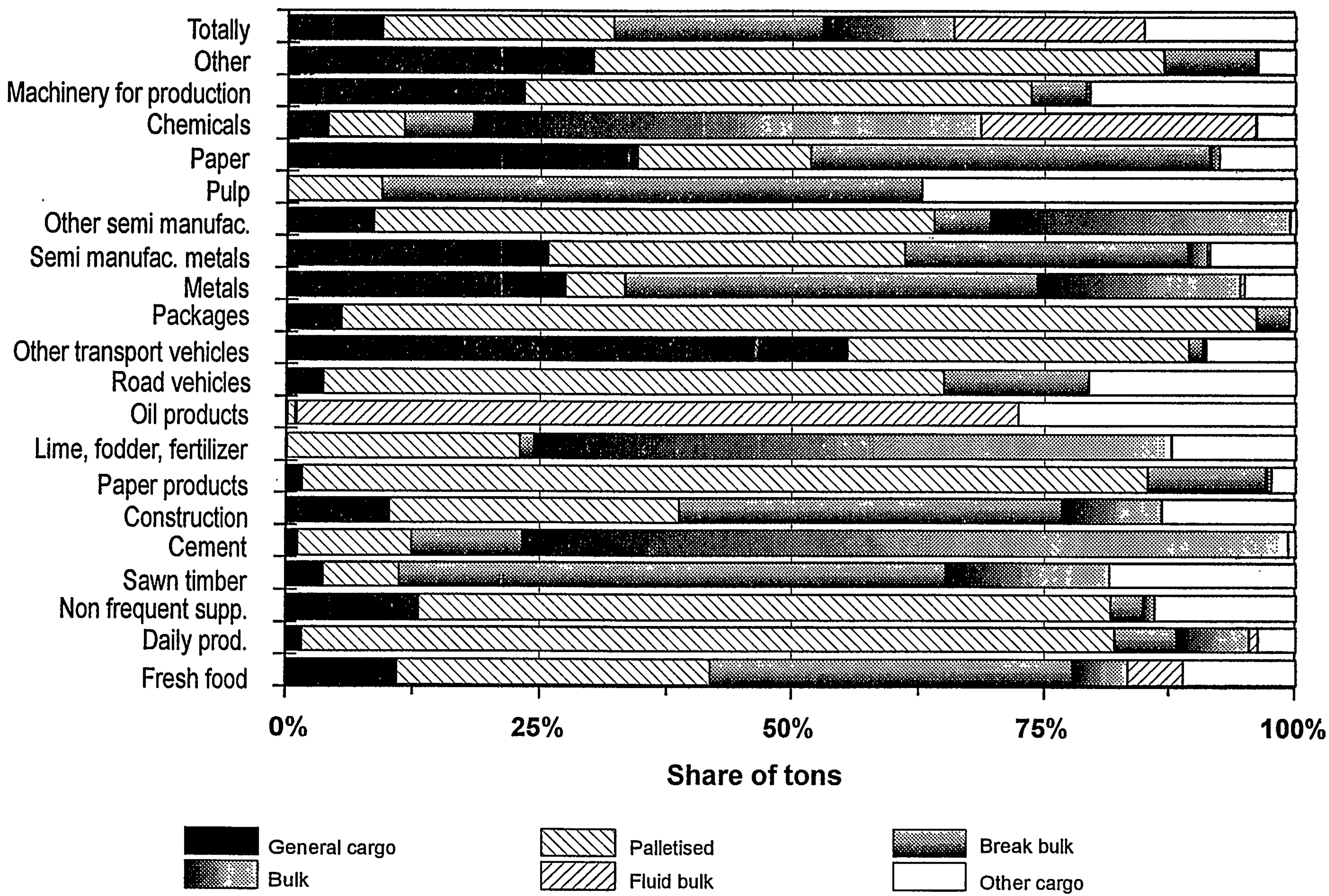
Delivery transports 1990, Cargo density



Enclosure IX

Manufacturing industry

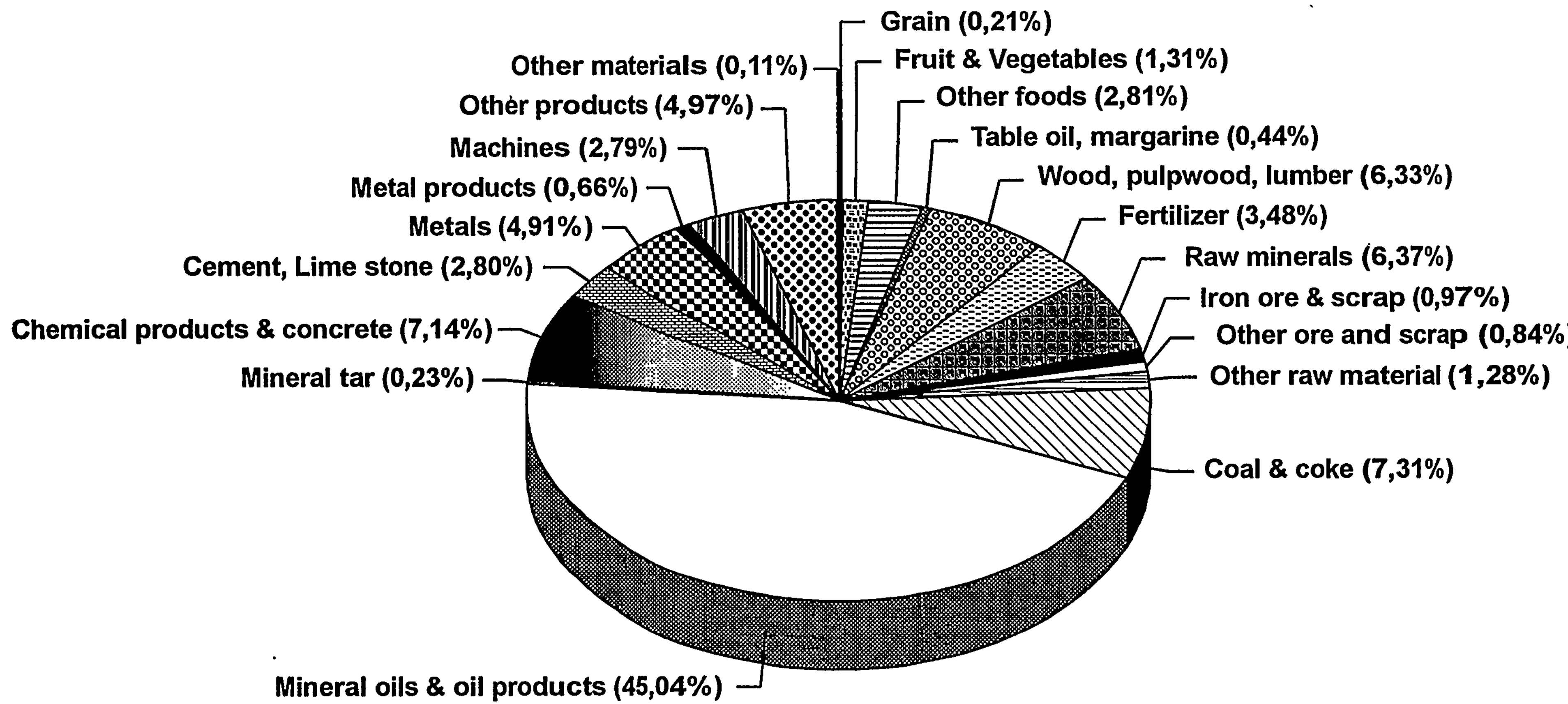
Delivery transports 1990, Type of goods



Enclosure X

Imports 1990

Cargo category (SCB)



Enclosure XI

Imports 1990

Mode of transport at border (SCB)