3.

THE COST OF TRANSPORTATION - ENERGY AND ENVIRONMENTAL IMPACT

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3.1 Energy for transport

Transport energy amounts to some 20 per cent of total final energy use in Europe. More than 90 per cent of it is based on petroleum fuels. About two-thirds of transport energy is used for passenger transport. The transport share of total energy-use, as well as the per capita transport energy-use, is larger in western European countries than in most central and eastern European countries (see examples in Table 3.1).

While the increase in total energy-use has been very moderate in industrialized countries during the 1970s and 1980s, energy-use for transport has increased significantly. For example, transport energy-use in the EU-countries doubled between 1970 and 1990 whereas energy-use in other sectors showed only a minor increase.

Technical developments have reduced specific energy-use (MJ/vehicle-km) during the period, but this reduction has been counteracted by the very large increase in transport volume. For example, passenger transport in western Europe almost doubled between 1970 and 1990 whereas the transport of goods increased by almost 70 per cent. A large fraction of the potential energy-efficiency improvements for vehicles has also been lost due to increases in vehicle weight and power.

There are also additional factors that have led to increased energy-consumption. Firstly, transport has tended to use less energy-efficient modes of transport, such as road transport instead of train and air instead of roads. Secondly, vehicles are used less efficiently: as occupancy and load-factors of vehicles are being reduced. Finally, driving conditions, in particular the increasingly crowded roads, have worsened and this has also contributed to increasing energy-use.

Higher average speeds on highways is another factor. Efficient energy-use is heavily dependent on vehicle speed. Energy-use is lowest at average speeds of approximately 60–80 km/h. At higher speeds energy-use increases rapidly. This is mostly due to increased air-drag.

In cities it is the other way around. Here the speed is often much lower than optimal. A larger energy-consumption at low average speeds in urban traffic is a result of its inefficiency. There is relatively larger engine fric-

The environmental impact of traffic

The relative importance of mobile sources (road, rail, sea and air vehicles and machinery) for air pollution in 1990 within the Europe:

Total CO emissions	59%
Total NO_x emissions	57%
Total SO_2 emissions	5%
Emissions of NMVOC (non-methane volatile organic compounds)	34%
Emissions of CO_2	17%

O_3 is produced from vehicle emissions indirectly, through oxidation of atmospheric oxygen in the presence of VOCs, NO_x and sunlight.

The importance of motor vehicles for local air pollution may be even larger than what the percentages given above imply since the pollutants from motor vehicles are emitted at ground level.

Table 3.1. Total and per capita transport energy use in a selection of countries in 1992 (Share of total energy and petroleum used for transportation).

	Germany	Nordic-4[a]	Poland	Baltic States[b]
Transport energy use (PJ/yr)	2600	1000	360	110
Per capita transport energy use (GJ/yr, cap)	33	44	9.6	15
Transport share of total energy use (%)	26	26	14	18

[a] Denmark, Finland, Norway and Sweden

[b] Estonia, Latvia and Lithuania

(Source: OECD)

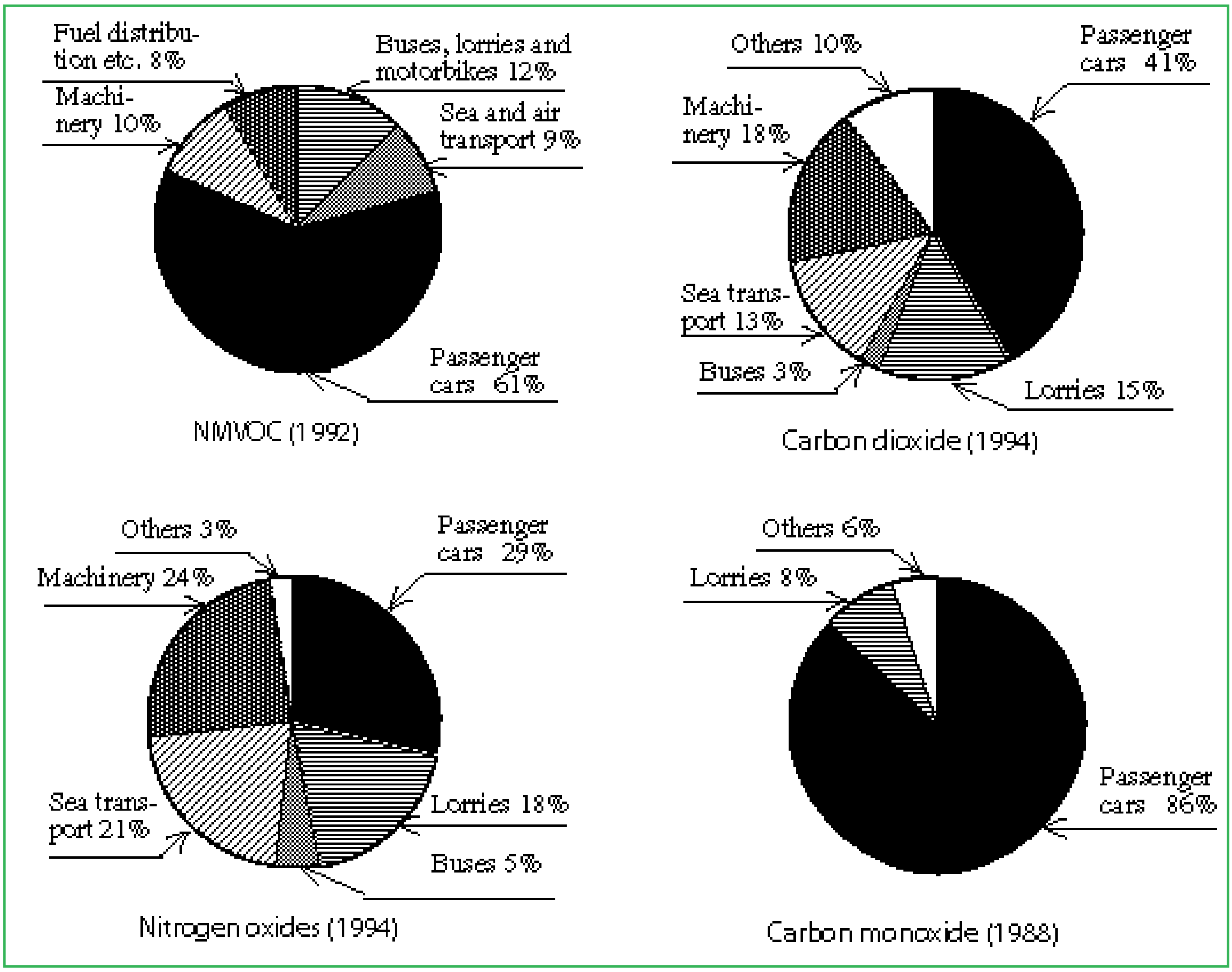

Fig 3.1. Emissions of CO, NMVOCs, NO_X, and CO_2 from mobile sources in Sweden by source. Year of emissions are shown in brackets.

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3.2 Air pollution from traffic

Energy-use in the transportation sector is a major source of air pollutants. These pollutants contribute to several local, regional and global environmental problems. Traffic is an important source of local high concentrations of carbon monoxide (CO), volatile organic compounds (VOCs), sulphur dioxide (SO_2), nitrogen oxides (NO_X), ozone (O_3), lead (Pb) and particulate matters (PM).

All these emissions are harmful to humans, animals and plants. SO_2 emissions contribute to acid rain. NOx contributes to the region's problems of the acidification and eutrophication of, for example, lakes and the Baltic Sea. Carbon dioxide (CO_2) is the most important anthropo-geni-cally produced greenhouse gas. Increasing concentrations of greenhouse gases in the atmosphere induce a risk for global climate change.

Sulphur dioxide, SO_2, emissions are not important in respect of car traffic since petrol does not contain much sulphur. However, they are important in respect of sea transport where oil is used.

Nitrogen oxides. Car traffic is a very important source of air pollution by nitrogen oxides. NO_X emission is mainly produced from atmospheric nitrogen and oxygen as a result of the combustion of fuels under high pressures and at high temperatures. Therefore, there might be a conflict between the objectives of high energy-efficiency and low NO_X emissions. Only a small amount of NO_X emission is produced from nitrogen in fuel. NO_X can be much reduced through exhaust-gas treatment (see below).

Carbon dioxide. The emission of CO_2 is directly determined by fuel-use and the carbon content of fuels.

Lead is emitted in the exhaust gases from leaded fuels. The emission is directly determined by fuel-use and the lead content of fuels. No technology for exhaust-gas treatment is currently available for lead or, needless to say, for carbon dioxide or sulphur dioxide.

Both *CO and VOC emissions* are caused by incomplete fuel-combustion. There are also significant VOC emissions from the evaporation of fuel from petrol vehicles and service stations. VOCs are a very heterogenic group of compounds with large differences both in direct health effects, carcenogenicity and ozone-forming potential. Since VOC emission is the result of incomplete combustion of fuel, the fuel structure is very impor-

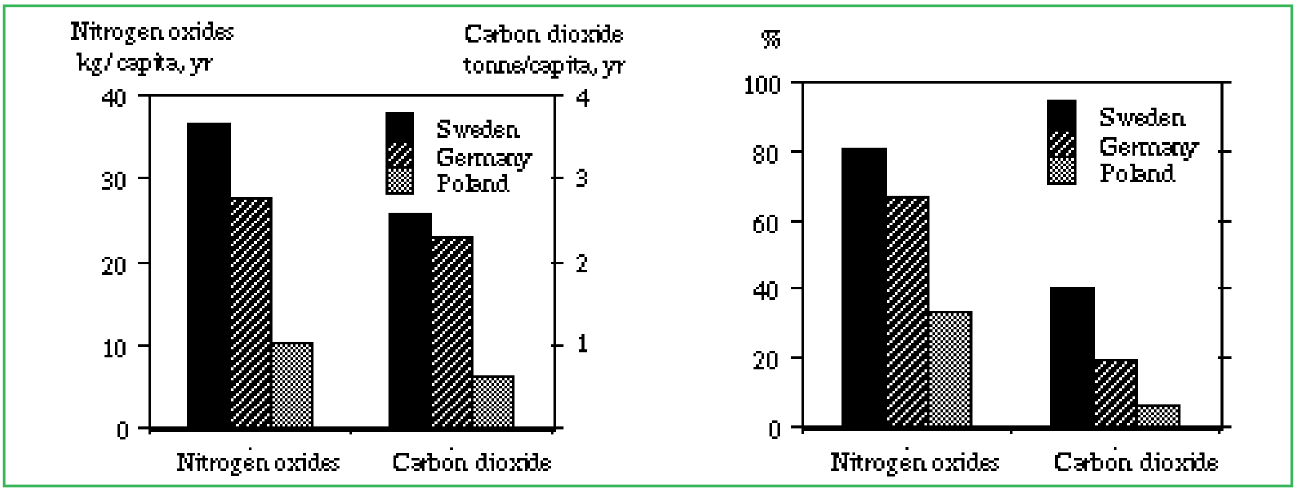

Fig. 3.2. Per capita emissions of NO_X and CO_2 from mobile sources in Sweden, Germany and Poland in 1991 and the share of total emissions produced by mobile sources.

tant as regards the detrimental effects of the emissions.

CO and VOC emissions are determined both by the fuel used and different combustion parameters. Furthermore, the technology of exhaust-gas treatment can have a significant impact on these emissions.

The emission of particulate matter is associated primarily with diesel engines, with emissions 30 to 70 times greater than for petrol engines. Again, it can be reduced through exhaust-gas treatment.

3.3 Techniques for reduction of emissions

The amount of pollutants varies extensively. Total transport emissions are determined by:

1. the transport work conducted by the different modes of transport,
2. the occupancy and load-factors of the vehicles, and
3. the specific emissions per vehicle-km.

The specific emission, that is how much pollution a vehicle emits per km, may vary considerably. Firstly, it is dependent on the fuel used. Secondly, it is dependent on the motor and other factors of vehicle technology and, not least, on how the vehicle is maintained. Thirdly, it is very much dependent on how the vehicle is driven: average speeds, accelerations and retardations, and gear-shifting.

The implementation of exhaust-treatment technology has made it possible to reduce the connection between energy-use and emissions of CO, NO_x, VOCs and particulate matters.

Stricter emission standards in Sweden have, for example, led to reductions in road transport NO_x emissions from passenger cars in Sweden by 10 per cent between 1980 and 1994 and in VOC emissions by 20 per cent between 1988 and 1994 although Swedish road transport energy-use increased by almost 20 per cent between 1980 and 1994.

CO emissions have probably also been reduced, although statistics on CO emissions are lacking. However, although NO_x emissions from road transport decreased significantly between 1980 and 1994, the total emissions from mobile sources did not decrease during that period.

Emissions of lead have decreased significantly in western Europe since beginning of the 1980s as a result of the introduction of low-leaded and unleaded fuels. In Sweden, leaded petrol has vanished from the market completely.

Three-way catalytic converters for petrol-fuelled vehicles can, under favourable conditions, reduce emissions of CO, VOCs and NO_x from petrol-fuelled cars by 90, 95 and 90 per cent respectively. Several factors, such as non-functioning catalysts on cold-starts and the decreased efficiency of the vehicles' catalysts due to ageing, result in average reductions on vehicle operation that are significantly lower than this.

For diesel engines, particulate traps and oxidation catalysts can be used to reduce particulate, CO and VOC emissions.

External costs of transportation

The results of several studies estimating the external social costs of transportation have shown that these costs are significant. The most important costs are those concerning:

- air pollutants
- noise
- accidents

For example, the social and environmental cost of road transport in Germany has been estimated to 2.5 per cent of GDP. For OECD countries as a whole, the cost of road transport has been put at nearer 5 per cent of GDP.

Table 3.2. Specific energy use and emissions of HC, NO_x for a selection of different modes of transport in Sweden

Passenger transport	Energy use[a]	Hydrocarbons	Nitrogen oxides
Short distance	kWh/passenger-km	g/passenger-km	g NO_2/passenger-km
Passenger car (no catalyst)	0.91	3.6	1.7
Pasenger car (catalyst)	0.87	0.3	0.3
Bus	0.22	0.09	0.9
Electric commuter train[b]	0.05-0.13	–	<0.01

Passenger transport	Energy use	Hydrocarbons	Nitrogen oxides
Long-distance	kWh/passenger-km	g/passenger-km	g NO_2/passenger-km
Passenger car (no catalyst)	0.33	0.52	0.96
Pasenger car (catalyst)	0.32	0.02	0.08
Bus	0.13	0.08	0.6
Electric train[b]	0.1-0.2	–	0.01-0.02
Aeroplane	0.7-0.9	0.06-0.22	0.6-1.6

Goods transport	Energy use kWh/net tonne-km	Hydrocarbons g/net tonne-km	Nitrogen oxides g NO_2/net tonne-km
Lorry	0.2-0.6	0.06-0.2	0.7-1.9
Electric train[b]	0.06-0.1	–	0.003-0.005
Sea transport	0.05	0.01	0.45
Aeroplane	1.5-8	0.2-11	1.5-9

a Energy end use. For vehicles using petroleum fuels primary energy use will be 10-20% higher than the energy end use. For electric vehicles using electricity from hydro, primary energy will be only slightly higher than energy end-use. For electric vehicles using electricity from condensing plants, primary energy use might, however, be 2-2.5 times larger than the energy end-use.

b Emissions from the use of electric trains are based on the Swedish electricity production. For an electricity system to greater extent based on fuel combustion, the emissions of hydrocarbons and nitrogen oxides will be higher but still much lower than the emissions from other modes of transport.

(Source: M. Lenner. "Energy consumption and exhaust emissions regarding different means and modes of transportation", Swedish Road and Traffic Research Institute, Linköping, Sweden (1993) In Swedish, English summary)

3.4 Comparing different modes of transport

Average specific emissions and energy-use vary significantly among different modes of transport. Energy-use per passenger-km is significantly higher for passenger cars and air transport than for buses and trains. Transporting goods by rail and by sea is, on average, more energy efficient than transporting goods by lorry and by air. Average values do not necessarily imply that a certain mode of transport is always less energy efficient since the estimates depend on the occupancy of the vehicle. The importance of technology development on the specific emissions is illustrated by the difference in emissions between passenger cars with and without catalytic converters.

Road transport is the main source of the emissions of CO, VOCs, NO_x and CO_2 from mobile sources in Sweden (see Figure 3.1) and in other European countries as well. However, sea transport and diesel-fuelled machinery together produce approximately 45% per cent of Swedish NO_x emissions from mobile sources.

Sea transport is an important source also for SO_2 emissions which result from the high sulphur content (2–2.5%) in bunker oils. There are no regulations on the sulphur content of fuels used for sea transport but there are, for example, in respect of diesel fuels for road transport. In Sweden, the maximum sulphur content of diesel fuel is 0.2 per cent but, in most of the diesel oils used, the sulphur content is even lower.

Total air transport emissions are still relatively low compared to emissions from road transport but they have increased quickly and are expected to continue to grow in importance in the future. The effect of emissions on high altitudes is also still relatively poorly understood.

3.5 Differences between countries

There are large differences between countries both in per capita transport emissions and the relative share of the total emissions produced by different sources. In Sweden, where electricity production is based on hydro and nuclear power, the relative importance of transport emissions is greater than in Poland and Germany where there is more fossil-fuel-based electricity production (Figure 3.2).

Transport emissions per capita in Germany and Sweden are significantly higher than in Poland. The per capita CO2 emissions, however, are much lower than in North America where, in 1990, they were almost 6 tonnes/capita per year. The high American per capita energy use is a result both from more per capita travel and higher travel-energy intensity (MJ/passenger-km). Differences in income levels, fuel prices, urban structures and life-styles are some factors that explain the differences in energy-use and emissions between different countries.

3.6 Life-cycle analysis of air pollution from traffic

In official statistics as well as in the discussion above, energy-use and emissions from the transportation sector are defined as energy-use and emissions from the operation of vehicles. Transportation is, however, also responsible for energy-use and emissions from fuel, in the form of vehicle and infrastructure production.

It has been estimated that approximately 70 per cent of the life-cycle greenhouse gas emissions for a petrol-fuelled passenger car originate from the operation of the petrol-fuelled passenger car, whereas fuel production contributes 20 per cent and vehicle production 10 per cent of the total life-cycle greenhouse gas emissions.

Energy will also be used for the manufacture, operation and maintenance of the transport infrastructure but this energy-use has not been much analyzed. The energy-use for infrastructure per vehicle-km depends both on the mode of transport and on the utilization of the infrastructure. Energy-use for infrastructure is significantly higher for road and rail transport than for air and sea transport. A recent life-cycle assessment has estimated that the energy-use for the construction, operation and maintenance of a road with 5000 vehicles/day will be approximately 5–10 per cent of the energy-use of its traffic.

3.7 Use of other natural resources in the transportation sector

Vehicles and transport infrastructure utilizes significant amounts of natural resources other than energy. Transport infrastructure occupies about 1.3 per cent of the land area in the EU countries. Natural habitats are, in general, irreversibly destroyed when transport facilities are built, and new transportation infrastructure leads to a fragmentation of landscapes and creates barriers impeding the migration of animals.

Large amounts of material are used for infrastructure and vehicle-building. The pressure on natural resources depends, however, not only of the demand for material but also on the recycling of materials. In Sweden 50–60 per cent of all aggregates (sand, gravel, crushed bedrock, etc.) are used for road construction. Vehicles are more than 70 per cent metal but also consist of large amounts of rubber, plastic and glass. Vehicle materials have a relatively large recycling-rate compared to other products. For example, in Sweden, Germany and the US, approximately 75 per cent of a vehicle's weight (mostly metal scrap) is recycled.

3.8 Water pollution from transportation

Transportation affects water resources negatively both in normal operation and through accidents.

The deposit of air pollutants from the transportation sector is an important source of the acidification of water. Run-offs from roads and airports containing oil,

salts and solvents from road surfaces may cause pollution of surface and ground water. Discharges of ballast water, sewage and waste from ships are important sources of water-pollution. Accidental and operational oil spills can have a devastating impact on the local and regional flora and fauna. The connection between such oil spills and the transportation sector is two-fold, namely, they occur as a result of sea transport and the majority of the oil transported is intended for the transportation sector.

3.9 Noise

Silence is an important resource currently widely intruded upon by the transportation sector. Noise can induce both physiological and psychological reactions. People react differently to traffic noise and it is therefore difficult to define absolute limits above noise can be regarded as a disturbance. Noise levels can differ significantly in the same general area and there can be a large variation during the day, week and year. Road traffic is the main cause of high noise levels. Some 65 per cent of the population of Europe is exposed to environmental noise levels above 55 dB(A), the level at which noise may cause annoyance and sleep disturbances. About 17 per cent are exposed to levels above 65 dB(A), the level above which serious impacts of noise are noticeable. Approximately 1.4 per cent of the population of Europe is exposed to levels above 75 dB(A). Exposure to noise differs among countries (see Table 3.3).

Table 3.3 Share of the population exposed for noise disturbance in a selection of countries

	Road transport noise		Aircraft noise		Railway noise	
	>55 dB(A) %	> 65 dB(A) %	>55 dB(A) %	> 65 dB(A) %	>55 dB(A) %	> 65 dB(A) %
Germany (west)	50	15	n. a.	1.0	19	3
Sweden	16	3	0.7	0.02	n. a	n. a
Finland	17	5	n. a	n. a	n. a	n. a
Denmark	29	10	1.7	0.1	n. a	0.6
Poland	39	6	n. a	n. a	n. a	n. a