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Environmental indicators in transport

Measures for ecological comparisons between various means of transports

Summary Paper

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1. Environmental indicators as a measure of environmental efficiency

Environmental indicators form a measure for ecological comparison between various means of transport. They form the basis for responding to transport-specific questions such as:

- How environmentally efficient are *today's* means of transport in passenger and freight transportation?
- What technical and organisational potential is to be anticipated *in the future*?
- What guidelines can be formulated for an optimal use of transport means?

It is essential that environmental efficiency be raised, if the environmental impact of transportation is in future to be reduced. With the aid of environmental indicators the environmental efficiency of individual means of transport can be expressed.

Environmental Indicator =	**Environmental Impact per Transport Unit (Person- or tonne-km) of a given means of transport**

Predominant considerations concern energy consumption, carbon dioxide emissions, air pollution, noise, land use and accident frequency. It is to be noted that a transport means not only creates an impact when actually in operation. Energy generation (for example, electricity generation for railways, manufacture and scrapping of rolling stock and infrastructure), also have an environmental impact. According to means of transport, this indirect impact can vary considerably. Much depends upon the nature of decision to be taken, in determining how far such impacts will need to be taken into account.

The better the technical potential of the individual means of transport is exploited, and the higher the load factor or degree of utilisation, the higher its environmental efficiency will be, and the lower its specific environmental impact. It is of no help, when, technically, the vehicle is made environmentally more friendly, but at the same time its load factor falls.

This publication sets out to make more apparent the links between environment and transportation, with the aid of environmental indicators, to make these more apparent to a broader public, and to describe the current state of knowledge. It is based on several projects, which have addressed the issues of environmental impact within and also outside Switzerland. Already in 1973 environmental indicators were examined for Switzerland (Basler and Hoffmann 1973)[1]. These indicators were brought up to date in 1991 with recent transportation and environmental information, and extended to various means of transport (INFRAS 1991)[2]. As part of the priority programme on environment this data

1 Basler & Hoffmann: Die Belastung der Umwelt durch den Verkehr, 1973

2 INFRAS: Umwelt und Verkehr, GVF-Report 5/91

was again comprehensively updated (Environment profile Transport, INFRAS 1995)[3]. This work analysed several process levels (operations, manufacture and disposal processes), in the transport sector and researched all significant direct and indirect environmental impacts of each means of transport. It has been the principal source of data for the present publication. Thanks to these observations, a differentiated view is now possible.

2. Present levels of environmental efficiency of means of transport

Dividing the environmental impact of a means of transport by the number of passenger-kilometres in passenger traffic, or tonne-kilometres in goods traffic, gives a value for its present average environmental impact.[4] These values were assessed for all means of transport in 1993. Indirect impacts have also been included.

- The **energy consumption** is expressed in Megajoules per Pkm or Tkm. In this are included both renewable and non-renewable energy sources. In passenger travel the most energy intensive is air travel, followed by private car. One third of the private car's energy consumption is „grey energy“[5] indirectly involved through manufacture of fuel, construction and disposal of the vehicle and the road. Less than half as much energy is required for road public transport, about as much as for rail. Rail is however only slightly better than road in its energy consumption when, as in local passenger traffic, it is operating at a very low load factor. A significant part of rail's energy requirement, about 80%, relates to pre- and post- transport processes, especially in building and maintaining the infrastructure. Rail is in fact most economical in energy, when its operation alone is considered.[6]
  In freight traffic, the delivery truck is the most intensive in energy use. However, the indicator tonne-kilometre is in this case not ideal for the transport output,[7] since delivery trucks are often conveying high value products of low weight. An air cargo aircraft has an energy consumption around three times higher than a road heavy goods vehicle. The various rail freight services consume less than half the energy of the heavy goods vehicle.

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3 INFRAS: Ökoinventar Transporte, 1995

4 It should be observed that an individual means of transport may be itself of a most heterogeneous composition. This is for example the case for private cars. These include today both environmentally friendly small vehicles, and also older large capacity limousines. The specific characteristics, for example in energy consumption, cover a wide range.

5 One Liter petrol (gasolene) corresponds to about 30 Megajoules.

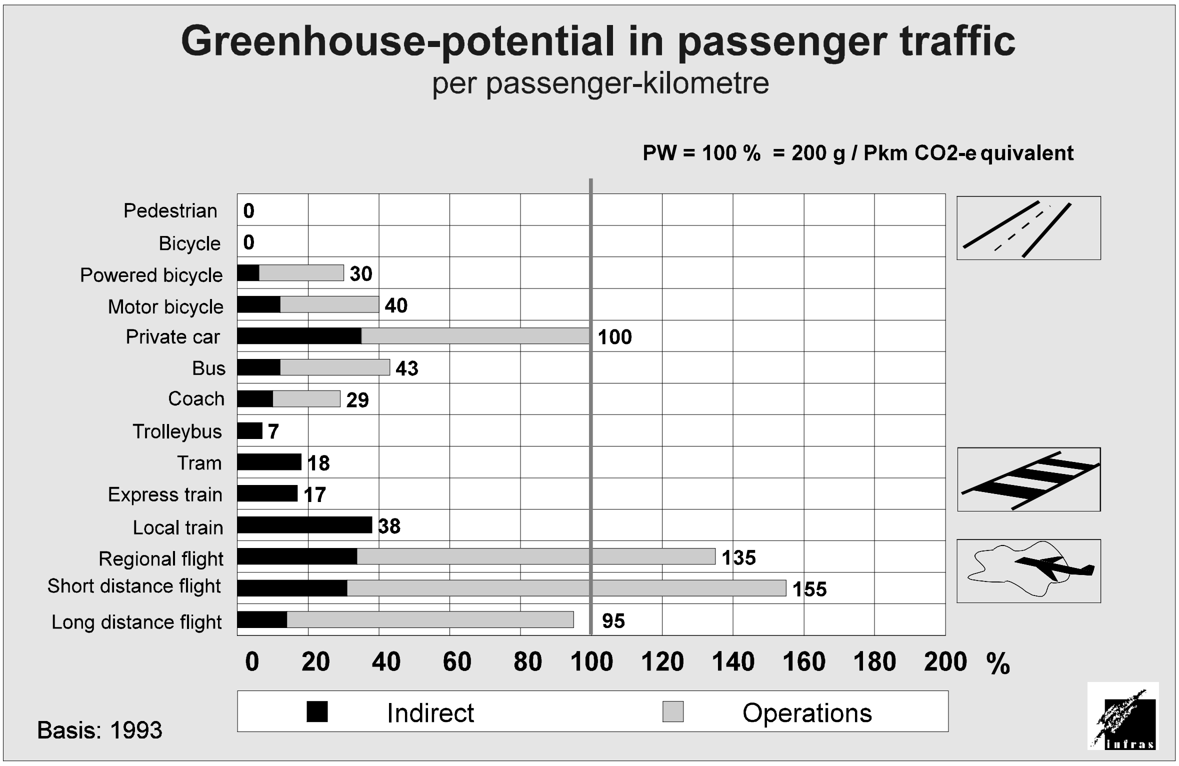
6 Such a comparison is only admissible in a short term view (see section 4).

7 This makes the limit of interpretation of such an indicator apparent. The weight of goods is only one possible indicator. A more differentiated view would take in other criterias such as volume, category of goods, and quality. However, on these aspects very little reliable information is available.

- The environmental efficiency in the **climatic sector** is shown in figure S-1. As indicator the various emissions (carbon dioxide, methane, nitrogen monoxide) are used, aggregated as carbon dioxide equivalents.
  As opposed to energy consumption, rail appears here most favourably, with emissions at a level four or five times less than road traffic. This is primarily because rail electricity in Switzerland is generated without carbon dioxide production. Only 2% of the SBB-electricity is produced from fossil fuels. The greatest part is water power (in other countries, the fossil share may be significantly higher). On average in Europe, 40-45% of electricity is generated from fossil fuel sources, coal, oil or natural gas.

- As indicators for **air pollution**, the principal harmful products nitric oxide, hydrocarbons and particles are considered. Air transport emits the greatest amounts of nitric oxide, but relatively little hydrocarbons and particles. Specific emissions are high also for private and public road transport. On account of use of diesel engines, the nitric oxide emission of a bus is 40% above that of a private car. Thanks to its environmentally more friendly energy production, the railway causes a level of pollution from harmful emissions 5-10 times lower than road transport, and then almost entirely from pre- and post-transportation processes.
  In freight transport, rail is compared to road heavy haulage even more at an advantage, with levels of emissions at 2-8% of those of a road goods vehicle. With the imposition since the 1980s of more stringent exhaust conditions for goods vehicles, there has been a steady overall improvement in road’s environmental indicators, despite lower load factors. For road goods vehicles, however, the fall in load factors has led to a situation where technical improvements have not led to any significant overall improvement of specific environmental efficiency.

- Regional (local) trains cause five times as much **noise** per passenger as a private car. The cause lies with the often low load factors, and the use of older rolling stock. If, in a given time period, a section of track is to be used wholly by local trains, a noise carpet (area) of over 5 hectares would be subject to a noise level of over 60 dB(A). According to the noise protection regulations, in residential areas this level of noise should not be exceeded. In freight transport, rail is some 20-40% quieter than road. Air transport causes especially in short-distance operation a high level of noise pollution. Short-range jets are on average about twice as much noise as turboprop aircraft and consequently somewhat louder as private car traffic.



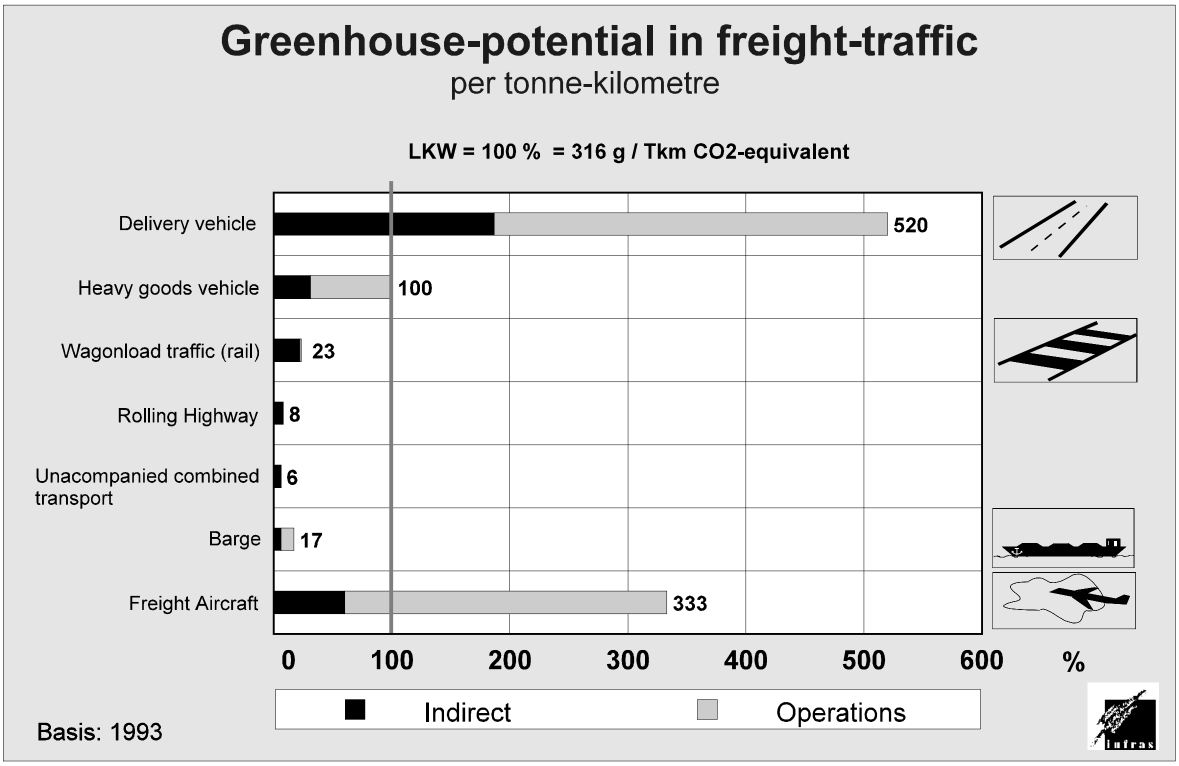


Figure S-1: Specific climatic emissions in passenger and freight transport in Switzerland

Present-day averages, taking account of both direct emissions, arising during operations, and indirect emission, from energy generation, production and disposal of the means of transport, and infrastructure, 1993

- The bigger a vehicle of a transport mode is, and the lower its average load factor is, the higher will be the corresponding specific **land surface area** impact. On the other hand, the more traffic there is on a given infrastructure, the lower is the specific land surface impact. Since, above all, the local rail lines, in thinly populated areas and at the marginal times of day, are relatively poorly utilised, the railway has, in relation to road transport, a higher specific land use. Regional (local) trains have, for example, a greater land use requirement than private cars.

- Transportation is the cause of **further forms of environmental impact**, which can only partly be expressed in numerical terms. In recent times the amount of heavy metals, and especially lead, could be substantially reduced. In future however, further substances will be critical, whose quantities are increasing in connection with the use of catalysers, such as nitrous oxide and ammonia. There is also an increase to be anticipated in the amounts of cadmium, as a result of the manufacture of composition surfaces for roads .

- The number of serious **accidents** has fallen markedly in recent years, although the number of road accidents over the last twenty years has, despite the rise in the traffic density, remained practically constant. Private road transportation, both of passengers and of goods, still remains by a clear margin the most dangerous form of transportation. The rail accident rate in, for example, high speed passenger traffic, some three times lower. Safest of all is public passenger traffic, with an accident risk some 5 times lower than the private car.

- Looking at the environmental indicators in relation to **time,** it becomes apparent that the majority of the factors demonstrate a tendency to fall. However, only the factors of air pollution and of accidents resulting in death or injury have actually shown a significant improvement over the last twenty years. In the case of the other forms of environmental impact, the worsening level of utilisation has offset a part of the potentially positive trend.

Figure S-2 shows the comparison between road and rail. Although an environmental advantage for rail in the sectors energy, climatic influences, and air pollution, are not in question, it is apparent that road transport is making up its disadvantage.[8] Noise pollution may be seen as the principal weakness of rail.

8 This environmental advantage derives principally from the advantageous mix of electricity generation for rail.

Comparison Rail and Road

Passenger traffic, rail = 1

		Operation only	Operation & energy generation	Total effect (including rolling stock and infrastructure)
Energy	***1 :***	**7**	**5**	**1.7**
CO_2	***1 :***		**70**	**4**
NOx	***1 :***		**140**	**4**
Noise	***1 :***	**0.4**	**0.4**	**0.4**
Surface	***1 :***		**45**	**0.7**
Accidents	***1:***	**10**		

Example: in direct operation, a passenger private car requires 7 times as much energy per passenger-kilometre as a passenger train. Taking all indirect effects into account, the ecological advantage of rail falls to a factor of 1.7.

Comparison Rail and Road

Freight traffic, rail = 1

		Operation only	Operation and energy generation	Total effect (including rolling stock and infrastructure)
Energy	***1 :***	**8**	**5**	**2.5**
CO_2	***1 :***	**78**	**40**	**5**
NOx	***1 :***	**50**	**44**	**15**
Noise	***1 :***	**1**	**1**	**1**
Surface	***1 :***		**32**	**2**
Accidents	***1:***	**6**		

Example: A road goods vehicle requires about 8 times as much energy per tonne-kilometre as a typical freight train, taking into account only the direct energy of operation. When, however, indirect effects are taken into account, the road goods vehicle requires 2.5 times as much energy as a freight train.

Figure S-2: Environmental indicators for rail and road compared

The Figure distinguishes between, on one hand, the direct operational impact of transportation (operations and energy generation) and on the other, the indirect impact resulting from the manufacture and disposal of rolling stock and infrastructure.

3. Potential for the future

Our comparison of the present-day average environmental efficiency of various means of transport has of course validity in describing the present prevailing conditions. It does not, however, give any indication of their respective potential for improvement, nor the differing composition of the various means of transport. For this, a more differentiated view into future development will be required.

- For **private cars** the potential for improvement in energy consumption and in respect of air pollution is high. This applies as much to engine development as to fuel. It is scarcely to be expected that present concepts with Otto cycle and diesel engines will seriously be displaced in future. With the anticipated tightening of regulations for exhaust emissions in the European Union (EURO 3 and 4 for the period 2000/2005) today's critical particle pollution will fall. In total the potential for reduction in air pollutants lies around 80-90%. Greater potential improvements in energy use can only then be realised, when both size and weight of vehicles are reduced. This is however dependent upon other influences, determining behaviour by the purchase of vehicles. In recent times the technical potential for improvement has constantly been compensated by the sale of bigger vehicles, so that an average consumption of 9 litres per 100 km has remained approximately stable for some years. A further important potential lies in improvement of the load factor. If the present average occupation of 1.6 persons could be raised to 2.0 persons, the environmental indicators would fall by 20%.

- For the **Heavy Goods Vehicles**, the greatest potential for improvement lies without doubt in the area of air pollution. Compared to today, pollutant emissions could be reduced by up to 90%. At the heart of this is the use of exhaust recycling installations, and diesel catalysers. Somewhat more expensive would be the reduction of particle emission by the use of particle filters. These cost today some 5'000-7'000 Swiss Francs.
  With the aid of improved fuels, such as the use of sulphur-free diesel fuel, a massive improvement can be secured. For Switzerland, an important comparison is that between heavy Goods vehicles of all-up weight (including payload) of **28 tonnes** and of **40 tonnes**. This comparison is particularly interesting where the vehicle is fully loaded with heavy goods, as in the case of Alpine transit traffic. A direct comparison demonstrates that a 40-tonne truck for the same load causes a 15% higher air pollution. However, when a 40% average load factor is taken into account, the 40 tonne truck appears 25% better on account of the higher payload. Figures for the average load of non-Swiss goods vehicles are only available for Alpine transit traffic, where they show average loads above the threshold indicated above. With an average of 17 tonnes payload, the load factor on the Brenner and Mont Cenis routes, for 40 tonne

vehicles, is at around 70%, whereas in Switzerland, with 28 tonne vehicles, the average is only 6.2 tonnes, or about 35%.[9]

- As a result of their fixed supply arrangements, alternative fuels can be introduced relatively cheaply for use by public road transport authorities. A relatively favourable Cost-Benefit performance can be obtained for gas-fuelled vehicles. Compared to a diesel engine bus, in particular the level of air pollution can be reduced by 70-90%. The energy consumption is however less advantageous than a diesel vehicle.

- A large potential for improvement exists also for **rail.** First of all there is the **noise** sector. With the use of new brake materials, and especially disc brakes, the present level of noise could be more than halved. There are however for rail transport certain elements which could in future deteriorate. For example, it is foreseeable, that future levels of energy requirements can no longer be provided under such favourable environmental conditions. It could be expected that increasingly fossil fuel sources, such as gas-combination generating plant, might have to be used to produce additional energy. This leads to a corresponding worsening of the position for carbon dioxide and for air pollution Should in electricity generation the international average, the so-called UCPTE-mix, with 50% share of fossil fuels, apply in place of the present Swiss mix of generation sources, then there would be a marked increase in the environmental impact directly connected with service output (operations and energy generation). Since road transport can reduce its NO_x emissions drastically, in the long term the environmental advantage of railways will be eroded. In the climatic sector, however, rail should retain, despite a deterioration of its energy generation mix, a four to five times better performance than road, if efforts to reduce the specific energy consumption are undertaken. The future development of high speed trains could however lead in the opposite direction, since higher speeds require on one hand higher levels of energy in operation, and, on the other hand, also call for greater radius in curves and larger tunnel profiles.[10]

- **Air transport** has achieved greater technical improvements during the last twenty years, in all environmental sectors. This development may now slow down, but in spite of this some further improvements, especially in the emission of air pollutants, are to be expected. An improvement of the specific energy consumption in air transportation is most probably to be obtained from organisational measures such as optimisation of the route network.

9 Apart from the lower capacity, the high proportion of empty journeys is also an important reason for the low average load of road goods vehicles. This results from many goods vehicles using a diversionary route under load from north to south, while the empty journey to the north can be made directly through Switzerland, also because the lower level of charges makes this cheaper.

10 This is shown also by the planning of the European High Speed Network, in Switzerland with Bahn 2000 and NEAT).

4. Optimal use of means of transport

An environmentally efficient use of means of transport can be evaluated transparently by use of environmental indicators. It is however, to avoid drawing false conclusions, necessary to define precisely the exact conditions which will apply for the decisions which are to be taken. Most important is then the question, which environmental impacts are to be considered and at which stage:

- For a decision on use of a means of transport, the critical consideration will be the direct impact of the transportation-dependent operation, and fuel production, for railways the electricity generation. If we restrict ourselves to a limited area such as a city, where above all local pollution is important, then even energy production may be ignored. As a result of the laid-down timetable, the impact of use of public transport is in the short term zero. Such a view is necessarily only short-term.

- For a longer-term view, all environmental impacts, including the indirect ones, that is, provision of rolling stock and infrastructure, have to be included. This is justified by the assumption that, sooner or later, each additional transport demand leads to the requirement that new vehicles and infrastructure must be employed, which then create additional indirect impact.

- As long as the available capacities are not fully employed, only the direct environmental impact of a additional individual journey need to be considered.

A comparison of environmental efficiency between individual transport sectors is of interest. Here the different features and potentials can be better taken into account:

a) Passenger transport

- In **Urban transport** the local emission levels occupy a central position. The strengths of public transport are then most apparent, particularly the efficient use of land surfaces as a result of the high load factor in peak periods. Modern and light private cars display a disadvantage environmental performance, because rail-based public transport in city areas have no harmful air-polluting emissions. A problem is the particularly high level of pollutant emissions of diesel buses. This can only be reduced significantly by the use of new technologies, such as particle filters. A modern private car emits, per passenger, even in the rush hour less than half the nitric oxide of a modern diesel bus. Alternative transport systems such as Park and Ride bring in urban traffic only very modest additional environmental advantages.

- For **Business travel** time and comfort are prime considerations. As a consequence, air travel has claimed steadily increasing market shares. In spite of a less favourable generation mix in international traffic, rail has still a 50% better environmental performance than air or a business car. In pricing terms, however, this advantage is not reflected in journeys in the countries to the north of Switzerland.

- For **holiday travel** the private car is significantly less favourable than the train, when the car is not full. The threshold lies at 3.5 persons. In this market segment generally in recent years there has been considerable growth. Thanks to lower prices, air travel has increased rapidly. For long distances the only possible transport means is clearly air transport. Environmental considerations suggest therefore that not the choice of means of transport, but the destination of the journey, should be questioned. The total energy consumption is then a most significant factor, especially for air travel. The energy consumption for a single person for a flight to the Caribbean is some 70 times the average daily energy consumption per head in Switzerland.

- At off-peak times, the load factor of public transport leads to a relatively unfavourable position in comparison with the private car. This is particularly the case for air pollution when buses are used. In order that the comparison with the private car is favourable for the bus, some 15-20 people on average must be travelling in the bus. Such loads are not achieved at off-peak times. However, should it be considered that the bus service is also there to offer a throughout public transport alternative, so facilitating the its choice in preference to the private car, then the overall result still be positive even when load factors are low. Even more favourable is then Park and Ride at outlying rail stations.

- In **Rural Traffic** bus services are often proposed as an alternative to the existing rail service. Although the pollutant and carbon dioxide emissions speak clearly in favour of rail, the energy consumption and noise factors alter the position. In addition to environmental factors, cost is a further significant consideration, since the bus service may be 30-50% cheaper.

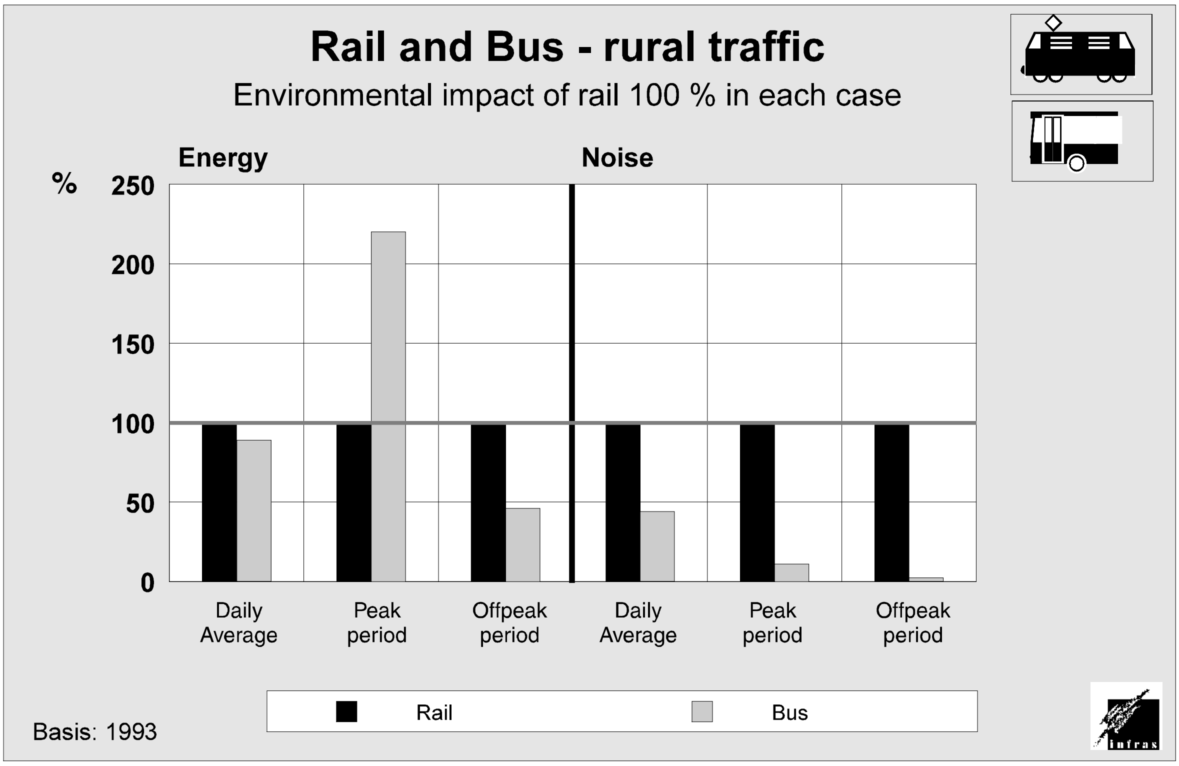


Figure S-3: Train and Bus compared: As long as the rail service can be provided with relatively few buses, the bus is comparable with rail in respect of noise and energy consumption.

b) Freight transportation

- In urban freight traffic, **City-Logistic**-Projects can appreciably improve environmental efficiency. An efficient transport chain with rail and transhipment, on an environmentally friendly truck or delivery vehicle, incurs in comparison to delivery by a conventional heavy goods vehicle one third of the energy consumption, and about 10% of the air pollution emissions.

- In **national freight traffic,** rail based wagon-load traffic is in environmental terms unbeatable, when already available private sidings can be used more efficiently. The carbon dioxide emissions per tonne of payload, based on today's electricity generating 'mix', are only 3% of those of the average competing heavy goods vehicle. The noise level by rail is only marginally better than the road vehicle, especially when older rail vehicles are used. A meaningful alternative to road haulage is also to be found in combined transport, as long as the transfer terminals are as far as possible economical in the space and land use requirements, and can be installed on existing rail land. Their environmental advantage is then some three times better than the use of road haulage.

- In **Alpine transit** the regulatory conditions will be changed in future. The New Rail Alpine Transversal NEAT should raise the competitivity of rail. At the same time, with a proportional heavy goods vehicle levy, it is intended that, despite the removal of the existing 28 tonnes limit on all-up weight, the Constitutional clause on protection of the Alps should come into effect. Hopes are set high for combined transport in this respect. In the short term, a high performance service offer should be achieved by provision of a rolling highway service through the projected base tunnel. If it is assumed that such a service can only be operated using electric power generated increasingly from fossil fuels, then in comparison to transportation by modern heavy goods vehicle the carbon dioxide emission would be about half as high. In terms of energy consumption, the road goods vehicle will be equally efficient than a high performance rolling highway. A comparison of the entire transport chain in transalpine traffic will also demonstrate that road can improve its position considerably. On rail, unaccompanied combined transport, which only carries the load unit and not the entire vehicle, is environmentally more efficient than the rolling highway. In this case, especially for long distances, the terminal transhipment is no longer a significant factor. The share of terminal transhipment in the through transport chain as operated today by HUPAC, is less than 2%.

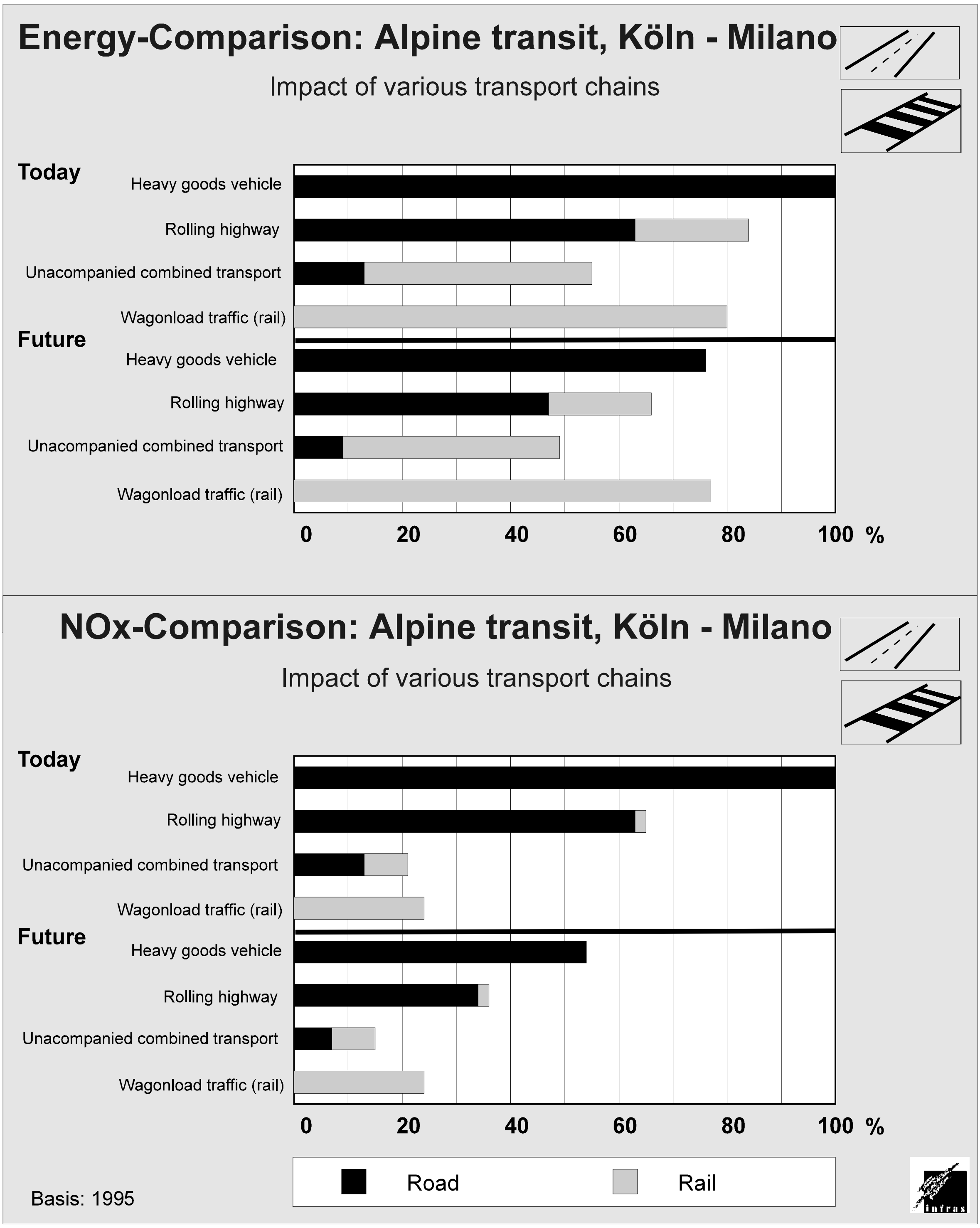


Figure S-4: Transport between Köln and Milano in Alpine transit traffic: various transport chains compared, today and in the future

Today:	*Road: 28 Tonne Limit, EURO II-Exhaust norm*
	Rail: SBB-Mix Switzerland, UCPTE-Mix elsewhere
Future:	*Road: 40 Tonne Limit, EURO III-Exhaust norm*
	Rail: SBB-Mix Switzerland, UCPTE-Mix elsewhere

(Total environmental impact including indirect elements)

5. Conclusions for an ecological transport policy

The following transport and environmental policy objectives can raise the environmental efficiency of individual means of transport:

- Exploit the technical potential (for example, through consumption or exhaust regulations)
- Make better use of capacity (increase load factors)
- Ensure environmentally efficient driving patterns (for example, with careful driving style and low speeds)
- Transfer to more efficient transport mode (public transport)

The transportation policy measures adopted in Switzerland already point in thugs direction. Technically orientated regulations (for example, exhaust standards or the planned reduction of the fuel consumption of new road vehicles) only improve environmental efficiency at particular points, relating to one particular environmental factor. Against this, pricing measures have a broader effect. An increase in the price of motor fuel not only leads to more economical driving, but also raises the incentive to purchase a more energy-saving vehicle or to transfer to public transport. This in turn indirectly raises the environmental efficiency of public transport, since the load factor rises and the investments are also used in a more environmentally efficient manner. Such a strategy is at present being pursued for the Alpine Transit traffic, which, with NEAT, differential heavy goods vehicle levy and Alpine transit charges, aims at making maximum use of the capacities being provided.

With the environmental indicators which have been used in this text, it is therefore possible to represent the specific environmental efficiency of individual means of transportation. An increase in environmental efficiency alone is however not enough to achieve a serious and lasting improvement in environmental impact of transportation. Decisive is finally the total impact of transportation upon its environment. Despite a marked reduction of harmful air pollution emissions, for example, we are running the risk that the positive effects (achieved especially by the use of catalysers) are offset again by the on-going growth of traffic. An environmentally orientated transport policy will therefore have to address the issue of the longer term growth in traffic.