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Energy savings by light-weighting - II

Final report

**Commissioned by the
International Aluminium Institute (IAI)**

Heidelberg, June 2004

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IFEU

**Institute for Energy- and
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1 Introduction

With the adoption of the “Kyoto Protocol” in 1997 many states have made the commitment to comply with targets for climate protection and the conservation of natural resources. The transport sector contributes significantly to the total global energy consumption and greenhouse gas emissions and is “... *the single most important sector accountable for increasing oil demand and CO₂ emissions in the OECD*” ([IEA 2002b]). Therefore, to achieve a further reduction of energy consumption and greenhouse gas (GHG) emissions in the future, also the transport sector has to be considered.

In the study “Energy savings by light-weighting” (also commissioned by IAI), which has been completed in January 2003, a weight reduction has been identified as one measure to reduce the energy consumption and thus Greenhouse Gas Emissions of transport vehicles. Weight reduction is particularly effective because if energy demand at the wheel is reduced, all the energy consumption associated with upstream processes such as the extraction and processing of fuels and electricity, the distribution and conversion into mechanical energy will be reduced over the whole operational lifetime of the vehicle.

In this follow-up of the first study, the focus was expanded and an in-depth analysis has been undertaken for a range of important aspects:

- **Additional transport modes** such as planes, ferry boats and ocean vessels as well as light-duty vehicles have been analysed within the methodological framework of the first study.
- To improve the transparency of data and to identify transport modes and uses suitable for the efficient use of light-weighting, different typical vehicles as well as extreme cases have been calculated for each transport mode, to show the possible **range of energy savings** by light-weighting.
- In order to show the ecological relevance of light-weighting, an estimate of the **total potential impact of light-weighting** has been undertaken on a **global level**. The analysis follows a top down approach by using figures on the transport energy consumption for different economic regions.

In the present study an executive summary gives a conceptual overview and highlights the main results (chapter 2). The goal and scope definition is discussed in detail in chapter 3. Efficiency factors for upstream processes and carbon dioxide emissions factors for the analyses are derived in chapter 4.

The additional vehicles¹ (light-duty vehicles, ocean vessels, aircrafts) are analysed in chapter 5. Sensitivities will be illustrated by calculating different usage cases in chapter 6 and the potential annual global energy savings by a weight reduction of all vehicles are calculated in chapter 7. The overall results of the study are finally commented in chapter 8. A collection of further data, data discussion and more detailed analyses can be found in the commented annex (chapter 9).

¹ To simplify matters, the term “vehicles” will be used in this report for all means of transport. This includes ocean vessels and aircrafts.

2 Executive summary

A conceptual overview and important results of this study will be highlighted (as CO₂ emission savings) in this chapter. A detailed description of background data and calculation methods will be part of the respective sections. The presented results in this chapter include:

- life-time CO₂ savings for different vehicles and
- annual global CO₂ savings by light-weighting of all vehicles.

2.1 Life-time CO₂ savings for different vehicles

A weight reduction directly reduces the energy consumption of a vehicle and is thus avoiding environmental impacts of all upstream activities (fuel supply, energy conversion in the engine, etc.). The potential life-time CO₂ savings depend on the specific CO₂ savings (per distance travelled) and the life-time performance (mileage) of the respective vehicle.

The total CO₂ emissions and savings of a vehicle are also determined by the efficiency and impacts of the transmission, engine and energy supply. To allow for a comparison of the results the primary energy savings and the related CO₂ emissions which take into account the efficiencies of transmission, engine and energy supply, have been used.

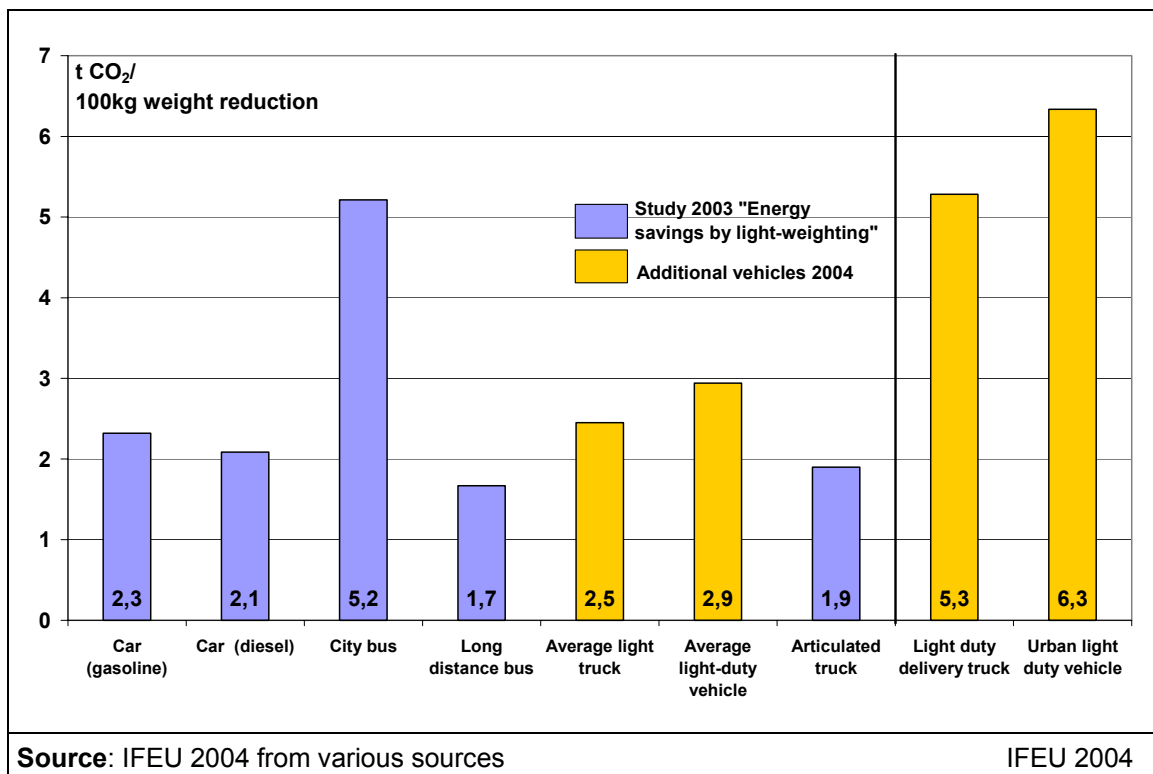


Fig. 1: Life-time CO₂ savings for road vehicles

A range of road vehicles has already been studied in the first study ([IFEU 2003a]). Light-duty vehicles and light trucks have been added in this study. Life-time savings for average vehicles are similar to life-time savings for passenger cars, but considerably lower as for city buses. Light-duty commercial delivery vehicles, which are mainly used in an urban environment, show higher life-time savings compared to average vehicles.

Ocean vessels face resistances which are entirely different from road vehicles. The life-time savings for average ocean vessels are somewhat higher compared to road vehicles, especially for container and other general cargo ships. High-speed ferries show an exceptional potential for CO₂ savings by weight reduction, which is about 10 times higher as for normal speed ocean vessel (Fig. 2).

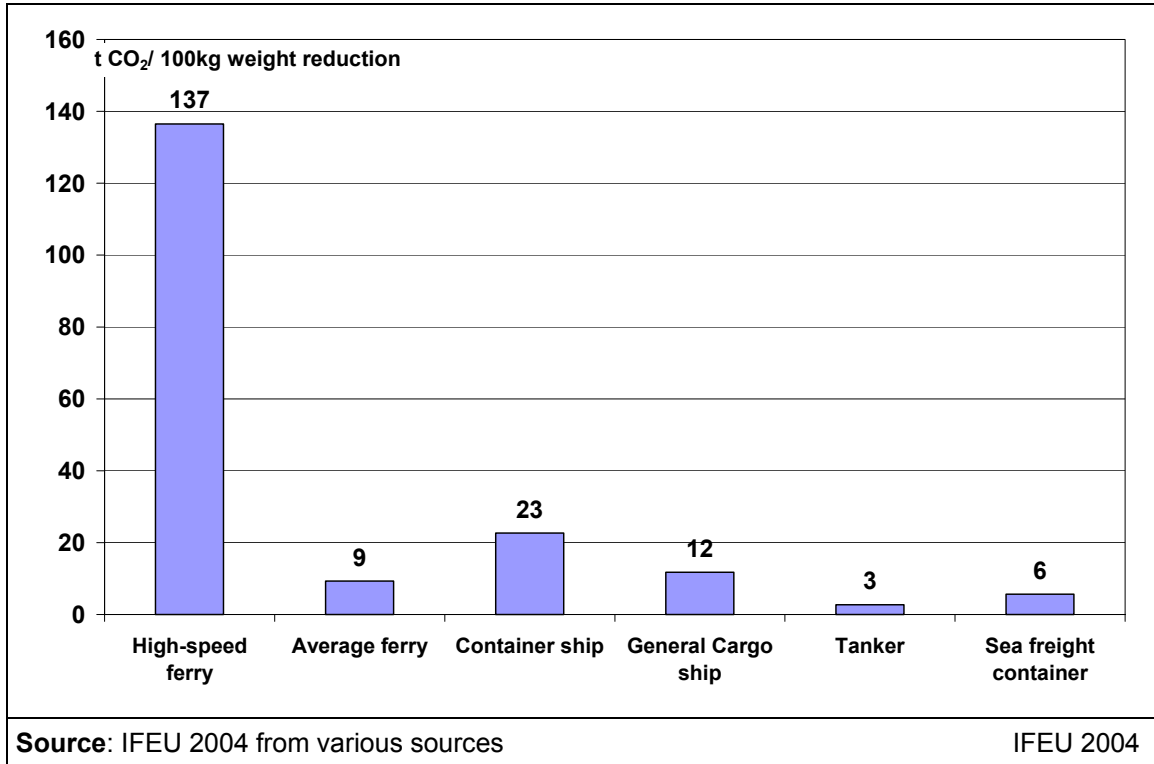


Fig. 2: Life-time CO₂ savings for ocean vessels

The highest life-time savings per 100kg weight reduction have been calculated for aircrafts. The range is between over 2 kt CO₂ for an aircraft in a long-distance flight pattern and about 1.5 kt CO₂ for a short-distance flight pattern. These savings are again over 10 times higher as for high-speed ferries and about 100 times higher as for average ocean vessels and road vehicles. Potential life-time CO₂ savings can therefore be located on different scales for different vehicles (Fig. 3), which may also indicate priorities for the use of light-weighting technologies.

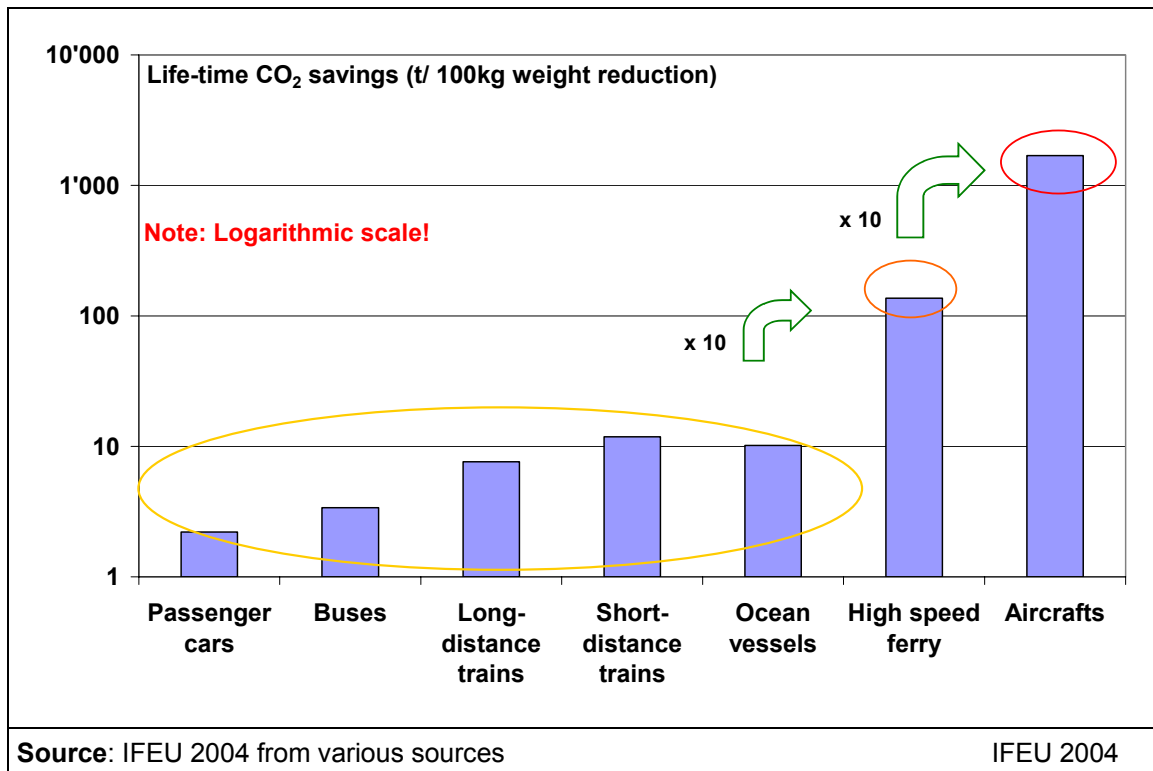


Fig. 3: Life-time CO₂ savings for different vehicles on logarithmic scale

2.2 Annual global CO₂ savings by light-weighting

A weight reduction of all globally used transport vehicles would result in a reduction of the global transport CO₂ emissions. The global potential for such savings has been assessed in different scenarios in a top down approach, meaning that the approach begins at the highest conceptual level and works down to the details. In this case the highest conceptual level are figures on the transport energy consumption and CO₂ emissions for different economic regions for the year 2000. This is referred to as the **Baseline** of the calculation. Two scenarios have been calculated relative to this baseline:

a) **Average new vehicles scenario:** The total transport CO₂ emissions have been calculated for an assumed fleet with the specific energy consumption of new registration for the basic year 2000. All other parameters like the total transport performance have been maintained. The energy savings of this assumed fleet (compared to the baseline) can be attributed to a range of different factors. The new vehicles scenario indicates the energy consumption which can be expected without further interventions and efforts in favour of light-weighting. This scenario refers to the average specific energy consumption of the new vehicles. Some of these may already use state of the art light-weighting technology. On the average, however, a further weight reduction is possible.

b) **Weight reduction scenario:** The total transport CO₂ emissions have now been calculated for an assumed fleet of additionally weight reduced vehicles for the basic year 2000. This time all vehicles will be assumed to be weight reduced as much as state of the art technology allows for. A top runner approach is used to define the state of the art potential for weight reduction: The most weight reduced comparable new vehicle has been used as the reference for an estimation of the weight reduction potential. This time all energy savings can be attributed to a weight reduction.

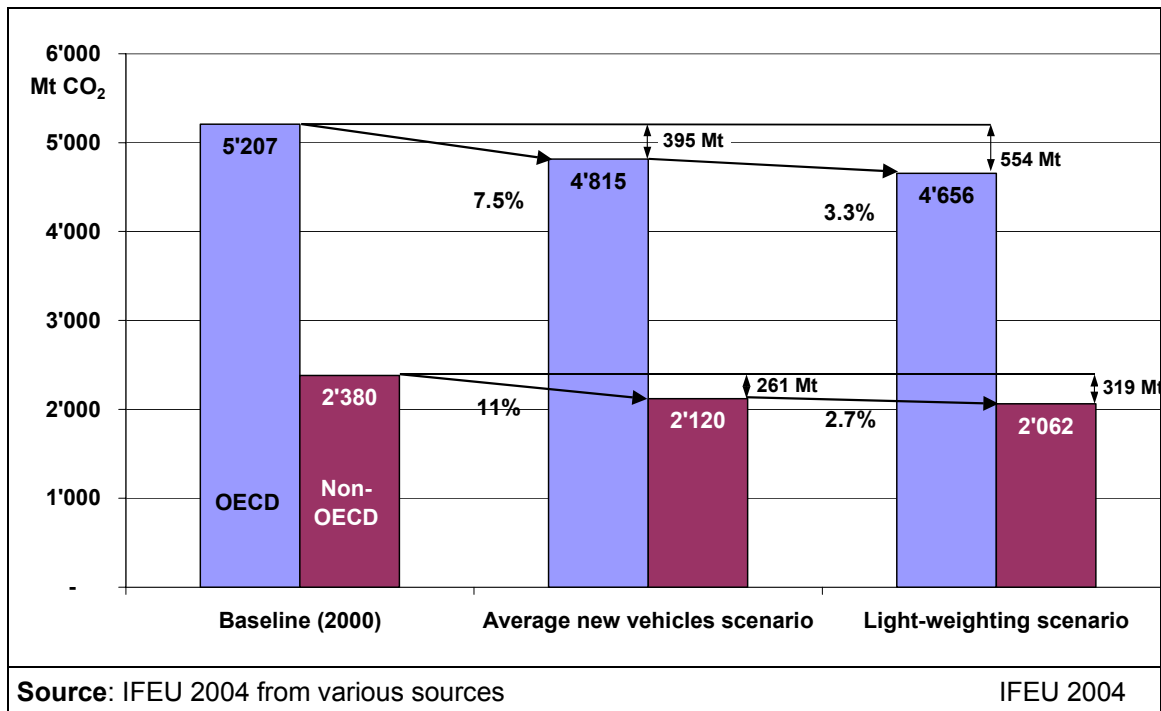


Fig. 4: Annual transport CO₂ emissions for different scenarios

Assuming that the entire transport volume is performed by average new vehicles, a 7.5% reduction in energy consumption and CO₂ emissions can be expected in the OECD countries and an 11% reduction in the non-OECD countries (Fig. 4). Due to the comparatively older fleet in the non-OECD countries, higher savings can be achieved by the introduction of new vehicles in the non-OECD countries. For an additional weight reduction of all vehicles a further 3.3% reduction in the OECD and 2.7% reduction in the non-OECD countries can be expected. Slightly higher savings have been achieved in the OECD countries because of the high share of private passenger cars and LDVs.

Overall energy savings by the maximum utilisation of light-weighting compared to the average new vehicles scenario are in the range 220 Mt CO₂ annually. Almost 77% account for the OECD countries which is even higher as the overall transport energy consumption share. This is due to the fact that the OECD countries have a higher share of private passenger cars and LDVs, which show among the highest weight savings and energy savings by light-weighting potential. Passenger cars and LDV also make the greatest overall contribution to the total potential for energy savings by light-weighting, followed by aircrafts and other road vehicles. The total potential for rail and water is lower.

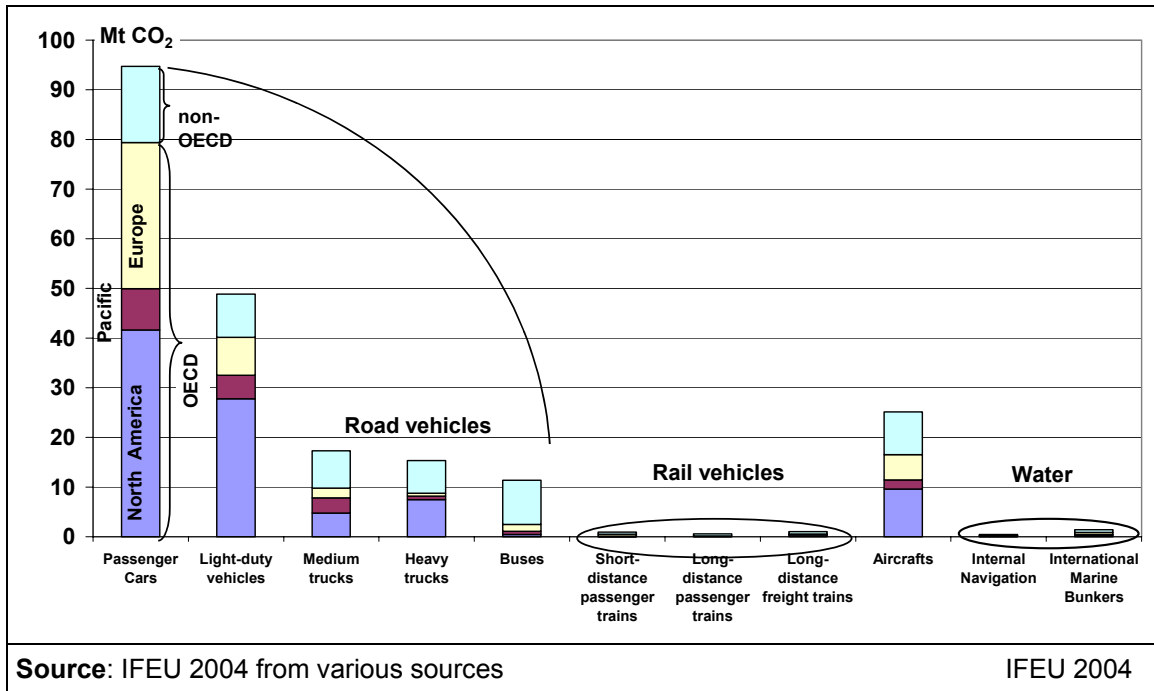


Fig. 5: Global annual CO₂ savings by light-weighting

3 Goal and scope definition

Goal

The objective of this literature study is to determine the energy and CO₂ emission savings by the operation of weight reduced vehicles. Therefore, the

- **life-time** energy savings for the whole operational life of **single vehicles** as well as the as the
- potential global **annual** energy savings of an assumed **fleet** of weight reduced vehicles

have been analysed. The means by which the weight reduction is technically realised, e. g. if the weight reduction is achieved by the use of lighter materials or by other means, are not part of this study. The energy savings for a single vehicle directly depend on the

- specific energy savings by weight reduction and the
- life-time performance of the vehicle.

Both variables are also influenced by a number of sub-parameters such as (amongst others) the use pattern (e.g. driving cycle, flight pattern, etc.), resistance factors, tank to wheel efficiency as well as daily performance and durability of the respective vehicle. For surface vehicles, these parameters have already been discussed in detail in the first study ([IFEU 2003a]). The technical background for air and sea transport will be discussed in the respective sections of this report.

A top-down-approach is used for the estimation of global annual energy savings for an assumed fleet of weight reduced vehicles. For the potential energy savings by weight reduction (besides other technical efficiency improvements (e.g. aerodynamics, drive train, etc.)),

- the potential for a weight reduction of different vehicles as well as
- the relative efficiency of weight reduction of different vehicles

have to be taken into account.

It has to be noted that the operational life of a vehicle is a part of the full life-cycle of the vehicle and commonly analysed within the concept of life-cycle analysis. This study, however, is **NOT** a life-cycle analysis. This study takes into account the energy consumption and CO₂ emissions associated with the operation of the vehicles. This does not allow for an assessment of light-weighting as such, which may present a different picture.

Scope

Energy savings have to be analysed along the lines of a defined functional unit and for a specific performance. The functional unit defines the reference parameters for the comparison, in this case the vehicle and its performance.

The vehicle performance can refer to the mileage or the transport performance (Passenger-km or tonne-km). All parameters at the vehicle, except for its weight, should be maintained. It has to be noted, however, that other specifications, like the power to weight ratio of the vehicle, change with the weight of the vehicle. Thus not all

benefits of the weight reduction can in some cases be fully realised, because the vehicle will not anymore be in the range of optimum efficiency. Adjustment can therefore be made in the transmission and other parameters.

Benefits of a weight reduction have to be measured as energy input per unit of performance output. Two cases for a comparison of the **performance** can now be distinguished:

- Generally, a weight reduced vehicle is assumed to carry the same number of passengers and the same amount of load. The mileage performance (km) as well as transport performance (Passenger-km or ton-km) will be the same, but less energy will be required. In this case, the power to weight ratio of the operating vehicle changes. This benefit will be referred to as **direct energy savings**.
- For freight vehicles, however, in the case of weight limited cargo (e.g. freight trains, ocean vessels), a weight reduction can be used for an increased payload. In this case the operating vehicle is also maintained in terms of power to weight ratio. The specific energy consumption as well as the mileage performance (km) will be the same, but the transport performance (ton-km) will be higher. The benefit of a higher transport performance will be referred to as **indirect energy savings**. Energy can be saved, because less mileage performance will be needed to achieve the same transport performance.

Some vehicles (e.g. high speed ferries) will rather use a weight reduction to increase their speed with energy consumption and number of passengers maintained. In this case no energy savings by the weight reduction as well as no increase in the transport performance (P-km or t-km) can be achieved, because in this study speed and time are not considered to be part of the transport performance. High-speed vehicles in general, however, have a high specific fuel consumption and therefore high potential energy savings by weight reduction if the speed is assumed to be maintained.

Methodology

To determine the energy savings, either measured data or simulated data obtained from complex models can be used. For some vehicles a range of estimates (rules of thumb) on weight induced energy savings can be found in the relevant literature. These estimates lack a scientific chargeable basis, but will be used for comparison or if no tests or simulations are available. Data on the global transport energy consumption are taken from international and national statistics and allocated to the vehicle types analysed in this and the preceding "Energy savings by light-weighting" study.

Depending on data availability, two different parameters and thus terms will be used to characterise energy savings by light-weighting:

- **Specific energy savings** are energy (kJ) or fuel (litre) savings per 100km which will be achieved for a 100kg weight reduction. This value already takes into account the specific energy consumption of the considered vehicle, but not the total (e.g. annual or life-time) consumption.
- **Relative energy savings** are energy savings in relation to any total consumption (e.g. life-time, annual or per 100km) which will be achieved by a 10% weight reduction of the vehicle. This value does not take into account the

specific energy consumption of the considered vehicle, but shows somewhat the efficiency of a weight reduction. Only with all vehicle resistances being dependent on the vehicle weight, 10% energy savings will be achieved for a 10% weight reduction. In most cases, however, some energy demanding resistances (e.g. aerodynamic resistance) are weight independent.

The data used in this study are from a variety of sources and are of different qualities. The main focus is on North America and Europe due to availability of data and the importance and number of transport vehicles in these regions. Data have been gathered mainly by literature research (scientific publications and published documents from political and industrial organisations) and communication with associations, industry and research institutes. Data gaps have been filled by using expert judgements, data extrapolation or system modelling. The data quality, however, is very different, depending on the countries, vehicles as well as the parameters. The appraisal of the potential life-time energy savings for different vehicles and the global potential for annual energy savings is undertaken on the basis of this unequal data.

4 Energy supply efficiency and CO₂ emission factors

The vehicles analysed in this study are operated with different fuels (Diesel, Gasoline, Kerosene, etc.) as well as electricity (rail vehicles). Especially in the case of electricity, relevant differences between different regions occur in the efficiency of energy supply and overall CO₂ emissions. The differences are mainly due to different energy splits being used for the electricity generation. Therefore OECD and non-OECD countries will be distinguished for electricity. To be able to compare the different energy carriers, this analyses also distinguished different levels of energy consumption:

- The basic amount of energy needed to move a vehicle is determined by the physical resistances the vehicle has to overcome during its operation. This so-called **basic energy consumption** is therefore directly affected by a weight reduction of the vehicle.
- Some energy, however, is lost during the transmission from the engine to the wheel and within the engine itself (“tank to wheel”). The total **final energy consumption** at the engine of the vehicle is therefore higher than the basic energy consumption at the “wheel”.
- Energy is also needed for the energy supply of the vehicle, mainly the exploration, conversion and distribution of a primary energy carrier (e. g. in power plants or refineries) (“well to tank”). The total **primary energy consumption** includes all energy consumption mentioned above and therefore allows for a comparison of different vehicles with different energy carriers.

The difference between the energy input and the energy output of a certain process (power plant, refinery, engine and/or transmission) is called efficiency and will be stated as energy output in percent of the original energy input. Most vehicles to date are fuel (either gasoline or diesel) powered. Some rail vehicles, however, have electric engines which have a very different efficiency compared to diesel engines.

While for vehicles with combustion engines the highest energy losses occur in the engine (less than 30% efficiency), for vehicles with electric engines (over 90% efficiency) the highest energy losses occur in the electric power plants ([DLR 2001]). The efficiency of energy supply in turn is higher for fuels (refineries) and lower for electricity (power plants). While the basic energy consumption at the “wheel” is independent of the type of engine, the final energy consumption is very different. Differences in energy consumption between combustion engines and electric engines mainly show up in the final energy (Fig. 6).

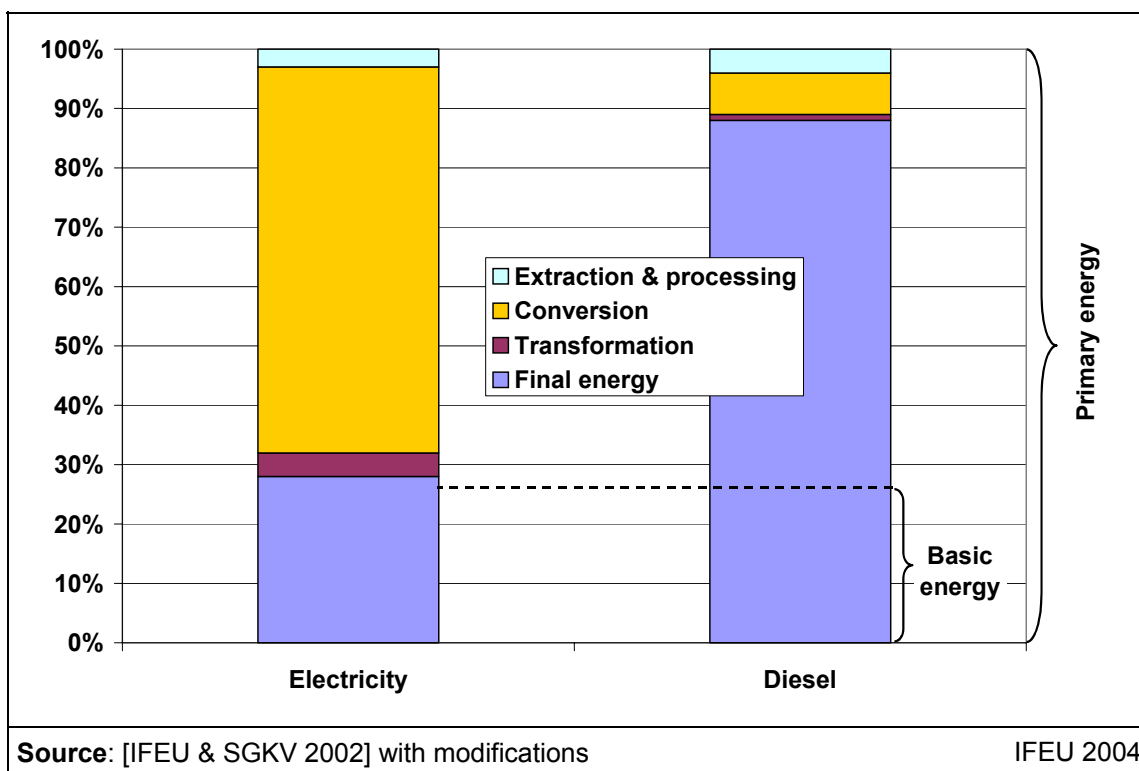


Fig. 6: Energy chain for diesel and electricity (schematic presentation)

The basic year for the analyses in this study is 2000 and therefore energy supply and CO₂ emissions data refer to the basic year 2000. This sections only takes into account processes directly linked to the energy supply (Extraction, processing, conversion, etc.). The construction of power plants, refineries and other infrastructure required for the energy supply is not taken into account. All CO₂ emission factors are derived based on the assumption of a complete oxidation of all carbon contained in the respective energy carrier.

Tab. 1: Efficiency of energy supply

Final energy carrier	Efficiency (Final energy/ primary energy)	t CO ₂ /TJ primary energy
Diesel/ Kerosene	87%	83.4
Gasoline	83%	87.0

Source: [IFEU 2003a] IFEU 2004

The efficiency and CO₂ emission factors for Diesel/ Kerosene and Gasoline are used as derived in [IFEU 2003a] (Tab. 1). Two sets of efficiencies are used for electricity generation. One reflects the energy split for OECD and the other for non-OECD countries. This generalisation seems to be appropriate since electricity accounts for only a minor share of the global transport energy consumption. Nuclear, Hydro and thermal generation of electricity have been taken into account. The efficiency of electricity generation in thermal power plants ranges from about 30 to 40% in the EU countries, but can be considerably lower in developing countries. Therefore 35% average efficiency are assumed for the OECD and 25% for the non-OECD countries. *“For other types of electricity production (nuclear, hydro) no efficiency can be*

calculated... For these energy carriers, conventions have to be made to quantify the 'primary energy input'. As is common practice in international energy statistics ..., we assume an energy efficiency of nuclear power plants of 33%. Hydroelectric power plants are set to 100% efficiency" ([IFEU & SGKV 2002]). The share of different energy carriers being used for electricity generation is taken from [IEA 2002a]. The OECD countries show a higher share of nuclear power generation compared to non-OECD countries, which in turn have a higher share of hydro power (Tab. 2).

Tab. 2: Efficiencies for electricity generation

Energy carrier	OECD		Non-OECD	
	Share	Efficiency *	Share	Efficiency *
Nuclear	16.9%	33%	4.7%	33%
Hydro	10.4%	100%	17.8%	100%
Thermal	72.7%	35%	77.5%	25%
Overall efficiency	41.4%		38.7%	
Source: [IEA 2002a] & [IFEU & SGKV 2002]				
* Final energy/ primary energy				IFEU 2004

Since nuclear and hydro power generation create negligible CO₂ emissions, a CO₂ emission factor has to be derived for thermal power plants. The split of different energy carriers is again taken from [IEA 2002a]. Again, CO₂ emission factors are derived based on the assumption of a complete oxidation of all carbon contained in the respective energy carrier. The average carbon content of the different energy carrier and pre-chain emission factors are taken from [IFEU & SGKV 2002] as shown in Tab. 3. With the respective shares of thermal power plants in respect to overall electricity generation ([IEA 2002a]) 66 and 70 t CO₂ per TJ primary energy have been calculated for OECD and non-OECD countries respectively.

Tab. 3: CO₂ emission factors for electricity generation in thermal power plants

Energy carrier	Share	Carbon content	Prechain	Total
Unit	% of fossil fuels	t CO ₂ / TJ Input		
Coal	60.7%	100	4.6	105
Oil	12.3%	78	8.3	86
Gas	27.0%	56	5.9	62
Overall emission factor for thermal power plants (t/ TJ primary energy)				91
Emission factor for electricity in OECD countries (t/ TJ primary energy)				66
Emission factor for electricity in non-OECD countries (t/ TJ primary energy)				70
Source: [IEA 2002a] & [IFEU & SGKV 2002]				IFEU 2004

The emission factors for coal in Tab. 3 are also used for other coal types. This generalisation seems to be appropriate since coal accounts for only a minor share of the global transport energy consumption. Furthermore is the emission factor for gas used for LPG, natural gas, biogas and solid biomass. An overview of the emission factors used in this study is given in Tab. 4.

Tab. 4: Overview CO₂ emission factors (t of CO₂ per TJ primary energy)

Energy carrier	t of CO ₂ per TJ primary energy
Oil based fuels	
Crude Oil	86
LPG & Ethane	62
Motor Gasoline	87
Aviation Gasoline	87
Jet Fuel	83.4
Kerosene	83.4
Gas/ Diesel	83.4
Heavy Fuel Oil	83.4
Other Products	83.4
Other energy carriers	
All coals	105
Natural Gas	62
Electricity OECD	66.0
Electricity non-OECD	70.4
Source: IFEU 2004 from various sources IFEU 2004	

5 Life-time energy savings by selected vehicles

This chapter expands the scope of vehicles which have already been analysed in the first study. Both studies combined cover most of the relevant means of transport in terms of energy consumption. This coverage is also of importance for the analysis of potential global energy savings by weight reduction in chapter 7.

This chapter analyses the primary energy savings during the life-time of the different vehicles by reducing the weight by 100kg. The additional vehicles in this chapter are

- light-duty vehicles and light trucks (chapter 5.2),
- aircrafts (short- and long-distance use) (chapter 5.3) and
- different ships (chapter 5.4):
 - Passenger ferries (normal and high speed)
 - Ocean vessels (Tankers, Container and General Cargo ships).

Also potential energy savings for a weight reduction of air- and sea-freight containers will be estimated based on the results for the carrying vehicles.

5.1 Approach and scope definition

The energy consumption of a vehicle is determined by the resistances the vehicle has to overcome during its operation. In the first study only surface vehicles (road and rail) have been considered. Road as well as rail vehicles mainly have to overcome the same resistances, which have been described in detail in the first study ([IFEU 2003a]). In this study also ocean vessels and planes, which face entirely different resistances, will be covered. A technical background will thus be part of the respective sections.

The vehicles covered in this section vary in respect to the energy carrier they use as well as their total weight. Differences between both, engine and energy supply efficiencies are taken into account by using primary energy for the comparison. To be able to compare all vehicles despite their different sizes and weights, 100kg is used as the reference unit for the weight reduction. Though this is a significant weight reduction for a light-duty vehicle, it is negligible for ocean vessels such as container ships and tankers. It has to be noted, however, that the 100kg weight reduction is only used as a reference for comparison, but can easily be converted to a weight reduction in the range of several hundred tons.

The life-time performance (mileage, operation hrs, cycles, etc.) is of great influence on the life-time energy savings. For the **life-time performance**, the whole life of the vehicle has to be considered. Even if a vehicle starts its "career" as a commercial vehicle in the U.S. and continues to operate for several years in rural Mexico as a taxi, the weight reduced option will continue to save energy without any further maintenance. No definite statistics for the global average of the entire life-time performance exist. Estimates are based on national statistics and communication with experts from associations and operators.

5.2 Light-duty vehicles and light-duty trucks

5.2.1 Vehicle definition

Passenger cars, several types of buses and articulated trucks have already been covered as road vehicles in the first study. These vehicles are rather on the two ends of the weight spectrum of road vehicles and have different specific fuel savings by weight reduction and different uses. Mid-size road vehicles will now be exemplified by light-duty vehicles and light trucks. The calculation will be undertaken based on data for relative energy savings, which requires a clear definition of the exemplified vehicles.

The term light duty vehicles is used differently and covers a wide range of road vehicles from passenger vans similar to passenger cars (in fact the California definition of light-duty vehicles is identical to passenger cars ([EPA 1998])) to light-duty trucks with a gross weight of up to 7.5 t. This study defines

- **light duty vehicles** as vehicles primarily used for the carriage of goods with a maximum gross weight up to 3.5 tonnes (about equivalent to EU N1 vehicles ([EU 1970]) and US Light light duty trucks (LLDT) ([DieselNet 2004])) and
- **light trucks** as vehicles used for the carriage of goods with a maximum gross weight up to 7.5 tonnes (about equivalent to EU N2 vehicles ([EU 1970]) and US Heavy light duty trucks (HLDT) ([DieselNet 2004])).

Besides the maximum gross weight, for definition purposes also the average vehicle weight and average load, both adding up to the average gross weight, are of interest. The average vehicle weight and average load factor used for this analysis, are shown in Tab. 5.

Tab. 5: Vehicle specifications for exemplification

Vehicle type	Average vehicle weight	Average load	Average gross weight
LDV (< 3.5t)	1.5t	0.5t	2t
Light trucks (< 7.5t)	3t	1.5t	4.5t
Source: [IFEU 2000]			IFEU 2004

While light trucks are assumed to be used for commercial purposes only, light-duty vehicles are in many cases (especially in the US) private vehicles. In addition to the average light-duty vehicle (mileage and use pattern including private as well as commercial vehicles), a commercial light-duty vehicle for urban distribution, delivery and services will be exemplified.

Only direct energy savings will be analysed, though the *“Reduction of weight will improve fuel economy by increasing payload capability and by improving both ton-miles and mpg under empty and part-load conditions. The benefit of increased payload efficiency does not occur for loads that occupy maximum volumetric capacity of the vehicle before the maximum allowable weight is reached. In this case, only supplementary benefits are realized. Given that a significant portion of payload transported by medium trucks is limited by volume, particularly during multiple-stop delivery runs, estimates of the benefits of reduced tare weight need to reflect this reality”* [Woodrooffe et al. 2000]. Since changes in total vehicle weight are common for distribution and delivery vehicles also axle adjustments cannot be taken into account.

5.2.2 Relative energy savings and specific fuel consumption

For reasons of data availability, specific fuel savings for the above mentioned vehicles will be calculated from relative fuel savings (% fuel savings for a 10% weight reduction) with data on the specific fuel consumption and average weight of the vehicles.

High relative energy savings are stated in the relevant literature, mainly for urban delivery vehicles (Tab. 6). Such high values are also confirmed by IFEU modelling of ECE test cycle. The model calculation takes into account all relevant parameters such as rolling and air drag coefficients, engine and transmission efficiencies and the vehicle weight. This calculation method has also been used in [IFEU 1999]. Modelled values for the NEDC seem to be considerably lower due to less acceleration and a higher share of aerodynamic resistance. Because of data uncertainties and the fact that the data are rather rules of thumbs than results of tests and measurements, conservative values of 7.5% for a city cycle and 5% for the average cycle will be used. Specific fuel savings can now be derived from the specific fuel consumption as stated in Tab. 7.

Tab. 6: Relative energy savings by weight reduction for light duty vehicles and trucks

Vehicle	Weight reduction	Fuel efficiency improvement	Relative energy savings *	Source
Pick-up truck (City)	20%	15%	7.5%	[Woodrooffe et al. 2000]
Medium delivery truck (City)	33%	30%	9%	
Light and medium trucks (City)	20%	15%	7.5%	[TSA 2001]
Light-duty vehicle (ECE)			8%	IFEU modelling
Light-duty vehicle (NEDC)			5%	
Used in this study (urban)			7.5%	IFEU estimate
Used in this study (average)			5%	
* % energy savings per 10% weight reduction				IFEU 2004

Tab. 7: Specific fuel consumption for light-duty vehicles and light trucks

	LDV (<3.5t)	Light trucks (<7.5t)	Source
City (Germany)	13.2l	20l	[IFEU 2000]
Extra Urban (Germany)	11.2l	16.8l	
Average (Germany)	11.8l	17.8l	
Average (US)	13.5l		[BTS 2002b]
Used in this study (average)	12l	18l	IFEU estimate
Used in this study (urban)	13.5l	20l	
IFEU 2004			

5.2.3 Life-time energy savings by weight reduction

Light-duty vehicles are used as private as well as commercial vehicles. Thus two cases will distinguished. The average light-duty vehicle (mainly private use) with use similar to the NEDC and the commercial light-duty vehicle for urban delivery use, with a higher than average mileage and use similar to the urban driving cycles of the EU (ECE) and U.S. EPA (New York City Cycle (NYCC)). Light trucks will be assumed to be commercial vehicles only, but distinguished in light trucks for urban delivery and light trucks for other uses.

The annual mileage of distribution, delivery and service trucks has been estimated in a study by [DIW 2003] (Tab. 8). [IFEU 2000] uses lower average values, but the average use of these vehicles is representing the distribution and delivery pattern as well as private use. A commercial delivery truck is also analysed in a study on UPS vehicles, which will be used for the exemplification in this study. All relevant sources and the rounded data used for this analysis are listed in Tab. 8. A life-time of 15 years (similar as for passenger cars) is used for average and 12 years for the heavily utilised commercial vehicles. Though the use phase in industrialised countries may sometimes be shorter, some trucks will still be sold and continue to operate in other countries before scrappage.

Tab. 8: Annual mileage of LDVs and light trucks 2000 (km)

	LDV (<3.5t)	Light trucks (<7.5t)	Source
Average (Germany)	17'230km	23'558km	[IFEU 2000]
Average EU	20'000km		[RAND 2003]
Average US	19'000km	19'000km	[BTS 2002b]
Commercial Delivery (Germany)	30'000km	60'000km	[DIW 2003]
Commercial (UPS)		38'000km	[USDE 2002]
In this study (average)	20'000km	25'000km	IFEU
In this study (delivery)	30'000km	38'000km	IFEU
			IFEU 2004

All relevant data and the calculation for average and urban delivery vehicles are summarised in **Tab. 9**.

Tab. 9: Life-time energy savings for average vehicles

	Light Duty Vehicles (<3,5t)	Light trucks (<7,5t)
Maximum gross weight	3.5t	7.5t
Average gross weight (t)	2t	4.5t
Average use (commercial and private use)		
Fuel consumption (l/ 100km)	12	18
Relative Energy savings (%/ 10%)	5%	5%
Specific Fuel savings (l/ (100km*100kg))	0.3	0.2
Annual performance (km)	20'000	25'000
Life-time	15	15
Life-time performance (km)	300'000	375'000
Life-time final energy savings (GJ/100kg)	30	25
Life-time primary energy savings (GJ/100kg)	35	29
Life-time CO ₂ savings (t/100kg)	2.9	2.5
Urban delivery use (commercial use only)		
Fuel consumption (l/ 100km)	13.5l	20l
Relative Energy savings (%/ 10%)	7.5%	7.5%
Specific Fuel savings (l/ (100km*100kg))	0.45	0.3
Annual performance (km)	30'000	38'000
Life-time	12	12
Life-time performance (km)	360'000	456'000
Life-time final energy savings (GJ/100kg)	65	54
Life-time primary energy savings (GJ/100kg)	75	62
Life-time CO ₂ savings (t/100kg)	6.3	5.3
IFEU 2004		

5.2.4 Overview: Road vehicle life-time energy savings

The life-time primary energy savings for average light-duty vehicles and light trucks are in the same range as most other road vehicles. The average city bus still shows the highest life-time energy savings. High performance delivery trucks as exemplified above, however, show exceptionally high life-time energy savings which may be in the range of a city bus. This is due to the high relative energy savings by weight reduction and the high specific fuel consumption if compared to the vehicle weight.

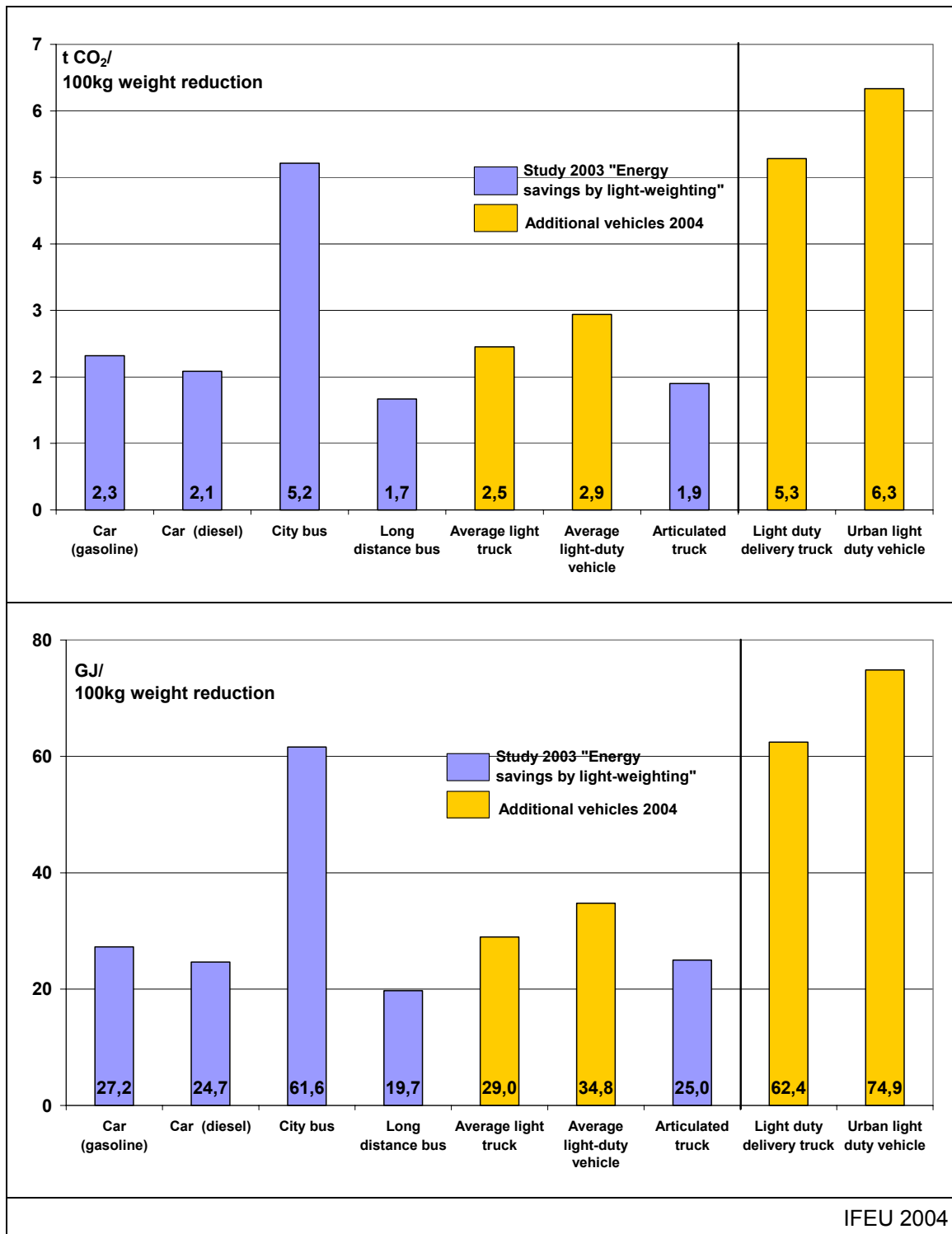


Fig. 7: Life-time primary energy and CO₂ savings for road vehicles

5.3 Aircrafts

The flight of an aircraft consists of different segments ([Pfüller 2002]) which have a different fuel consumption and face different resistances: After the **engine start up and idle** (ESID) and the **taxi out**, the

- **take off** is the first major segment of the flight. After take off, the
- **climb** is bringing the aircraft up to the cruising altitude. The
- **cruise** will afterwards perform the major transport work. As the aircraft approaches its destination it starts the
- **descent** followed by the
- **landing** and the **taxi in**.

If the flight exceeds a distance of about 500 to 600km, the cruise becomes the most important segment of the flight in terms of energy consumption. As the aircraft loses weight, the optimal cruising altitude will be changing as well. The fuel consumption of the different flight segments of two different flights is illustrated in Fig. 8. For the flight from Frankfurt to Palma de Mallorca, already 68% of the total fuel consumption is during cruise. For a longer distance (Hamburg - Teneriffa) over 80% of the total fuel consumption is during cruise. Overseas flights will show even higher shares of cruise fuel consumption. Thus for better understanding, the resistances at a level, steady speed cruise will be discussed in detail.

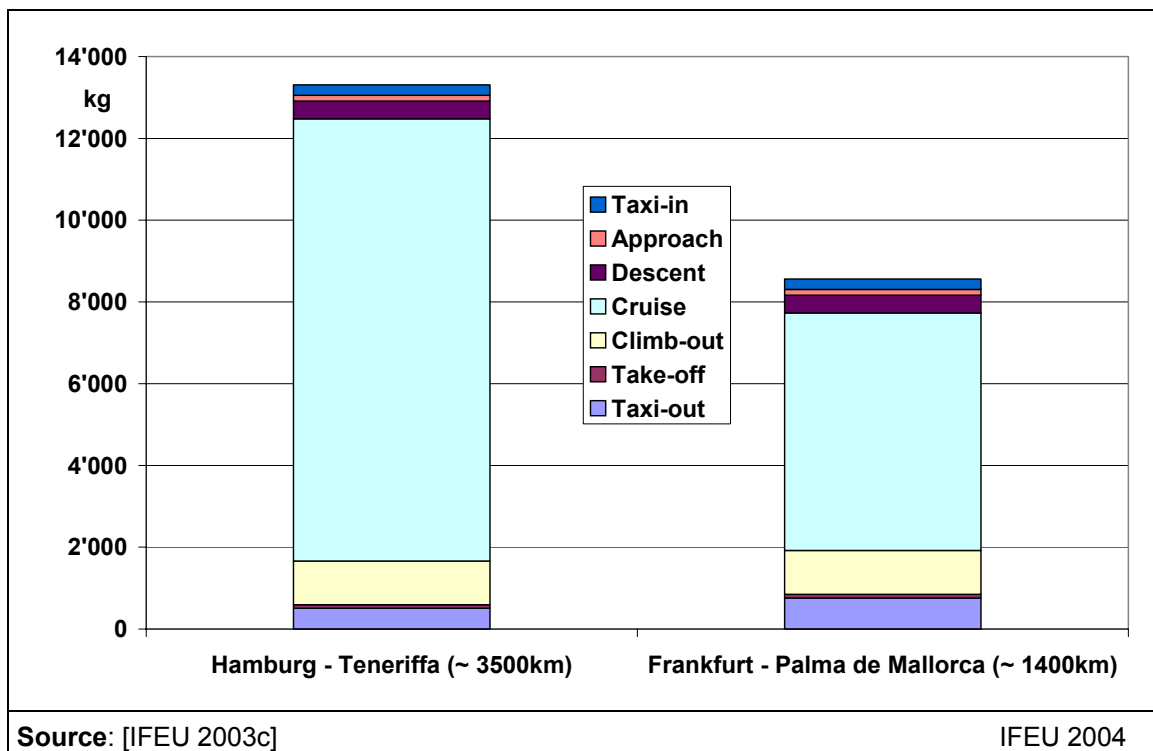


Fig. 8: Fuel consumption for different flight segments (Airbus A310-203)

The fuel consumption of an aircraft is heavily dependent on its weight. In fact, the fuel itself makes up a major part of the aircraft's take off weight. The aircraft will be constantly losing weight during the flight, the specific fuel consumption will thus be constantly changing. As an additional effect of a weight reduction of the aircraft itself, higher weight savings will be achieved in respect to the take off weight, because less fuel has to be carried.

5.3.1 Resistances for aircraft cruise

The resistance factors for aircrafts are different from surface vehicles. Basically four forces are affecting a steady and level plane:

- The *weight* of the plane pulls it downward
- while the *lift* keeps it up.
- The *aerodynamic resistance* in turn
- has to be overcome by the *thrust*.

The weight and aerodynamic resistance have to be overcome by the thrust. A lighter plane will require less lift and thus less thrust for the performance of same route characteristics as a heavier alternative. Since aerodynamic resistance is the main resistance to be overcome by the thrust, most planes are also optimised for aerodynamics. The thrust, however, is also required to create the lift equal to the weight of the plane. The fuel consumption is therefore directly linked to the weight of the aircraft.

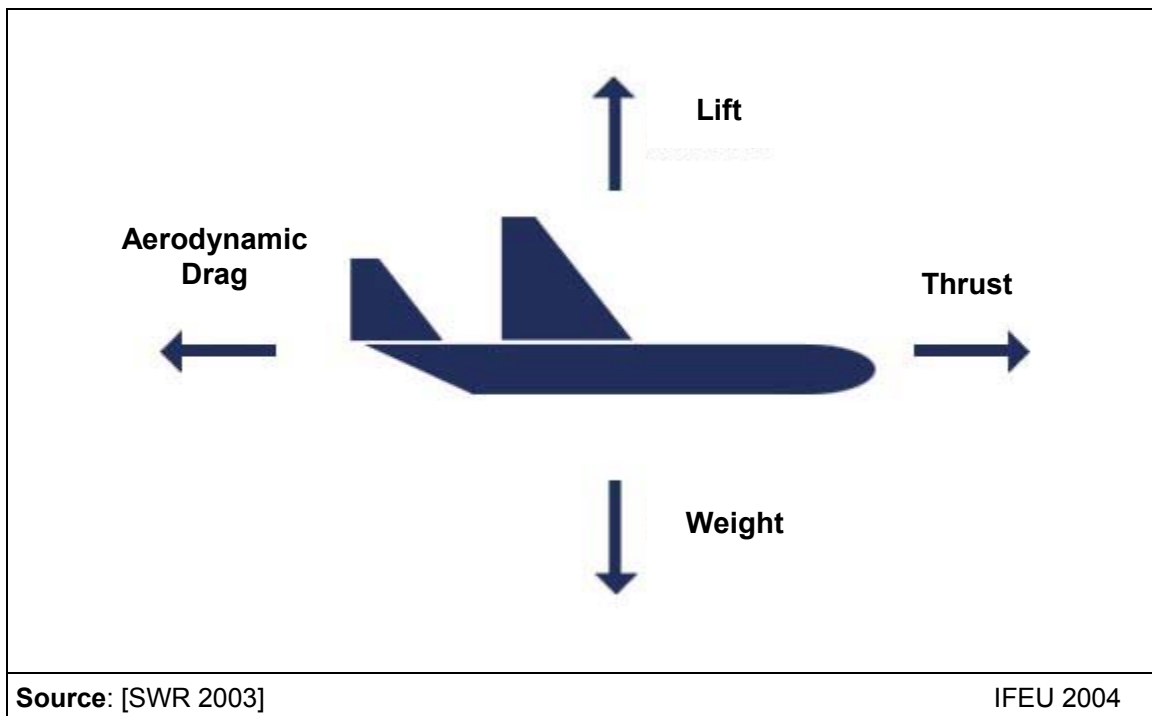


Fig.9: Resistances to an aircraft

Since the fuel itself makes up a great share of the aircrafts total weight (Fig. 10), the weight is constantly changing. Therefore there is no such thing as “the gross weight” of the aircraft in operation. Energy savings by weight reduction will refer to differences in the take-off weight of the plane and there is no difference between a weight reduction achieved by light-weighting of the aircraft or the aircraft carrying less fuel. A weight reduced plane, however, will require less fuel, and therefore be weighting even less. Additional energy savings have to be taken into account.

5.3.2 Relative energy savings by weight reduction

[FZKA 2003] studied the environmental impacts of a weight reduced aircraft hull within a life-cycle analysis. The operation weight empty (OWE) of the plane has been reduced by 2.5t which is a relative weight reduction of over 6%. The load however, has not been reduced, so that a lower weight reduction of the gross weight will be achieved. In addition to the weight reduction at the plane itself, however, also less fuel has to be bunkered, so that, depending on the distance of the flight relation, around 3t reduction of the take-off weight can be achieved. The fuel consumption of the different aircraft versions has been estimated with so called “mission performance calculations”. Relative energy savings are in the range of 9.3% and 8.6% per 10% weight reduction for short- and long-distance flights respectively (Tab. 10). Energy savings are higher for short distances, because “*Specific energy consumption and emissions of air cargo transport depend heavily on the length of the flight. This is because their values vary between different flight phases: thus for example the take-off has the highest specific energy demand. Its share of the total flight obviously declines as the length of the flight increases*” [IFEU 2003b].

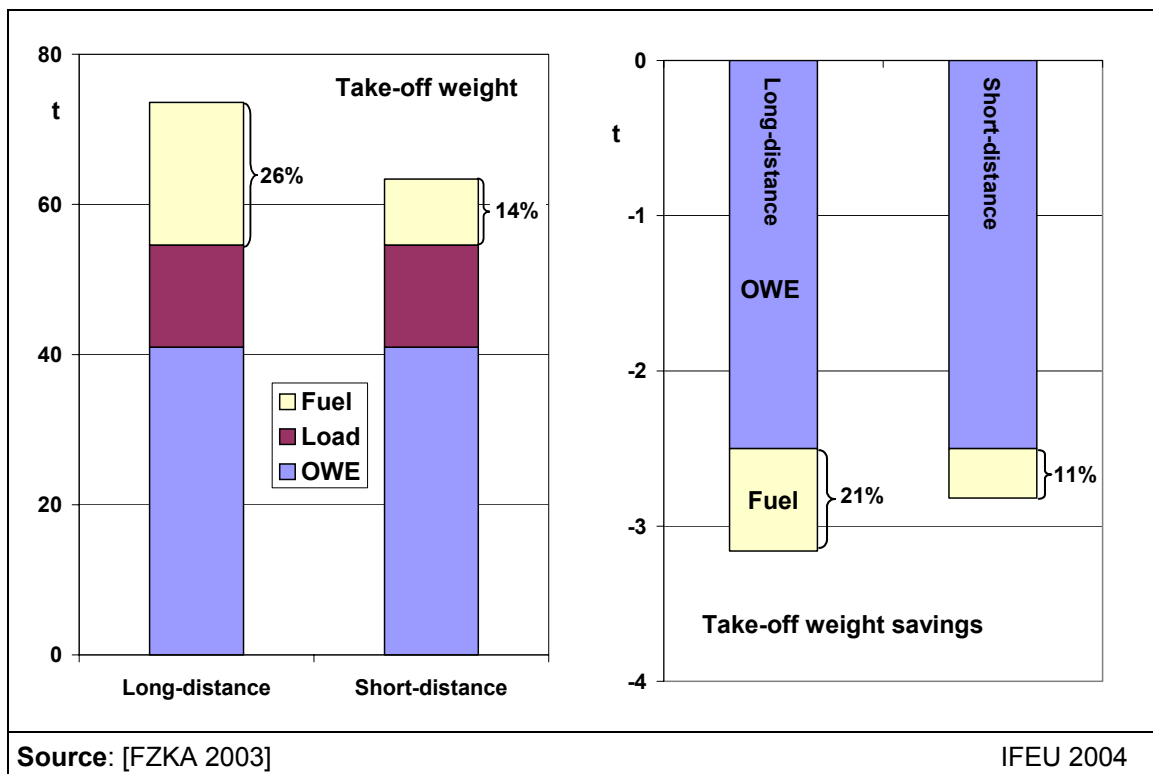


Fig. 10: Composition of take-off weight and take-off weight savings

Tab. 10: Fuel consumption of a weight reduced aircraft

	Weight (kg)		Weight reduction	
OWE	40'925kg		- 2'500kg (-6.1%)	
Load	13'607kg		-	
	Short-distance		Long-distance	
	Weight	Weight reduction	Weight	Weight reduction
Fuel	8'823kg	- 319kg (- 3.6%)	19'144kg	- 664kg (-3.5%)
Fuel consumption	5'569kg	- 226kg (- 4.1%)	15'399kg	- 563kg (- 3.7%)
Total take off weight	63'355kg	- 2'819kg (- 4.4%)	73'676kg	- 3164kg (- 4.3%)
Relative energy savings	9.3%		8.6%	
Source: [FZKA 2003]			IFEU 2004	

Air freight container

Generally, also the weight reduction of air freight containers saves the same amount of energy. In this case, the load weight will be reduced instead of the operation weight empty (OWE). Also additional weight will be saved, because less fuel has to be carried. It has to be noted, however, that air freight container will have less annual airtime, due to more time consuming loading and unloading. 50% airtime compared to aircrafts are assumed for exemplification. In addition, the service life of air freight containers seems to be shorter. Various depreciation tables state a container service life in the range of 7 years. This is about 23% of the service life of an aircraft. The overall life-time energy savings for 100kg weight reduction will thus be about 12% of the aircraft life-time energy savings.

5.3.3 Life-time energy savings by weight reduction

The life-time primary energy savings will be assessed based on two sources:

- a) The first assessment for an Airbus A320 follows the relative energy savings as derived above ([FZKA 2003]).
- b) The second assessment uses original Lufthansa data on annual fuel savings by weight reduction ([Lufthansa AG 2003]).

a) The life-time fuel consumption of an Airbus A320 is around 200kt for short- and 222kt for long-distance flights ([FZKA 2003]). With an average weight of about over 60t and 70t respectively, this results in life-time primary energy savings of around 15 TJ for short distance and almost 13 TJ for long-distance flight for a 100kg weight reduction (Tab. 11). This value is about 100 times higher as the values estimated for rail vehicles. This can be attributed to the high specific fuel consumption and the very high life-time performance.

Tab. 11: Exemplification of the life-time energy savings of an Airbus 320

Airbus A320	Short-distance	Long-distance
Take of weight (t)	63t	74t
Relative energy savings (%)	9.3%	8.6%
Life-time fuel consumption (t)	200'000t	222'000t
Life-time fuel savings (t/100kg)	295	258
Life-time final energy savings (GJ/100kg)	12'683	11'084
Life-time primary energy savings (GJ/100kg)	14,579	12,740
Source: [FZKA 2003]		IFEU 2004

b) A “weight manager” has been developed by Lufthansa AG to calculate the fuel consumption and weight relationship. Data from this tool ([Lufthansa AG 2003]) indicates the life-time energy savings of an A320 based on an assumed operational life-time of 30 years even higher. The life-time primary energy savings of long distance aircrafts are in the range between 20 and 30 TJ. Planes in a long-distance flight pattern show higher life-time energy savings according to [Lufthansa AG 2003] data, due to their higher number of hours in the air and thus higher total fuel consumption. Differences may be due to operational hours. Data within the short-distance flight pattern is very consistent, also compared to the [FZKA 2003] data.

Fig. 11: Energy savings by weight reduction data for various plane types

Aircraft type	Flight pattern	Annual fuel savings (t/100kg/a)	Life-time final energy savings (GJ/100kg)
A319-100	Short distance	13.2	17,012
A320-200		12.3	15,852
A321-100/200		11.7	15,079
737-300		13.4	17,270
747-400	Long distance	21.2	27,323
A340-300		17.2	22,167
Source: [Lufthansa AG 2003]			IFEU 2004

Air freight container

For exemplification, an airfreight container is assumed to have about equal shares of long- and short distance flights. Average values will be used for the energy savings for both modes.

The overview of CO₂ and primary energy savings for aircrafts (Fig. 12) shows the LCA data for long-distance flights to be considerably lower as the Lufthansa data. This may be due to different reasons such as the total energy consumption of the A320, as a small aircraft compared to the 747 and the A340, having a much lower total fuel consumption. The long-distance use pattern between smaller (A320) and larger aircrafts (747 & A340) may also show considerable differences. Data for short-distance flights from both sources seems to be consistent.

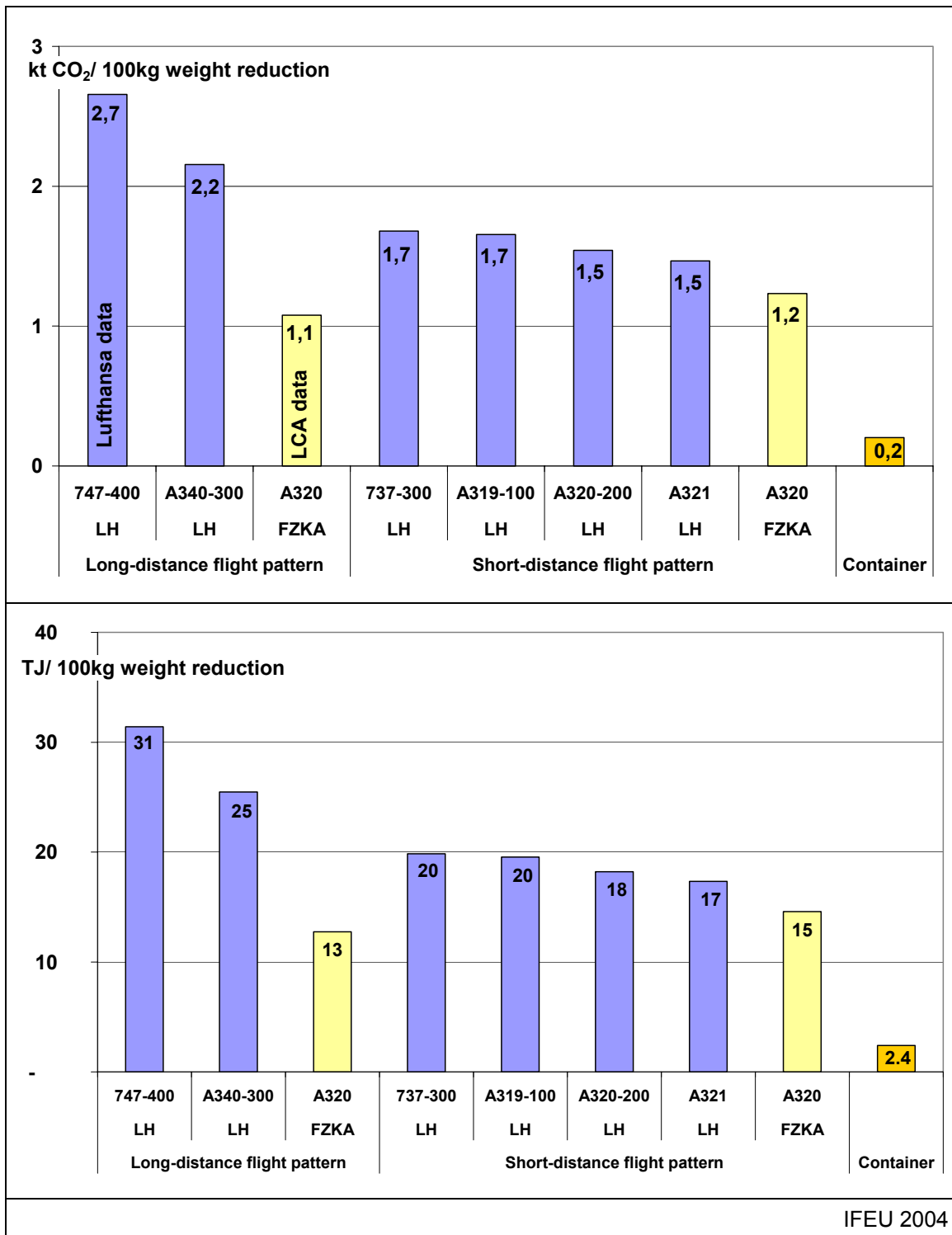


Fig. 12: Life-time primary energy and CO₂ savings for aircrafts

5.4 Ships

This chapter analyses the potential life-time energy savings for weight reduced cargo ships and passenger ferries. The calculation has been undertaken on the basis of relative energy savings, which requires, as for light-duty vehicles and light-trucks, a definition of the exemplified ships in terms of weight and horse power rating. The ship types analysed in this chapter will be defined in the following section (5.4.1). Afterwards the resistance factors for ships will be discussed in detail (5.4.2). In the data section (5.4.3) relative energy savings will be derived from the theory of resistance factors. Thereafter the life-time fuel consumption for the different ship types will be assessed. The life-time energy savings are finally calculated from relative energy savings and the life-time fuel consumption (5.4.4).

5.4.1 Definition of ships for exemplification

Ship classification

Various classifications of ship types can be found. This study follows the Booz-Allen classification described in [EPA 2000] and distinguishes

- Container ships,
- General cargo vessels and
- Tankers

as freight carrying ocean-going vessels. The use characteristics of these vessels are described in Tab. 12.

Passenger boats/ferries can be ocean-going as well as non-ocean going. Here the case of ocean-going ferries is analysed. This study distinguished between

- an average ferry and
- a high-speed ferry.

Ship characteristics

The **ship size** is generally either stated as a

- **volume**, e. g. Gross Registered Tonnage (GRT) being the capacity in cubic feet within the hull, and of the enclosed spaces above deck, or as a
- **weight**, e. g. Deadweight Tonnage (DWT), being the weight in metric tonnes of cargo, stores, fuel, fresh water, ballast, passengers and crew.

Since this study analyses energy savings by weight reduction, the Deadweight Tonnage is used for the ship classification. Though DWT also includes the weight of fuel, food, crew and fresh water needed for the ship's operation, as this weight is very small in comparison with the cargo, **DWT is regarded as equivalent to the weight of cargo** that can be loaded on the ship. The maximum weight of a ship, meaning the maximum displacement, is set by the load line. This line is set by classification societies like the American Bureau of Shipping (AB) or, Lloyds Register of Shipping (LR). The load line differs according to season and region.

Tab. 12: Ocean going vessel characteristics

Vessel type	Capacity	Load Factor
General cargo vessels, Ro-Ro-vessel Containerships	9'000 t to 23'000 t	Operate more or less at full capacity on all trips. Ro-Ro-vessel are employed for short ferry boat trips.
Tankers	50'000 t to 200'000 t	Usually used for the transport of crude oil and operate either at zero or full capacity.
Source: [Borken et al. 1999]		IFEU 2004

Container ships and other cargo vessels operate more or less at full capacity on all trips and have a loading capacity of up to over 20'000t (Tab. 12). Tankers have a much higher capacity of up to 200'000t but normally don't operate always at full capacity (Tab. 12). These vessels often make one trip at full capacity but return almost empty or carrying ballast. For exemplification of ocean vessels a container ship and a general cargo vessel with 20'000t DWT and a tanker with 100'000t DWT is selected. In addition, passenger ferries are analysed as non-ocean-going vessels. The ship weight of cargo ships is assumed to be 25% of the deadweight, and thus to account for 20% of the total displacement at full load condition. All assumptions on the cargo ships exemplified in this study are listed in Tab. 13.

Tab. 13: Ship types and characteristics for exemplification

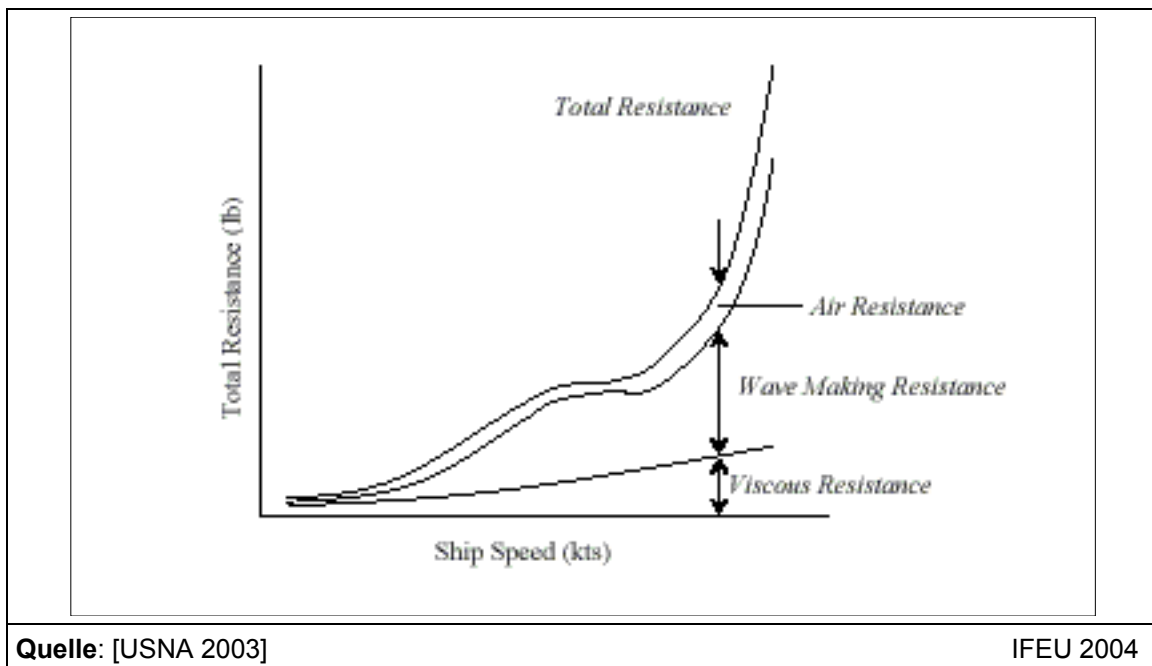
	Container ships	General Cargo vessels	Tankers
DWT	20'000t	20'000t	100'000t
Total weight	25'000t	25'000t	125'000t
			IFEU 2004

5.4.2 Resistance theory

A ship mainly experiences resistance from the water it is moving through [USNA 2003]: “As a ship moves through calm water, the ship experiences a force acting opposite to its direction of motion. This force is the water’s resistance to the motion of the ship, which is referred to as “total hull resistance”. “Testing of full-scale ships and models determined that the power required to propel a ship through the water was directly related to the amount of resistance a hull experiences when moving through the water.” The water resistance is composed of several resistances, which can be categorised as:

- **Friction** (depending on the surface of the hull underwater)
- **Pressure Resistance** of water pressure acting on the hull (depending on the amount of water displaced by the hull)
- **Wavemaking resistance** (energy required to create and maintain the ship’s characteristic bow and stern waves)

Also **air resistance** acts opposed to the ships motion, but it is generally far less a factor for ships as it is for faster surface vehicles and planes. Air resistance is the resistance caused by the flow of air over the ship with no wind present. “Resistance due to air is typically 4-8% of the total ship resistance, but may be as much as 10% in high sided ships such as aircraft carriers” ([USNA 2003]).



Quelle: [USNA 2003]

IFEU 2004

Fig. 13: Share of different resistances as a function of ship speed

Fig. 13 shows the different resistance factors as a function of speed (omitting pressure resistance). For ships at lower speeds viscous resistance (friction) dominates, while for ships at higher speeds wave making resistance takes over.

Friction (Viscous resistance)

The friction of the water acts over the entire wetted surface of the hull and causes a force against the ships motion. Friction depends on the roughness of the hull, the area of the hull which is submerged, the type of boundary layer and the speed of the ship.

*“Experimental data have shown that water friction can account for up to **85% of a hull’s total resistance at low speed** ..., and 40-50% of resistance for some ships at higher speeds.”* [USNA 2003] Friction is dependent on the weight of the ship via the area of the hull which is submerged which in turn affects the wetted surface area of the hull.

Pressure Resistance

In an ideal fluid the pressure acting on the front and the aft of the ship would be equal and no pressure resistance would be opposing the ships motion. Because of disturbances of water flow in the aft section of the boat, the pressure on the hull acting in the direction of the ships motion is lower than the pressure opposing the ships motion. The pressure resistance is mainly depending on the shape of the hull (which creates the disturbances in the aft section) and the displaced volume of the ship. Thus also pressure resistance is linked to weight of the ship via the displaced volume of the ship.

Wavemaking resistance

A ship moving through the water creates waves. Energy is required to make the waves and this energy will afterwards be stored in the wave, thus be lost for ships forward motion.

Admiralty coefficient

The resistance theory suggests that the fuel consumption of a ship is directly linked to the total ship weight which is also confirmed by [JJMA 2003]: *“To the first order it is appropriate to consider that the power-to-weight ratio for a ship is a constant for a fixed speed. ... However, this is only true if the ship is re-designed for the revised weight. For a real ship, where geometry remains fixed, the ship’s efficiency will degrade with increasing weight, due to the ship taking on a less attractive length-to-displacement ratio.”* This inefficiencies also apply to weight difference between an empty and a loaded ship. The relationships between the total ship weight (“displacement”) and the Power required to move the ship at a certain speed is approximated by the Admiralty Coefficient ([NPS 2004]):

$$\begin{aligned}
 P &= F \times v \\
 F &\sim R \\
 R &\sim v^2 \times A \\
 A &\sim D^{2/3} \\
 \Rightarrow P &= C \times D^{2/3} \times v^3
 \end{aligned}$$

with

P = Power (kW)

F = Force

R = Resistance

A = wetted surface

C = Admiralty coefficient (constant)

D = Displacement (long ton)

v = Ship speed (knots)

The dependency of the required power to propel the ship from the ships displacement to the power of $2/3$ signifies an almost 7% reduction in fuel consumption for a 10% weight reduction. At the same time, the required power is related to the cubed speed of the ship. The fuel consumption of ships is therefore dramatically turning upwards with higher speeds. High-speed ferries, therefore especially consider light-weighting technologies. This means in turn, that *“Reducing navigation speed by 10% would lessen fuel consumption by 10% to 20% even with the prolonged travelling time required to cover the same distance. Though, it is not necessarily consistent with the growing demand for faster transportation service in the modern society”* [SOF 2000]. For a given speed however, the fuel consumption can, besides the hull and propeller shape, be mainly influenced by the displacement of the ship.

5.4.3 Data sources

5.4.3.1 Relative energy savings

The life cycle costs and energy consumption of three different high-speed ferries have been analysed by [KTH & ETH 2002]: “*The main physical difference between the different versions is their weight.*” “... *the same service in terms of payload, range and speed is chosen to enable a comparison.*” This means the required engine power is reduced for the lightweight structure ship and the fuel consumption can be decreased. In this analysis, the total engine power rating of the lighter versions has been downgraded, with these ships still performing the strived speed of 42 knots. Fuel savings turn out to be around 7% for a 10% weight reduction, which confirms the relationship of the admiralty coefficient.

For cargo ships, however, the relative energy savings refer to the total ship displacement. Since a weight reduction is generally only achieved at the ship itself, a 10% ship-weight reduction stands for a much smaller weight reduction of the total displacement. If the ship weight as assumed accounts for about 20% of the total displacement, a 10% ship-weight reduction results in a 2% reduction of the total displacement and only 1.4% energy savings.

Though energy savings can principally be achieved for weight reduced container ships or tankers, a weight reduction is rather used for carrying a higher payload ([Blohm & Voss 2003]). Therefore, in theory, less ships would be needed to transport the same amount of goods for the same distance. For ferries, a weight reduction is normally used to achieve higher speeds, which however, would change the functional unit for a comparison. The ship weight can in many cases also not be easily reduced, because ships require ballast to operate safely. In many cases half of a voyage must be undertaken in ballast to compensate for the absence of cargo. A weight reduction for a cargo ship in almost empty condition would only create a need for more ballast and therefore no energy savings could be achieved. This is assumed to be the case for a tanker which will be fully loaded one way, but return empty or in ballast.

In the loaded condition, however, the lighter weight of the ship could be used to increase the deadweight tonnage and the total performance of the ship in terms of t-km or t-h can be improved. Depending on logistics, energy savings can be achieved by a higher payload, because less ship-km or ship-hrs will be required to transport the same amount of goods for a given distance. This means that 10% energy will be saved by a weight reduction of the ships gross weight of 10%. Thus 2% energy savings will be achieved for a 10% ship weight reduction if the ship weight accounts for 20% of the total gross weight. The relative energy savings as used in this study are resumed in Tab. 14. The weight of passengers is neglected, the ship and gross weight of passenger ferries is thus assumed to be equal.

Tab. 14: Relative energy savings for cargo ships

	Savings by weight reduction	Savings by higher payload
% energy savings per 10% gross weight reduction	7%	10%
% ship weight of total gross weight	20%	
% energy savings per 10% ship weight reduction	1.4%	2%
Operation share for Container/ General cargo ships	20%	80%
Average savings per 10% ship weight reduction	1.9%	
Operation share for Tankers	0%	50%
Average savings per 10% ship weight reduction	1%	
Source: IFEU assumptions based on [KTH & ETH 2002] [NPS 2004]		IFEU 2004

5.4.3.2 Fuel consumption

The life-time fuel consumption for the different ship types is an important parameter in the calculation of life-time energy savings from the relative energy savings derived above. The fuel consumption of commercial marine vessels has been analysed in detail by [EPA 2000]: *“Regression analysis indicates that fuel consumption is inversely related to fractional load² ...”* *“Ideally, rated horsepower would be more closely related to the maximum loaded weight of the ship (i.e., empty weight + payload) but data on empty weight was not available for a large fraction of the data records, and only deadweight (DWT) data is constantly available”* ([EPA 2000]). The specific fuel consumption is thus expressed in [g/kW-h] as a function of the fractional load:

$$FC = 14.1205 (1/FL) + 205.7169$$

with
 FC: Fuel Consumption (g/kWh)
 FL: Fractional load (%)

The engine power (kW or hp) essentially depends on the ship type and weight and the fractional load on the stage of the journey (mainly cruise). The fractional load during the cruise is 80% according to [EPA 2000]. The average horsepower can be calculated from a regression line as a function of deadweight tonnage (DWT) as follows ([EPA 2000]):

Container ships	HP = 2581 + 0.719 (DWT)
General cargo ships	HP = 3046 + 0.288 (DWT)
Tankers	HP = 9070 + 0.101 (DWT)

with
 HP: Horse Power rating
 DWT: Dead weight tonnage

² Fractional load is equal to actual engine output divided by rated engine output

The weight of the steel version high-speed ferry (2000 t) is used for the exemplification of a normal speed passenger ferry. According to [EPA 2000] data, the average horsepower of passenger ferries is 2'415 ([EPA 2000]). This is almost 7 times lower engine power as for high speed ferries (about 16'400 HP). The huge difference can be explained by the required power being related to the cubed speed, thus much higher engine power being required for higher speed.

5.4.4 Life-time energy savings

Cargo ships

The life-time operational hours have been estimated: According to the association of German Ship Owners ([VDR 2003]) large ocean vessel engines are almost continuously running, except for about 45 days per year loading and unloading in a port. Lower values of around annual 250 days at sea can be found in other studies ([SOF 2000])³. Therefore 300 annual days at sea are used. This results in 7680 hrs per year for about 25 years average use. The life-time operation is therefore about 180'000 hrs for all three ship types.

For sea freight containers, less annual days at sea can be expected, due to time consuming loading and unloading as well as forwarding. Half the annual days at sea are therefore assumed. The service life of a sea freight container is also assumed to be lower, compared to vessels. According to depreciation tables, half the service life of ocean vessels is assumed, so that overall life-time energy savings for a 100kg weight reduction of a sea freight container are (as for air freight containers) in the range of 25% of the life-time energy savings for a container ship (around 66 GJ/100kg).

Tab. 15: Exemplification for indirect energy savings of cargo ships

	Container ship	General cargo ship	Tanker
DWT	20'000	20'000	100'000
HP	16'961	8'806	19'170
Fuel consumption (t/hr)	5.1	2.6	5.7
Life-time final energy savings (GJ/100kg)	233	121	28
Life-time primary energy savings (GJ/100kg)	268	139	32
Source: IFEU calculation based on [EPA 2000]			

Passenger ships

Life-time energy savings of high speed ferries can be calculated from the annual energy consumption as stated in the life-cycle analysis of three different ferries by [KTH & ETH 2002]. In this case study, the total engine power of the lighter versions has been downgraded, with these ships still performing the strived speed of 42 knots. A 20 year life-time is assumed.

³ "To calculate the average days at sea of other vessel types, the average load utilization is set at 80% for the three major shipping routes between Asia, North America and Europe, and at 60% for other shorter distances. The average number of days at sea is calculated to be approximately 251 days/year/ship."

Tab. 16: Use pattern and total annual operation hours for ferries

Season	Month	h per day	Total days
Summer	May - September	18	140
Winter	October - April	12	160
January		Maintenance (yearly docking)	
Total annual running hours		4'440	
Source: [KTH & ETH 2002]			IFEU 2004

The life-time primary energy savings turn out to be in the range of 1'600 GJ (Tab. 17) which is far higher as for cargo ships and road vehicles but considerably lower as for planes. High-speed ferries can achieve very high absolute savings due to the fuel consumption being related to speed to the power of three. For normal-speed passenger ferries, the same annual use pattern as for high speed ferries (Tab. 16) is used. Normal speed passenger ferries, however, achieve lower fuel savings (Tab. 18).

Tab. 17: Life-time primary energy savings for high speed ferries

	Steel version	
Total weight	2030t	
Annual energy consumption	2'074'425	
	Aluminium version	Composite version
Total weight	1425t	1439t
Annual energy consumption (GJ)	1'649'760	1'649'760
Relative energy savings	7%	7%
Life-time final energy savings (GJ/100kg)	1404	1437
Life-time primary energy savings (GJ/100kg)	1614	1652
Source: [KTH & ETH 2002] and IFEU assumptions		
IFEU 2004		

Passenger cruise ships are in size and engine power rather similar to the cargo vessels analysed in this chapter, but as for the passenger ferries, the weight of passengers can be neglected. Also the annual operation hours are rather in the range of passenger ferries and therefore lower as estimated for cargo vessels. The life-time primary energy and CO₂ savings will therefore be in the range between passenger ferries and general cargo vessels.

Tab. 18: Life-time primary energy consumption for passenger ferries

	Passenger Ferry
DWT	2'000
HP	2'415
Fuel consumption (t/hr)	0.7
Life-time final energy savings (GJ/100kg)	104
Life-time primary energy savings (GJ/100kg)	120
Source: [EPA 2000] and IFEU assumptions	
IFEU 2004	

Overview

Life-time primary energy savings by a weight reduction of 100kg are outstandingly high for high-speed ferries. This is due to the high absolute fuel consumption which in turn depends on the total vehicle weight. Energy savings for normal speed passenger ferries are far lower and rather in the range of normal cargo ships.

For cargo ships, the potential indirect energy savings by an additional load are generally higher as potential direct energy savings. The highest savings can be found for container ships with a high HP per DWT ratio. Lower savings in turn have been found for tankers with a lower HP per DWT ratio and half of the trips operating in ballast. Despite fewer annual days at sea and a shorter service life, sea freight containers show higher life-time energy savings as tankers, mainly due to the higher load factor of container ships.

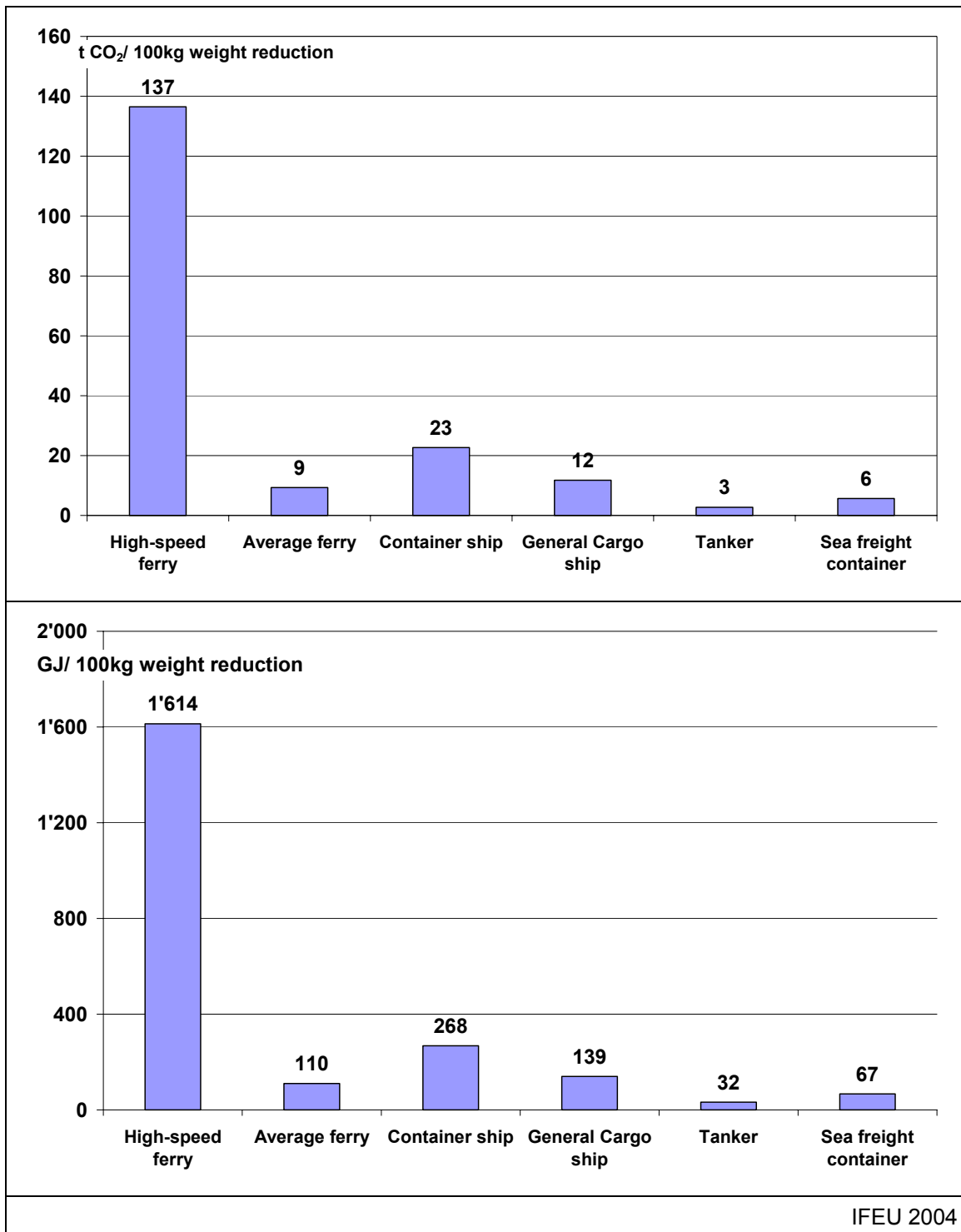


Fig. 14: Life-time energy and CO₂ savings for ocean vessels

5.5 Classification of life-time energy savings

With the data and results presented in this and the first study, figures on energy savings by light-weighting for the most important means of transport are available. The data show life-time energy savings on different scales. Three different groups in terms of order of magnitude for life-time primary energy savings can be identified. To allow for a visual comparison aggregated vehicle groups have been plotted on a logarithmic scale (Fig. 15).

- The gross of the considered vehicle (all road and rail vehicles as well as most ocean vessels) show life-time energy savings in a similar range. It has to be noted, however, that road vehicles, on the average, show somewhat lower energy savings compared to trains and ocean vessels. This is due the higher life-time mileage and operation hrs of the latter vehicle group.
- High-speed ferries show about 10 times higher energy savings if compared to ocean vessels and trains. This is due to the high specific energy consumption (related to v^3) and thus higher potential energy savings.
- Aircrafts again show about 10 times higher energy savings compared to high speed ferries and thus about 100 times higher energy savings compared to the gross of the vehicles.

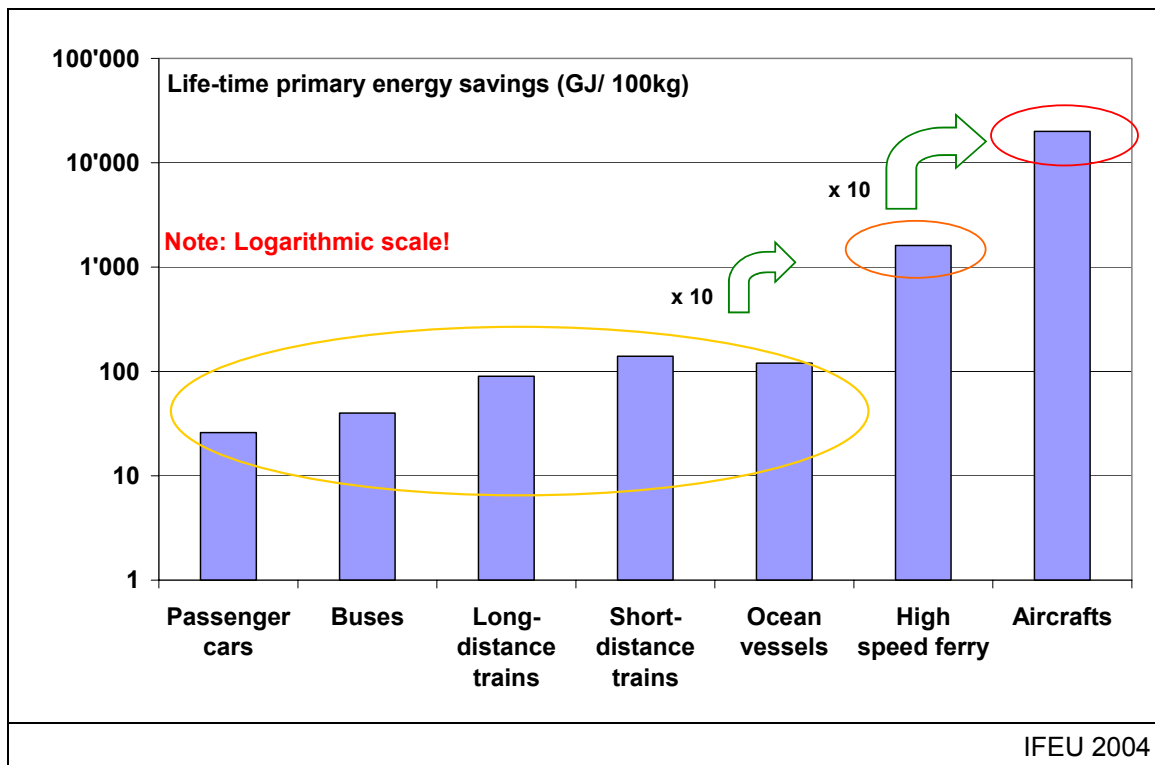


Fig. 15: Energy savings by vehicle groups compared (logarithmic scale)

6 Data ranges for the exemplified vehicles

6.1 Background and Methodology

In the first “Energy savings by light-weighting” study and in chapter 5 of this study, “average” vehicles have been identified and exemplified in respect to potential life-time energy savings by weight reduction. Apart from the vehicle types, especially the use of vehicles (driving cycle and performance) can be very different, depending on the respective countries and vehicle owners. These differences are also influenced by the standard of infrastructure and therefore exist also between industrialised and developing countries. The existence or absence of motorways and well paved roads and the general level of traffic have an influence on the driving pattern as well as the annual performance.

Also within the same region considerable variations in vehicle use (especially for passenger cars) can be found. An exemplification of the range for passenger cars has already been undertaken in the first part of the study. A vehicle with a very low mileage and an assumed average use (represented by the NEDC cycle) has been compared to an urban vehicle with a very high mileage (e.g. a taxi). The difference between both vehicles was found to be in the range of 10 times higher savings for the “taxi” if compared to a low performance vehicle (e.g. second car).

Variability significantly affects the results in respect to weight induced energy savings. In addition to the variability, data uncertainties have to be taken into account. “*Variability is understood here as stemming from inherent variations in the real world, while uncertainty comes from inaccurate measurements, lack of data, model assumptions, etc. that are used to ‘convert’ the real world into LCA outcomes*” ([Huijbregts 2001]). Here we aim to address variability and uncertainty in a single approach. Both arise in respect to data for the two main parameters,

- for the specific energy savings as well as the
- average life-time performance of the identified vehicles.

The sensitivity to variability and uncertainty in the input data has thus been calculated as a data matrix for each vehicle (see annex 9.1). In addition to the possible range of life-time energy savings, possible cases have been selected, marked and described. It has to be noted however, that these cases reflect rather extreme values on the two ends of the spectrum. They cannot be considered to reflect representative and average values for a taxi, company car, delivery truck, etc.

6.2 Data ranges exemplified

The spectrum of life-time energy savings as diagrammed in Fig. 16 and Fig. 17 shows a considerable range. For most road vehicles data uncertainties and variability cover an equal spectrum. Only city buses seem to have generally higher life-time energy savings due to the combination of high performance and urban use.

Generally, a high mileage, which in most cases occurs in heavy commercial use, will result in high energy savings. Private vehicles may in some cases have a very low mileage and therefore may potentially have among the lowest life-time energy savings. Only with the performance in the same range, specific energy savings are of importance. In this case vehicles with frequent accelerations show higher energy savings (e.g. city buses compared to long-distance buses).

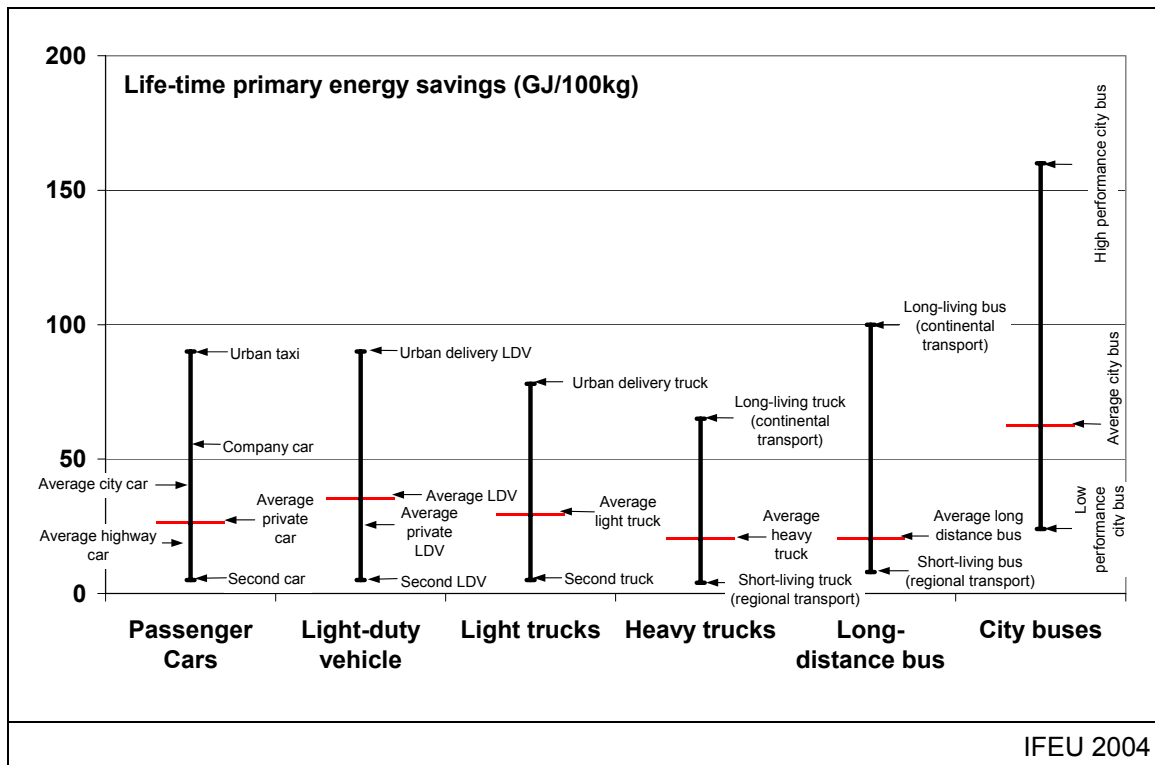
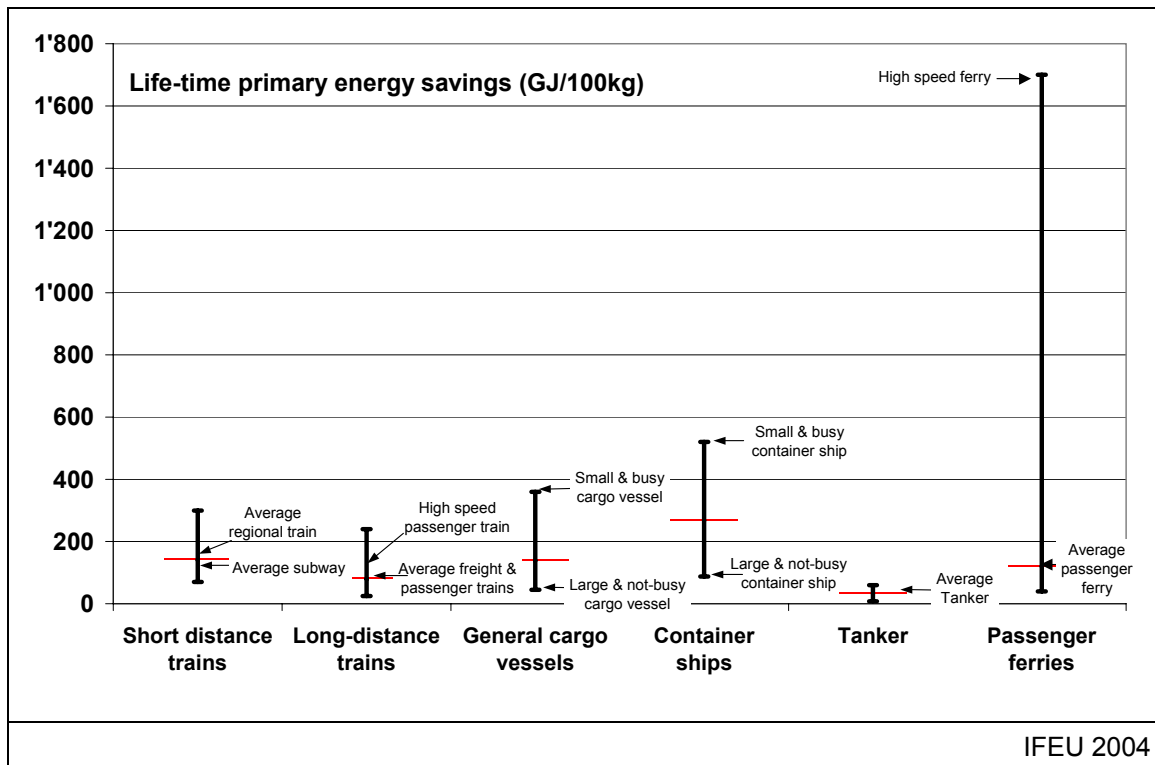


Fig. 16: Data ranges for road vehicles

Also other vehicle cover a similar range of potential energy savings. Again short distance trains can show higher than average life-time energy savings due to their combination of frequent acceleration and high total mileage. Generally commercial vehicles can be expected to have a higher performance and thus higher energy savings.

In the case of aircrafts, though short-distance aircrafts have higher energy savings per flight distance, long-distance aircrafts show higher overall energy savings due to their higher total performance in terms of miles and hours in the air.



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Fig. 17: Data ranges for rail and sea vehicles

Tab. 19: Vehicle examples for high and low life-time energy savings

	Higher savings	Lower savings
Road vehicles (Private and commercial)	<ul style="list-style-type: none"> • Taxis • Company cars • City buses • Delivery vehicles/ trucks 	<ul style="list-style-type: none"> • Average private cars • Second cars • Heavy trucks • Long-distance buses
Rail vehicles (All commercial)	<ul style="list-style-type: none"> • Subways/ Regional trains • High-speed trains 	<ul style="list-style-type: none"> • Average long-distance trains
Ships (All commercial)	<ul style="list-style-type: none"> • High-speed ferries • Container ships 	<ul style="list-style-type: none"> • Tankers
Aircrafts (All commercial)	<ul style="list-style-type: none"> • Long-distance 	<ul style="list-style-type: none"> • Short-distance

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7 Potential global energy savings by light-weighting

A weight reduction of all globally used vehicles would result in a reduction of the global transport energy consumption and CO₂ emissions. The global potential for such energy savings will be assessed in different scenarios based on the analyses of energy savings by weight reduction in chapter 5 and in the first study as well as an estimate on the weight reduction potential of the different vehicles.

Thereby different vehicles as well as different regions will be distinguished. This procedure shows the overall ecological relevance of light-weighting. The analysis follows a top down approach, meaning that the approach begins at the highest conceptual level and works down to the details. In this case the highest conceptual level are figures on the transport energy consumption for different economic regions for the year 2000.

7.1 Approach and scope definition

Approach

The global transport primary energy consumption and its development are influenced by a complex range of factors. The composition of a vehicle fleet, for instance, is constantly changing because new vehicles are introduced into the fleet, while old vehicles are put out of operation. If the new vehicles have a fuel consumption different from older vehicles, the specific fuel consumption of the fleet will be constantly changing as well. This may be due to a range of different technical changes such as engine and drive train improvements, aerodynamics, weight reduction, etc.

A weight reduction, amongst others, affects the specific energy consumption of the considered transport vehicles. If new vehicles are, in addition to other technical changes, also weight reduced, an additional change in energy consumption occurs. To separate changes in the energy consumption by the introduction of average new vehicles from changes by such an additional weight reduction, both cases will be considered in a two step calculation. The first step calculates the transport energy consumption in 2000 by a fleet with the specific energy consumption of average new vehicles. The second step considers the energy consumption by a fleet of additionally weight reduced new vehicles.

In addition to technical changes, however, also changes in the modal split, total transport performance, vehicle stock, etc. occur in the development over time. These changes depend on a range of not only technical, but also political, economical and sociological parameters. These parameters are difficult to predict and will therefore not be considered in this study.

To concentrate on the desired outcome, all scenarios assume an instant change in the vehicle fleet and thus use the transport performance and modal split of the basic year 2000. In reality the specific energy consumption of new registrations will only after several years become the average specific energy consumption of the fleet. This delay depends on the useful life of the vehicles.

Assuming a constant transport volume, modal split and no further efficiency improvements for new vehicles these savings can be expected to occur after a complete replacement of the current fleet. An almost complete replacement of all vehicles will be completed after say 40 years. For certain vehicles (e.g. road vehicles) and in some regions (e.g. OECD) an almost complete replacement of the entire fleet can be expected even earlier.

Scenarios

The calculation of potential energy savings by a weight reduction is undertaken in three steps (Fig. 18), all of which are referring to the vehicle stock composition and transport performance of the basic year 2000. First of all, the transport primary energy consumption and CO₂ emissions of the basic year 2000 are differentiated by transport mode and vehicle type. This will be referred to as the **Baseline** of the calculation. Two scenarios will be calculated relative to this baseline.

a) **Average new vehicles scenario:** The total transport primary energy consumption and CO₂ emissions will be calculated for an assumed fleet of vehicles with the specific energy consumption of average new registration for the basic year 2000. All other parameters like the total transport performance will be maintained. The energy savings of this assumed fleet (compared to the baseline) can be attributed to a range of different factors. The new vehicles scenario indicates the energy consumption which can be expected without further interventions and efforts in favour of light-weighting. This scenario refers to the average specific energy consumption of new vehicles. Some of these new vehicles may already use state of the art light-weighting technology. On the average, however, a further weight reduction will be possible.

b) **Weight reduction scenario:** The total transport primary energy consumption and CO₂ emissions will now be calculated for an assumed fleet of additionally weight reduced vehicles for the basic year 2000. This time all vehicles will be assumed to be weight reduced as much as state of the art technology allows for. A top runner approach is used to define the state of the art potential for weight reduction: The most weight reduced comparable new vehicle will be used as the reference for an estimation of the weight reduction potential of the average new vehicles. This time all energy savings can be attributed to a weight reduction.

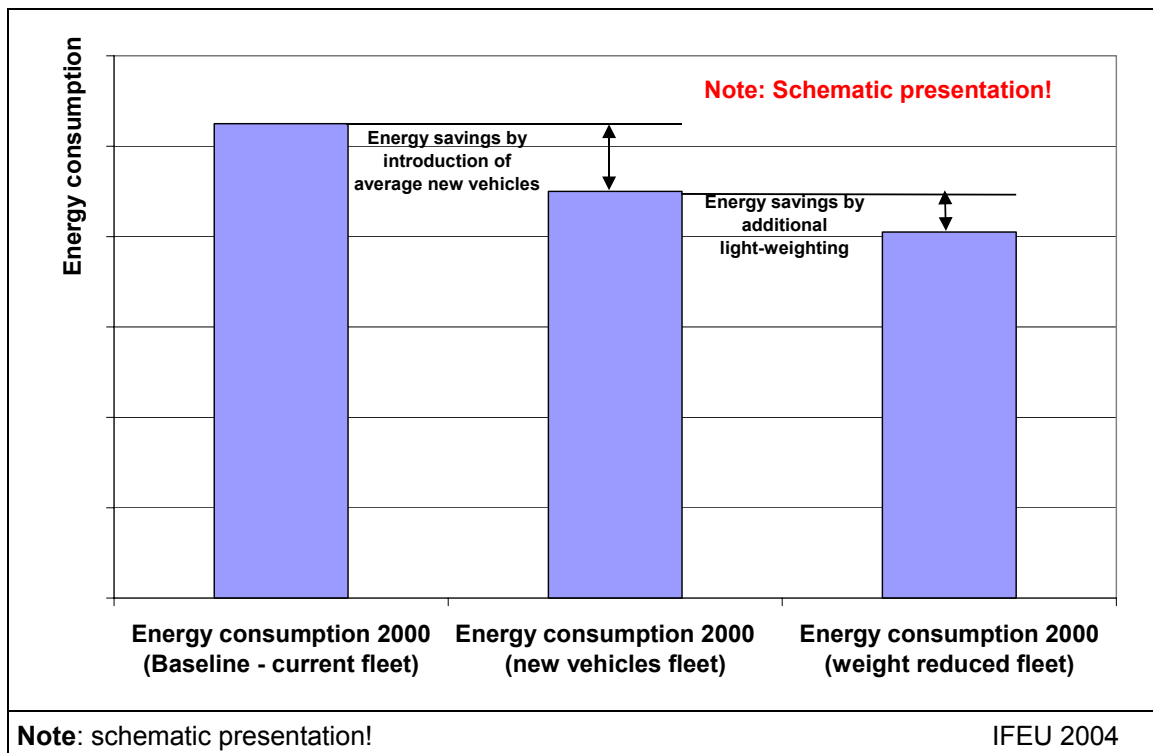


Fig. 18: Schematic presentation of different scenarios

Scope definition

A clear **definition of the baseline and the different scenarios** is essential to ensure the plausibility and utility of results. Guidelines and Standards for the quantification of GHG reduction projects have been formulated by [WRI & WBC 2003]. Such projects aiming at the reduction of GHG emissions are supposed to calculate reductions “... *relative to what emissions would have been in the absence of the project.*”

The emissions reduction which is achieved by the project (in this case an additional weight reduction of all vehicles) is therefore calculated as the difference between the emissions of the project scenario (additional light-weighting of all new vehicles) and the “business as usual” scenario (a fleet of average new vehicles). It has to be secured, however, that the project scenario only takes into account additional measures (additional weight reduction) which are not part of the business as usual scenario (weight reduction of average new vehicles).

The reduction of final energy, achieved in respect to a defined transport performance, can be defined as a **primary effect** of the vehicle weight reduction (Tab. 20). This is also referred to as **final energy savings**. Additional energy savings achieved in upstream processes (pre-chain) can be referred to as **secondary effects**. Primary and secondary effects combined add up to primary energy savings, which will be used for the assessment of the scenarios.

Tab. 20: Primary and secondary effects of different scenarios

Baseline: Primary energy consumption and CO ₂ emissions of all transport vehicles in 2000		
Scenarios	Primary effect	Secondary effect
Average new vehicles scenario	Final energy savings by introduction of average new vehicles	Prechain energy savings
	Primary energy savings by introduction of average new vehicles	
Light-weighting scenario	Final energy savings by state of the art light-weighting in all new vehicles	Prechain energy savings
	Primary energy savings by state of the art light-weighting in all new vehicles	

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The “project assessment boundary” by definition “... *encompasses all relevant primary and secondary effects that will be taken into account in the project calculation*” ([WRI & WBC 2003]). In this study, the global transport primary energy consumption of all transport vehicles will be taken into account. Energy savings relate to the same assessment boundary.

7.1.1 Energy and vehicle coverage

The energy consumption will be analysed based on statistics by the International Energy Agency (IEA). The IEA compiles energy data differentiated by energy carrier (various types of coal, oil products (including gasoline and diesel fuel), gas, combustibles and electricity) and transport mode (Air, Road, Rail, Inland Navigation, International Bunkers). All energy carriers, thus the total transport energy consumption, as used in the IEA statistics have been taken into account in this report. To allow for a comparison between energy carriers all energy consumption has been converted to the same energy unit (TJ) and into primary energy, taking into account the efficiency of the upstream processes (as derived in chapter 4).

Pipelines are not taken into account though their primary means is the transportation of goods. Pipelines, however, are not moving vehicles, and therefore no energy savings by a weight reduction can be achieved. Regional transport energy consumption therefore includes the following energy consumption as defined by [IEA 2003a]:

- **Road vehicles:** *“All fuels used in road vehicles (including military) as well as agricultural and industrial highway use. Excludes motor gasoline used in stationary engines, and diesel oil for use in tractors that are not for highway use”*
- **Rail vehicles:** *“All quantities used in rail traffic, including industrial railways”*
- **Air:** *“Deliveries of aviation fuels to international civil aviation and to all domestic air transport, commercial, private, agricultural, military, etc. It also includes use for purposes other than flying, e. g. bench testing of engines, but not use of fuels for road transport by airline companies”*
- **Water:**
 - Ocean vessels (International marine bunkers): *“International marine bunkers cover those quantities delivered to sea going ships of all flags, including warships. Consumption by ships engaged in transport in inland and coastal waters and by fishing vessels in all waters is not included.”*
 - Inland navigation: *“including small craft and coastal vessels not purchasing their bunker requirements under international marine bunker contracts.”*

The total energy consumption of the respective sectors has been differentiated by the vehicle categories as stated in Tab. 21. The share of other vehicles (e.g. motorcycles, private and military planes) of the above defined energy consumption is assumed to be negligible. For inland navigation no energy savings by light-weighting have been studied, but the energy consumption will be displayed as part of the water transport energy consumption. The considered transport modes and vehicle types follow the classification of the vehicles considered in the “Energy savings by light-weighting” studies ([IFEU 2003a] and this study), so energy savings by light-weighting can be easily calculated with data from these studies.

Tab. 21: Overview on considered vehicle types

Transport mode	Vehicle type	Main energy type
Road	Passenger cars	Gasoline
		Diesel
	Light-duty vehicles and trucks	Gasoline
		Diesel
	Articulated trucks/Truck-Trailer	
	Long distance buses	
City buses		
Rail	Short distance trains (Urban transport)	Electricity
	Long distance passenger trains	Electricity
		Diesel
	Long distance freight trains	Electricity
Diesel		
Air	Long- and short distance aircrafts	Kerosene/ Aviation gasoline
Water	Inland navigation	Heavy Fuel Oil/ Diesel
	International marine bunkers	
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7.1.2 Geographical coverage

The analysis takes into account the global transport primary energy consumption. The scenarios will be calculated for different regions. This analysis follows the geographical coverage of the IEA statistics (Tab. 22). The OECD countries within the regions (e.g. Europe, Pacific) will be treated separated from the non-OECD countries in the same regions. This is due to the significance and similar economic conditions of the OECD countries.

Tab. 22: Geographical coverage

Region (IEA)	Sub-Region	Countries
OECD	North America	USA, Canada, Mexico
	Europe	EU-15 + Czech Republic, Hungary, Norway, Poland, Slovak Republic, Switzerland, Turkey
	Pacific	Australia, Japan, Korea, New Zealand
Non OECD Europe		Albania, Bosnia and Hezegovina, Bulgaria, Croatia, Cyprus, Gibraltar, Macedonia, Malta, Romania, Serbia and Montenegro, Slovenia
Former USSR		Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzsbekistan
Middle East		Bahrain; Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, UAE, Yemen
China		
Other Asia/ Oceania		excluding China
Africa		
Latin America		excluding Mexico
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7.2 Baseline energy consumption (2000)

7.2.1 Methodology

7.2.1.1 Energy content

The vehicles considered in this study use a range of different energy carriers. To allow for a comparison between different energy carriers all energy consumption will be converted to the same energy unit (TJ or PJ) and CO₂. The average energy content of the different energy carriers can be assessed based on data from the IEA and the EU. The energy content of petroleum products is far more consistent than for coal products. Since Coal products account for only 0.38% of transports global final energy consumption, data uncertainties for coal products will not produce significant changes in the results. Petroleum products account for about 95% of transports global final energy consumption and are therefore most important for the final results. The average energy content which is used in the EU statistics will also be used for converting kt fuel consumption into TJ energy consumption. Furthermore, primary energy and CO₂ emissions are calculated as derived in chapter 4 to take into account the different efficiencies in energy supply of the respective energy carriers.

Tab. 23: Energy content of different energy carriers (TJ/kt)

Energy carrier	Value EU	Value IEA	AG Energiebilanzen	In this study
Coking Coal	28.5	> 23.9	28.7	28
Other Bit. Coal		>23.9	38	38
Sub-Bit. Coal		17.4-23.9		20
Lignite	15.8		9.2	16
Oven and Gas Coke				30
Pat. Fuel and BKB				30
Crude Oil	42.2		42.7	42.2
LPG & Ethane	46.0		46.6	46.0
Motor Gasoline	44.0		43.5	44.0
Aviation Gasoline			43.0	43.0
Jet Fuel	43.0			43.0
Kerosene	43.0			43.0
Gas/ Diesel	42.3		43.0	42.3
Heavy Fuel Oil			40.4	40.4
Other Products			40.0	40.0
Source: [IEA 2003a]; [EC 2002a] & [AGEB 2004]				IFEU 2004

7.2.1.2 Differentiation of energy consumption

Transport energy consumption figures can be found in a variety of reports for different geographical levels, e.g.

- world-wide acting organisations like the International Energy Agency (IEA) or the United Nations (UN),
- regional organisations like the European Union (EU), the Organisation for Economic Cooperation and Development (OECD), the Asia-Pacific Economic Cooperation (APEC), etc. or
- national statistics, like Bureau of Transport Statistics (BTS) for the USA.

The baseline final energy consumption this report very much follows the IEA energy statistics and their categories. The energy consumption by energy carrier and transport mode, however, has to be further differentiated by vehicle types. The global overview shows that road transport is by far the most important transport mode in terms of energy consumption. This makes a detailed differentiation of road transport energy consumption necessary.

For the differentiation a range of assumption of certain energy carriers as stated in the IEA statistics being used for certain vehicle types (even if not explicitly indicated in the statistics) are used:

- All electricity and coal not allocated to any transport mode is consumed by rail transport (Exception: Former USSR, where a share of electricity consumption is allocated to pipeline transport).
- All natural gas not allocated to any transport mode is allocated to pipeline transport
- All Heavy Fuel Oil not allocated to any transport mode is allocated to Inland Navigation.
- Diesel Fuel not allocated to any transport mode is allocated to rail transport and Inland Navigation with the share of 60% and 40% respectively (as derived from the statistical data for a selection of countries).
- Short distance passenger trains (subways and urban trains) use electricity only.

Road transport energy consumption can only in some cases be differentiated based on total fuel consumption statistics of a region. In many other cases, road transport energy consumption has to be differentiated according to motor vehicle statistics in exemplary countries. The motor vehicle fleet, however, has to be weighted according to specific fuel consumption and annual mileage. This can be achieved by using the unit 'equivalent cars': *"This relates the total consumption of motor fuels to a fictive stock of vehicles, measured in terms of a number of equivalent cars. The conversion of the actual stock of vehicles to the stock of equivalent cars is based on coefficients reflecting the average yearly consumption of each type of vehicle relative to that of cars."* ([WEC 2004]). The estimate of equivalent cars has been undertaken on the basis of data from the US and Germany. Though absolute values for specific fuel consumption and annual mileage may differ considerably for the regions, it is assumed that the relations between the absolute values and thus the ranking as equivalent cars is more or less consistent.

Tab. 24: Passenger car equivalents

Vehicle type	Annual fuel consumption (Equivalent to passenger cars)
Two- and Three-Wheeler	0.4
Passenger cars	1
Light-duty vehicles	2
Medium trucks	6
Heavy trucks	25
Buses	15
Source: IFEU estimate based on [BTS 2002b] and [IFEU 2000]	
IFEU 2004	

Rail transport energy consumption will be differentiated on the basis of rough estimates due to the small share of the global transport energy consumption.

Ocean vessels can not be easily differentiated by vessel type and region. This is due to the fact that the energy consumption statistics ([IEA 2003b]) and the vessel registration statistics are not always related. Ships are often bunkering fuel in other countries than registered. The world fleet will therefore be used to differentiate between vessel types. The respective shares will be used for all regions. Tab. 25 shows the shares of gross tonnage which is used as an assessment of marine bunker fuel consumption shares. Tankers and other bulk carriers account for over half of the registered gross tonnage and presumably also of the marine bunker fuel consumption.

Tab. 25: Differentiation of ocean vessels

Vessel type	Share of Gross Tonnage
Tankers/ Bulk carriers	56%
General cargo and other	30%
Container ships	10%
Passenger ships	4%
Source: [OECD 2004]	
IFEU 2004	

No long- and short-distance flights will be distinguished for **air transport** energy consumption. This is due to several reasons:

- Similar relative energy savings (about 9% for a 10% weight reduction) and therefore no quantitative differences for the result due to a differentiation.
- No good data available for the energy consumption share of long- and short-distance flight in the different regions.
- Difficult definition of long- and short-distance flights.

7.2.2 Global transport energy consumption and CO₂ emissions - Overview

According to IFEU calculations based on figures from the International Energy Agency ([IEA 2003a]), the global primary energy consumption in 2000 was around 396'000 PJ. Of this total energy consumption almost one quarter (23%) have been generated by transport. About one third have been generated by Industry and the rest originates from Households and other sources.

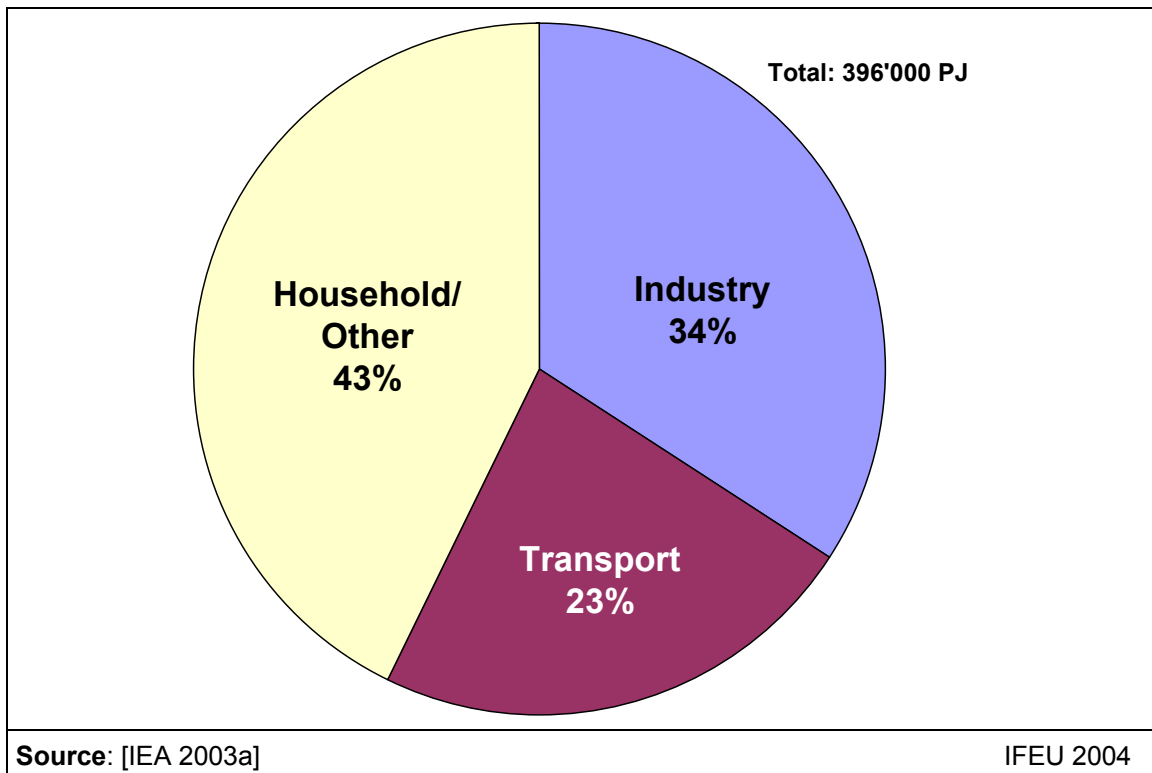


Fig. 19: Global primary energy consumption (2000)

The absolute transport primary energy consumption was around 94'000 PJ and CO₂ emissions almost 8'000 Mt in 2000. This figure excludes the pipelines. Road traffic accounted for about 75% of the global transport primary energy consumption and is therefore the most important transport mode in terms of energy consumption. All other transport modes, like air (12%), water (9%) and rail (4%), consume significantly less primary energy. Especially rail transport has a minor share of the worlds transport primary energy consumption.

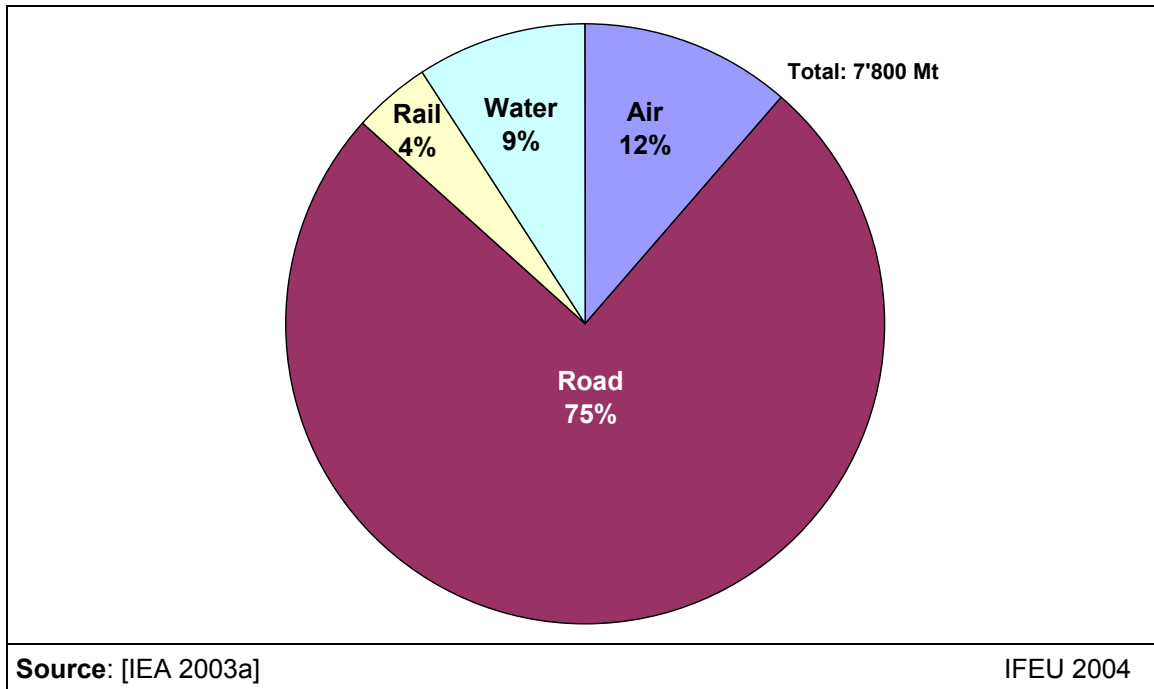


Fig. 20: Global transport CO₂ emissions by transport mode (2000)

The share of energy carriers of the global transport primary energy consumption shows that 75% are gasoline and diesel fuels which will be mainly used in road transport. The remaining diesel fuel will be used for railways and ships. Aircraft energy consumption is mainly in the form of jet fuel. Other energy carriers like electricity and coal have a much smaller share of the primary energy consumed by transport.

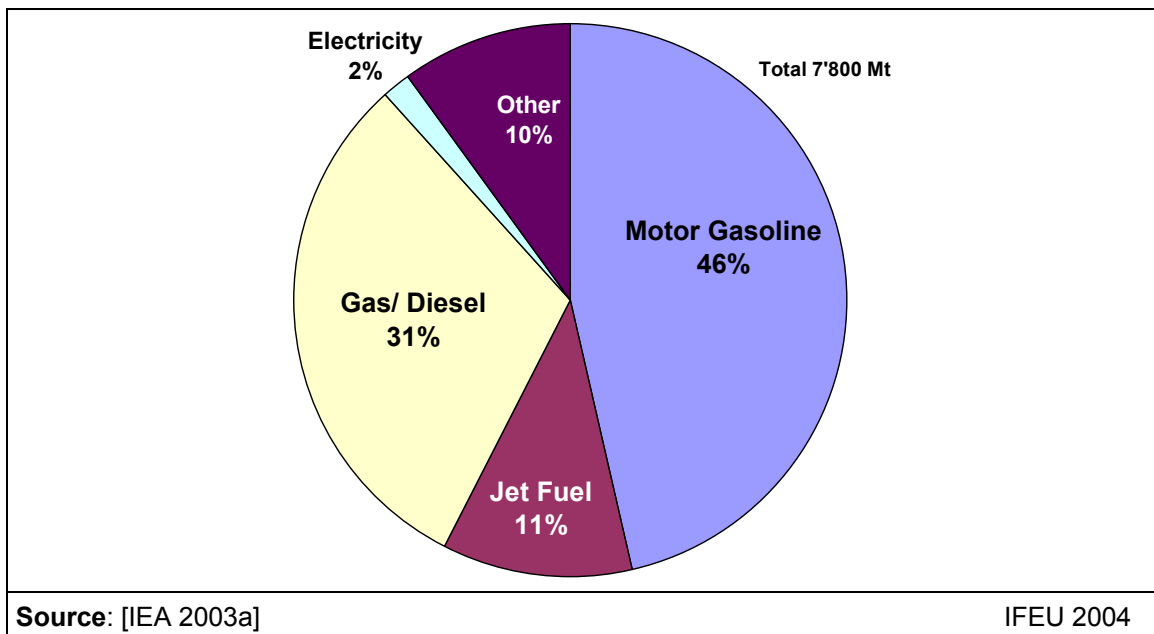


Fig. 21: Global transport CO₂ emissions by energy carrier (2000)

7.2.3 Regional transport energy consumption

The regional differentiation is dominated by the OECD countries, which are responsible for over two thirds of the global transport primary energy consumption and CO₂ emissions. Mainly Asia (Asia and China combined) also has a relevant share of about 14% transport related CO₂ emissions. Other regions have about similar smaller shares in the range of 3% (Africa) to 6% (Latin America).

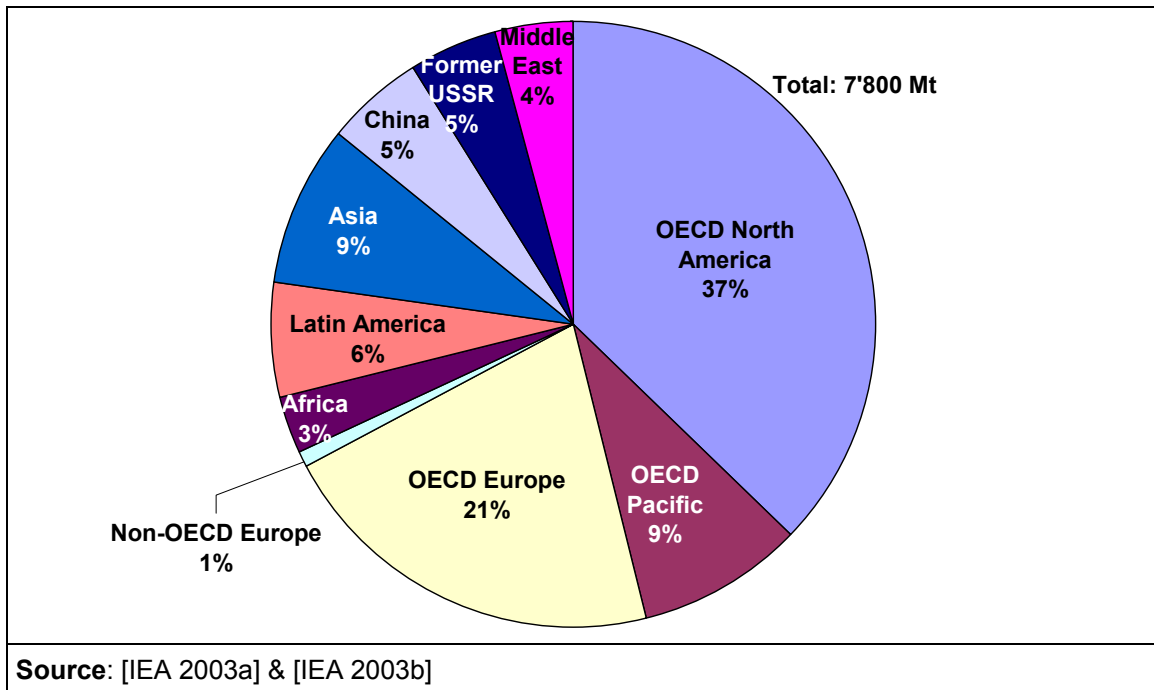


Fig. 22: Global transport CO₂ emissions by region (2000)

The overview figures in this section clearly show that the energy consumption in the OECD countries is dominated by passenger cars and light-duty vehicles (Fig. 24). Non-OECD countries show a much smaller share of these largely private vehicles. Here, in turn, public transport systems like buses (Africa, Asia) and rail transport (China, Former USSR) have a higher share. Differences in the shares of light- and medium trucks are significant, but may also be due to different vehicle definitions. Since relative energy savings can be expected to be in the same range, no quantitative differences will occur in the overall results. The differentiation methods and the respective data sources are highlighted in Tab. 26. A more detailed description of the differentiation can be found in the commented Annex (9.2).

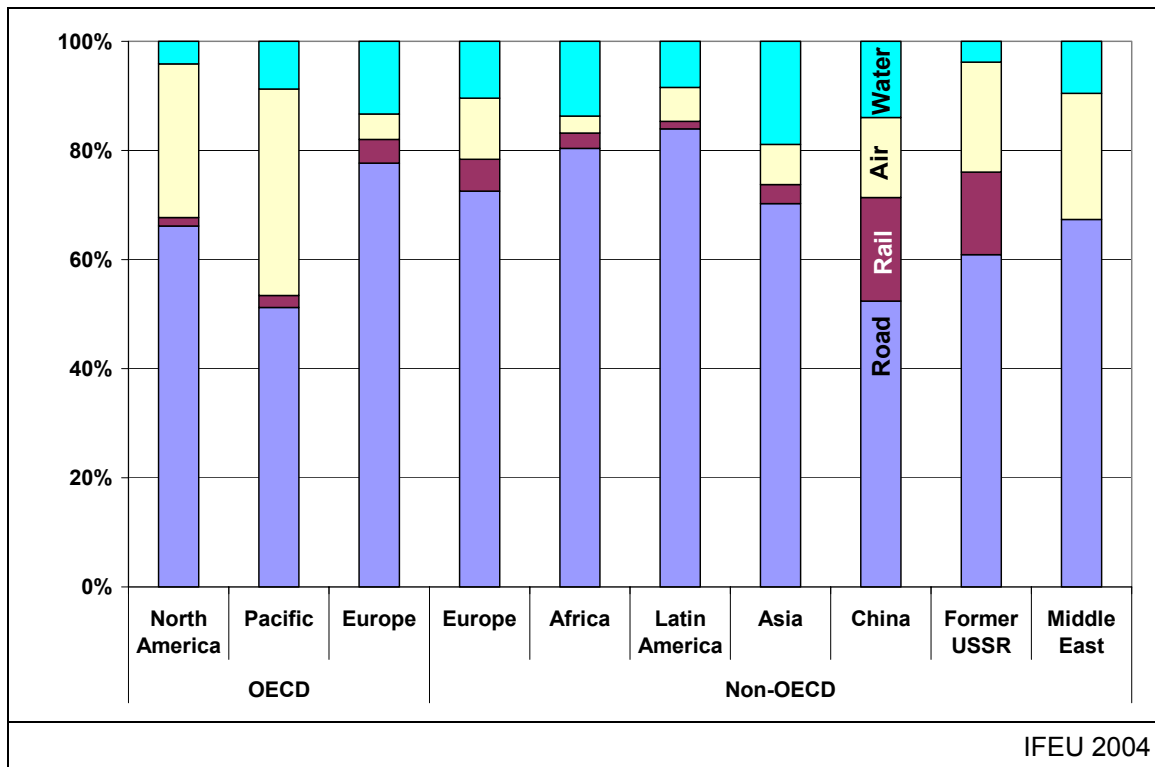


Fig. 23: Transport mode shares of regional transport primary energy consumption 2000

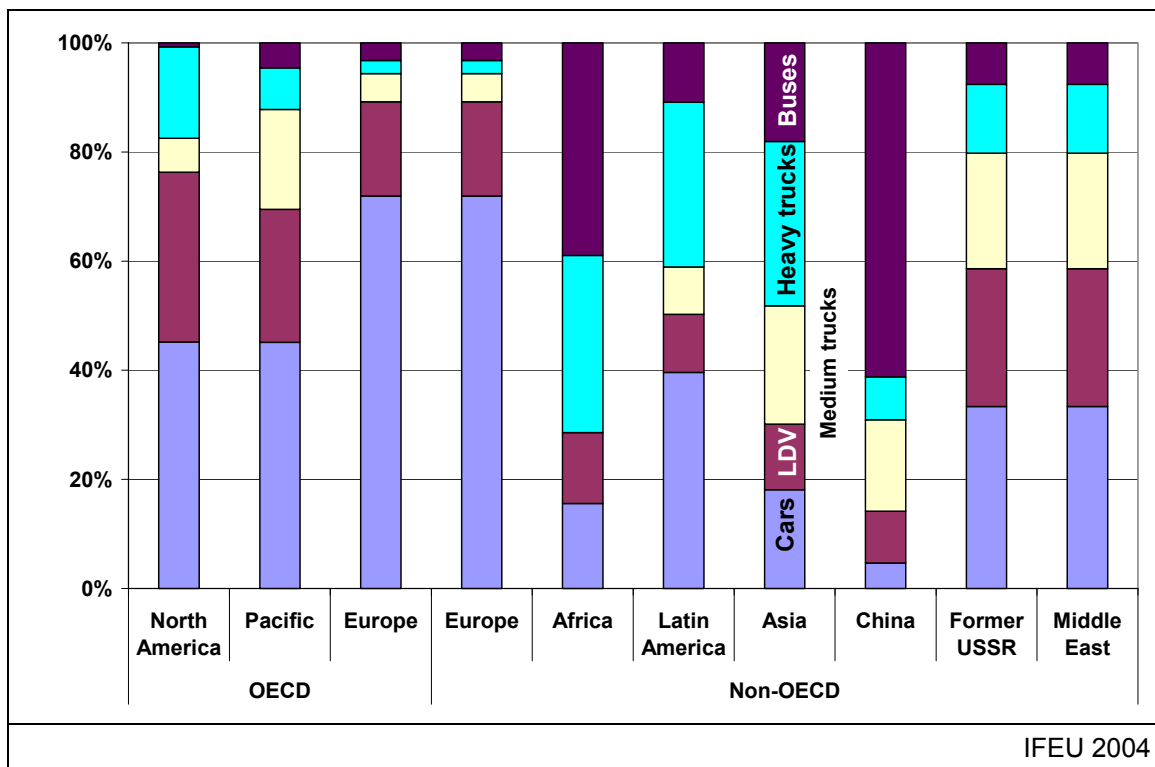


Fig. 24: Road vehicle shares of regional transport primary energy consumption 2000

Tab. 26: Differentiation of road transport energy consumption

Region	Differentiation	Sources
OECD North America	Energy consumption data from the U.S. Bureau of Transportation Statistics	[BTS 2002a]
OECD Pacific	Vehicle fleet statistics of Japan/ Australia	[AusStats 2002] & [JAMA 2003]
OECD Europe	EU vehicle fleet statistics	[EC 2002a]
Non-OECD Europe	As for OECD Europe	
Former USSR	Passenger car data for USSR and Goods vehicle data for other Former USSR countries	[CCFA 2003]
Middle East	As for former USSR countries	
China	Fuel consumption and vehicle fleet data	[CSEP 2001]
Other Asia/ Oceania	Vehicle fleet statistics for India & Indonesia	[GOI 2004] & [BPS 2004]
Africa	Vehicle fleet statistics for Ethiopia, South Africa, Uganda, Zambia & Zimbabwe	[AFREPREN 2003]
Latin America	Vehicle fleet statistics for Brazil	[ECEN 2003]
IFEU 2004		

7.3 Global transport energy consumption of new vehicles

The composition of a vehicle fleet is constantly changing because new vehicles are introduced into the fleet, while old vehicles are put of operation. If new vehicles have a fuel consumption different from older vehicles, the specific fuel consumption of the fleet will be constantly changing as well.

This chapter derives the energy consumption according to the average new vehicles scenario for an assumed fleet of vehicles with the specific energy consumption of average new vehicles. All other parameters like the transport performance (e.g. average payload) and mileage will be maintained.

7.3.1 Scope definition and Methodology

The energy consumption of an assumed fleet of average new vehicles (average new vehicles scenario) will be ascertained relative to the energy consumption of the current fleet (baseline). A detailed discussion of different approaches can be found in the commented annex (9.3). In this study, the relative change in the total energy consumption will be calculated based on two variables:

The first variable is the development of the specific energy consumption of new vehicles for different transport modes. This will be expressed as an annual efficiency improvement rate and some vehicles will experience greater annual efficiency improvement rates than other. A change in the specific energy consumption as used in this study refers to vehicle-km and therefore takes into account technical changes like

- engine and drive train improvements,
- change in aerodynamics,
- change in weight (light-weight materials vs. additional weight for safety and comfort features),
- change in engine power,
- etc.

The second variable has to reflect the age characteristics of the current vehicle fleet. The substitution of a comparably old fleet will result in greater changes in the transport energy consumption as for a comparably new fleet. The average age of the current vehicle fleet will be used.

A linear development of the specific fuel consumption (annual change rate) development can be assumed for an average age of a fleet of 15 years and less. The relative energy savings by the introduction of new vehicles can therefore be approximated as

$$RS = \text{Age} \times CR$$

with

RS: Relative savings (%) (New vehicles vs. average fleet)

Age: Average age of the current fleet

CR: Annual change rate of specific fuel consumption (%)

For older fleets (over 20 years), however, a progressive application of the annual change rate will be used.

7.3.2 Road Vehicles

Road vehicles are the most important transport mode in terms of energy consumption. Improvements in the fuel efficiency of comparable road vehicles can be observed constantly. The impact on the fleet, however, depends on consumer choice. In the USA no noticeable decrease in the average specific fuel consumption of new vehicles has been observed for passenger cars and light duty vehicles throughout the 1990s and most of 1980s. In turn “... ACEA has achieved improvements in new car CO₂ performance even with increases in other physical fleet characteristics” ([EC 2002b]).

7.3.2.1 Passenger cars

Annual change rate

Among the OECD countries, the USA and the EU have an outstanding share of the road transport and especially passenger car final energy consumption. ACEA data shows a significant decrease in the specific fuel consumption of EU-15 new vehicles in the past years ([EC 2002b]). This decrease is about 1.3% annually for gasoline and 2.1% annually for diesel cars. No significant change in the specific fuel consumption of US passenger cars has been observed throughout the 1990s ([BTS 2002b]). This may be due to a trend towards heavier vehicles with greater engine power. The larger Latin American Countries like Brazil have a moderate taxation on fuel, Argentina, Peru and Venezuela even subsidise their fuel. Exceptionally high taxation for fuels can be found in a range of smaller countries like Guatemala and Ecuador. The taxation shows a very small incentive for low fuel consumption vehicles. For passenger cars in Latin America therefore only a value of 0.4% as stated for light duty vehicles is used. For other regions a 1% annual fuel efficiency improvements is assumed. Higher values are used by [IFEU 2000], but similar values in the range of 0.8-1% by [IEA 1999].

Tab. 27: Annual specific energy consumption decrease for European Countries

% annual decrease	TREMOT	Dutch study	Hannover study	EU
Passenger cars	1,4%	0,8%	0,8-1%	0,8%
Light-duty trucks	1%	0,1%	0,8-1%	
Heavy duty trucks	0,5%	0,3%	0%	1,3%
Source: [IFEU 2000] & [IEA 1999]				IFEU 2004

Average age of fleet

“National comparisons suggest that the average age of passenger cars is correlated with GDP per capita” ([EEA 2002a]). For the EU, an average age of the fleet of just above 7 years is stated by the European Environmental Agency ([EEA]). “The average age of passenger cars in a selection of AC⁴s (covering more than 80% of the total car fleet) was around 11,5 years, ranging from 6.5 years in Slovenia to 15 in Bulgaria. ... This suggests that it takes longer for new vehicle technologies to penetrate into the car fleet in the ACs than in the EU, and that the vehicle fleet in the ACs probably has a worse environmental performance than that in the EU” ([EEA 2002b]). The value of 11.5 years average age of passenger cars is therefore used for non-OECD Europe.

⁴ Accession countries: Countries in the process for accession to the European Union.

The Bureau of Transportation Statistics ([BTS 2002a]) states the average age of the US passenger car fleet with 8.3 years, which will be used for OECD-North America. A similar value of 8 years will be used for the OECD Pacific region. The average age of passenger cars in Brazil ([ECEN 2003]) with 9.9 years is used to estimate energy savings by the introduction of new vehicles to non-OECD Latin America.

For the other, mainly not yet industrialised regions, a higher average age of the vehicle fleet can be assumed. As stated for some Former USSR countries: “*Although detailed data on the age distribution of vehicles are not readily available, the average age appears to be high, with a noticeable number of vehicles 20 years old or older*” ([WB 2003]). An average age of 15 years is therefore assumed for passenger cars in all other regions.

Overview

Tab. 28 sums up the variables and the total fuel consumption improvements for a fleet of new vehicles compared to the current fleet. High improvements can be expected in most non-OECD countries, due to their old vehicle fleet. Also Europe shows a significant improvement in the total fuel consumption, mainly due to the ACEA commitment. In the Americas, however, far lower improvements are expected, due to low fuel prices and young vehicle fleets.

Tab. 28: Fuel consumption change by the introduction of new passenger cars

Country/ Region	Annual improvement of specific fuel consumption	Average age of current vehicle fleet	Total improvement of annual fuel consumption
OECD-North America	0.0%	8.3	0.0%
OECD-Europe (Gasoline)	1.3%	7.1	9.2%
OECD-Europe (Diesel)	2.1%		14.9%
OECD Pacific	1.0%	8	8.0%
Non-OECD Europe	1.0%	11.5	11.5%
Former USSR	1.0%	15	15.0%
Middle East	1.0%	15	15.0%
China	1.0%	15	15.0%
Other Asia	1.0%	15	15.0%
Africa	1.0%	15	15.0%
Latin America	0.4%	9.9	4.0%
Source: IFEU 2004 from various sources			IFEU 2004

7.3.2.2 Light-duty vehicles and medium trucks

Annual change rate

As for passenger cars, data of the US Bureau of Transportation Statistics, indicates no significant change in the specific fuel consumption of new light-duty vehicles throughout the 1990s (about 0.2% annual decrease). The constant fuel efficiency of light-duty vehicles is supported by [IEA 2001]: „*Fuel economy for new light-duty*

vehicles has been nearly flat in most IEA countries since 1980, except for important improvements in the early 1980s and, in European countries, in the late 1990s. ... It appears that the voluntary commitment by European manufacturers to reduce CO₂ emissions in new cars by 25% by 2008 has begun to take effect: while car and light truck fuel economy in the United States remained flat in the late 1990s, it has sharply improved in most European countries since 1995. Whether this recent trend will continue is unclear..." [IEA 2001].

[IFEU 2000] and other European Studies ([IEA 1999]) assume about 0.8-1% annual fuel efficiency improvement. The average change rates for the annual fuel consumption of light-duty vehicles has also been estimated for different regions by [WEC 2003]. The value is between 0.4 (Pacific, Asia, North America) and 1.5% (Central & Eastern Europe, Former Soviet Union, Sub Sahara Africa). The low value for North-America and a value of 1% for Western Europe have also been proposed above. Higher values may also indicate that the average age of the fleet slowly decreases, as more and more new vehicles are introduced. The values, however, will be used for this analysis, because of the consistency with other data and good differentiation.

Tab. 29: Specific fuel consumption change of light-duty vehicles for different regions

Country/ Region	Specific fuel consumption 1995 (l/100km)	Annual average change rate
Western Europe	8.4	1.0%
North America	12.0	0.4%
Pacific OECD	12.1	0.4%
Former Soviet Union	10.0	1.5%
Central/ Eastern Europe	10.0	1.5%
Middle East/ North Africa	12.0	0.5%
Sub Sahara Africa	15.0	1.5%
South Asia	12.0	0.4%
China	13.0	0.4%
Other Pacific Asia	12.0	0.4%
Latin America	12.0	0.4%
Source: [WEC 2003]		IFEU 2004

Average age of fleet

The average age of light-duty vehicles in the US was 6.9 years in 2000 according to [BTS 2002a]. For Canada an average age of light vehicles of 7 to 8 years and for medium trucks about 10 years are stated by [TC 2000], which is in line with data from [BTS 2002a]. 8 years will therefore be used for OECD-North-America. The N1 vehicle age distribution for the EU ([RAND 2003]) indicates a similar range. Therefore 7 years will be used for the EU and the OECD-Pacific countries. The average age of "light-commercial vehicles" in Brazil seems to be only slightly higher with 8.3 years ([ECEN]). Medium trucks in Brazil, however, have an average age of 14.5 years. 10 years will be used as an average figure. For non-OECD Europe an average age of 11.4 years in 1996 is stated by [EEA 2003]. For all other non-OECD regions again 15 years as the average age of the vehicle fleet will be used.

Overview

Tab. 30 sums up the variables and the total fuel consumption improvements for a fleet of new vehicles compared to the current fleet. High improvements can be expected mainly for the Former USSR and Africa. Other regions show lower annual improvements of the specific fuel consumption.

Tab. 30: Fuel consumption change by the introduction of new light-duty vehicles

Vehicle	Annual improvement of specific fuel consumption	Average age of current vehicle fleet	Total improvement of fuel consumption
OECD-North America	0.4%	8	3.2%
OECD-Europe	1%	7	7.0%
OECD-Pacific	0.4%	7	2.8%
Non-OECD Europe	1.5%	11.4	17.1%
Former USSR	1.5%	15	22.5%
Middle East	0.5%	15	7.5%
China	0.4%	15	6.0%
Other Asia	0.4%	15	6.0%
Africa	1.5%	15	22.5%
Latin America	0.4%	10	4.0%
Source: IFEU 2004 from various sources			IFEU 2004

7.3.2.3 Tractor-Trailer/ Heavy trucks

Annual change rate

[VDA 2000] data indicate an average annual decrease of about 1% for heavy duty trucks. Other sources, however, assume that the potential for fuel consumption reduction for heavy trucks is rather limited: [IFEU 2000] uses a value of 0.5% annual decrease while other European studies ([IEA 1999]) estimate even less (0-0.3%). A conservative value of 0.5% will be used in this study for all regions.

Average change rate

The average age of the Canadian Heavy Truck fleet is between 7 and 8 years. For Brasil 14.5 years are stated by [ECEN 2003]. As generalisation 7 years will be used for the OECD regions and 14 years for the non-OECD regions.

Overview

Higher savings are expected for the non-OECD regions due to the older vehicle fleet.

Tab. 31: Fuel consumption change by the introduction of new heavy-duty vehicles

Vehicle	Annual decrease	Average age of fleet	Result
OECD-North America	0.5%	7	3.5%
OECD-Europe	0.5%	7	3.5%
OECD-Pacific	0.5%	7	3.5%
Non-OECD Europe	0.5%	14	7.0%
Former USSR	0.5%	14	7.0%
Middle East	0.5%	14	7.0%
China	0.5%	14	7.0%
Other Asia	0.5%	14	7.0%
Africa	0.5%	14	7.0%
Latin America	0.5%	14	7.0%
Source: IFEU 2004 from various sources			IFEU 2004

7.3.2.4 Buses

Annual change rate

The annual fuel consumption change is estimated to be in the range of heavy trucks. 0.5% will therefore be used in this study.

Average age of fleet

The average age of the Canadian bus fleet is about 8 years ([TC 2000]). This figure will be used for all OECD countries. Data from eastern European countries is in the range of 11 to 14 years (Tab. 32). 12 years will therefore be used for non-OECD Europe. Data from Brazil indicates 10 years average age ([ECEN 2003]) and will be used for Latin America. Other non-OECD countries are, as for heavy trucks, estimated to be in the range of 14 years.

Tab. 32: Average age of buses and coaches in selected accession countries

Country	Average age 1998
Estonia (1997)	11
Hungary	12.03
Latvia	13.2
Romania (1997)	12
Slovakia	14.07
Source: [EEA 2002a] IFEU 2004	

Overview

Again, higher savings are expected for the non-OECD regions due to the older vehicle fleet.

Tab. 33: Fuel consumption change by the introduction of new buses

Vehicle	Annual decrease	Average age of fleet	Result
OECD-North America	0.5%	8	4.0%
OECD-Europe	0.5%	8	4.0%
OECD-Pacific	0.5%	8	4.0%
Non-OECD Europe	0.5%	12	6.0%
Former USSR	0.5%	14	7.0%
Middle East	0.5%	14	7.0%
China	0.5%	14	7.0%
Other Asia	0.5%	14	7.0%
Africa	0.5%	14	7.0%
Latin America	0.5%	10	5.0%
Source: IFEU 2004 from various sources			IFEU 2004

7.3.3 Rail Vehicles

Not many data are available on the specific energy consumption development for trains which refer to vehicle-km. Most data refer to passenger- or tonne-km and therefore take into account the load factor. For passenger trains a general trend towards heavier (due to comfort requirements) and faster vehicles seems to compensate for technological advancements. Furthermore, *“Energy efficiency in train operations has generally had a quite low priority within railway companies. The cost of energy has typically been in the order of just 3-8% of the total cost ... The low priority has sometimes been reflected in a low interest and knowledge in energy related issues, although there are exceptions to this statement”* [Andersson 2000]. This statement is supported by statistics of the European Environmental Agency which states that overall *“... energy efficiency of rail has remained stable in recent decade”* ([EEA 2002d]). Due to very few data and the low share of rail energy consumption of the total transport energy consumption, only OECD countries and non-OECD countries will be distinguished. The non-OECD countries are assumed to have a significantly older, less efficient fleet. Potential energy savings will therefore be twice as high as for OECD countries. This analysis is mainly based on statistics of the European Environmental Agency ([EEA 2002d]) and the Bureau of Transportation Statistics ([BTS 2002b]).

7.3.3.1 Short distance passenger trains

For short distance passenger trains, such as trams, subways, regional trains which are assumed to use electricity, recent technological developments led to sharp decrease in the specific fuel consumption in the late 1990s. This is due to new materials being used. Despite new features like air conditioning, vehicles have become lighter ([Alstom 2003]). On the other hand, however, trains are used faster, because electricity consumption accounts for only a small share of the operating costs of regional/local transport compared to personnel costs, etc. Nevertheless, a new generation of local transport trains has been introduced during the late 1990s, which reduced the specific energy consumption about 10%-20% ([Alstom 2003]). In OECD countries some of these new short distance transport trains are already operating, so that lower energy savings can be achieved.

[IFEU 2000] uses a 0.5% annual specific energy consumption decrease for short distance trains. Taking into account the long-lifetime of these trains of 20 to 40 years, potential energy savings around 5 to 10% can be expected for a 10 to 20 year old vehicle fleet. This value is slightly more conservative compared to [Alstom 2003] and will therefore be used in this study: 5% relative energy savings will be used for the OECD countries and 10% will be used for the non-OECD countries.

7.3.3.2 Long distance passenger trains

“The energy efficiency of rail passenger transport has not changed much in recent decades” according to [EEA 2002d]. At the same time, *“Occupancy rates in rail transport have declined in most [EU-15] Member States, so the efficiency of use has not improved between 1980 and 1999”* ([EEA 2002c]). [IFEU 2000], as well, does not use any specific energy consumption change for long-distance passenger trains due to a trend towards higher speeds. The energy intensity of Amtrak passenger transport in the U.S. also has rather increased ([BTS 2002b]). No relative energy savings are

therefore taken into account for the introduction of new passenger trains in the OECD countries. The older fleet of the non-OECD countries, however, is assumed to have a considerable potential for energy savings by the introduction of new vehicles. 0.5% annual decrease with an average age of 20 years are assumed which will result in 10% relative energy savings.

7.3.3.3 Long distance freight trains

Data for diesel freight trains of the Bureau of Transport Statistics indicates no significant change in the fuel efficiency of Class I Railways trains ([BTS 2002b]). No improvements will therefore be used for OECD North-America. While the energy efficiency of rail transport has even decreased by 15% over recent years in the EU ([EEA 2002d]), this can be also attributed to a change in the average load factor as well as a shift from heavy to volume goods. Some EU countries, however, show increasing energy efficiency ([EEA 2002d]). [IFEU 2000] also assumes slightly increasing energy efficiency and uses a value of 0.5% annual specific consumption decrease. With an average age of 10 years for the OECD and 20 years for the non-OECD countries, again respectively 5% and 10% relative energy savings can be expected.

7.3.3.4 Overview trains

Tab. 34: Energy savings by the introduction of new trains

	OECD countries	Non-OECD countries
Short distance passenger trains	5%	10%
Long distance passenger trains	0%	10%
Long distance freight trains	5%*	10%
* OECD North America 0%		IFEU 2004

7.3.4 Ships and Ferries

According to [SOF 2000] for vessels “*Engine energy consumption has improved by 15% due to improved model development over the past 20 years*”. The average age of ocean vessels can be assessed based on data from [BTS 2002b] for the US flag vessel fleet. The average age for the different vessel type varies between 17 and 24 years. Around 20 years can therefore be used as good average and 15% energy savings are thus taken into account for an introduction of new ocean vessels.

Tab. 35: Average age of different ocean vessel types

	Dry cargo	Tanker	Towboat	Passenger	Dry barge	Liquid barge	All
Average age	20	21	24	19	17	21	18
Source: IFEU calculation based on [BTS 2002b]							IFEU 2004

7.3.5 Aircrafts

Aircraft fuel efficiency has been constantly improving over the last decades: “*Significant improvements in aircraft fuel efficiency have been achieved since the dawn of the jet age in commercial aviation. Historically, these improvements have average 1-2% per year for new production aircraft*” ([IPCC 2003]). Lower annual savings have been stated by [EEA 2002d]: “*The very few data available for domestic air transport (three countries only) show that energy efficiency has slightly improved in the past decade (+3%).*” But, as mentioned in the quotation, the data base is very small and will therefore not be taken into account.

Aircraft fuel efficiency improvement per plane and seat mile have also been analysed according to data from [BTS 2002b] for US carriers in the United States. While fuel efficiency per plane mile has been improving by 1.6% for international flights and an almost 5% for domestic flights annually, the fuel efficiency per seat-mile has changed only marginal throughout the 1990s. This indicates, that the majority of aircrafts has become smaller, which also explains for the high improvement per plane-mile. The fuel efficiency decrease for a comparable plane is therefore assumed to be in the range between 1% and 2% as stated by [IPCC 2003].

The average age of the aircraft fleet is assessed based on data for the US from [FAA 2003] and is about 13 years for the Airbus series and almost 20 years for the Boeing series. 15 years will be used in this study. With an average annual fuel consumption decrease in the range of 1.5%, 20% energy savings can be expected by the introduction of new aircrafts. This calculation takes into account a progressive application of the annual change rate.

7.4 Potential energy savings by additionally weight reduced vehicles

7.4.1 Scope definition and Methodology for the additionally weight reduced vehicles

After energy savings by the introduction of new vehicles have been analysed, energy savings by an additional weight reduction will be calculated. No scientifically established data on the average potential for a further weight reduction have been available. Therefore, this report uses case studies and expert judgement as a reference for such global average. Figures on the relative energy savings for a 10% weight reduction have already been derived in the “Energy savings by light-weighting” reports. The energy savings calculated, are now achieved by light-weighting only. This scenario therefore shows the additional potential savings by light-weighting compared to the average new vehicles scenario.

7.4.2 Summary of relative energy savings for different vehicle types

The relative energy savings by weight reduction for different vehicle types have been analysed in detail in this study and [IFEU 2003a]. For this analysis the relative energy savings for a 10% weight reduction will be used in combination with a top down approach to ensure that the total energy consumption of different vehicles is considered. Tab. 36 sums up the relative energy savings as used for this analysis. For ocean vessels an average factor (calculated according to the energy consumption shares in Tab. 25) will be used.

Tab. 36: Relative energy savings for additionally weight reduced vehicles

Vehicle	% savings per 10% vehicle weight reduction	Average savings per 10% vehicle weight reduction
Passenger car	5.7%	5.7%
Light-duty vehicle	5.7%	5.7%
Medium truck	5.7%	5.7%
Tractor-Trailer	4.0%	4.0%
City buses	5.6%	4%
Long-distance buses	2.4%	
Short distance passenger trains	7%	7%
Long-distance passenger trains	4%	4%
Long-distance freight trains	4%	4%
Aircrafts	8%	8%
Ferries	6.7%	1.4%
Tankers	1%	
Container ships	1.5%	
General cargo ships	1.5%	

Source: Preceding chapters and [IFEU 2003a]

IFEU 2004

7.4.3 Weight reduction potential

In this chapter the potential for a further weight reduction of new vehicles will be roughly estimated. No scientifically established data on the average potential for a further weight reduction have been available. Therefore, this report uses case studies and expert judgement as a reference for such global average.

A weight reduction can be achieved by different means such as new materials as well as construction techniques. The usage of aluminium in the transport sector has been studied for example by [RWTH 1999] and [fka 2002]. This weight reduction potential by aluminium use will therefore be used as a reference to estimate further potential weight savings of transport vehicles.

Passenger cars have been analysed in detail by [fka 2002]: *“The type of vehicle selected for the analysis is a compact-class steel monocoque, which is manufactured in high volume productions. ... The dimensions, properties and engine data of five typical, popular vehicles of this class are used to create a theoretical reference-car”* ([fka 2002]). Weight savings are now analysed in two steps which correspond to the methodology chosen for the assessment of energy savings in this and the preceding chapter 7.3:

- *“In the **first step**, the primary state-of-the-art weight reduction, current aluminium applications are analysed ...*
- *The **second step**, the primary latest-technology weight reduction, considers the potential of advanced materials and technologies*
- *In the **secondary weight savings** analysis the weight of body framing, motor, drivetrain and chassis was estimated due to a downscaling of the vehicle at constant performance”* ([fka 2002]).

The overall potential weight savings compared to a “state-of-the-art” vehicles (1003kg) turn out to be in the range between 13% (887kg vehicle) and 22% (785kg vehicle). If no downsizing (secondary weight savings) is taken into account, however, only about 7% weight savings can be achieved. This case seems to be more realistic in terms of consumer choice at the market and this conservative value will therefore be used for the analysis. The same value will also be used for light-duty vehicles.

For heavy (40t maximum gross weight) trucks about 1.5t weight saving potential are estimated by [RWTH 1999]. This value is also used to estimate the potential weight savings for buses. With a vehicle weight of about 16t for heavy trucks ([IFEU 2000]) and an average load factor around 50% ([IFEU & SGKV 2002]), 1.5t results in a 5% gross weight reduction. For buses with a lower load, potential weight savings will rather be in the range of 7%. This figure is in line with the weight savings potential derived for passenger cars above. A medium value of 6% potential weight savings is estimated for medium trucks.

State-of-the-art rail cars already use large quantities of light-weight materials and have therefore a lower potential for further weight savings. Due to the low contribution to the total energy consumption a simple estimate of potential weight savings in the range of 2% will be used. An aircraft hull weight reduction has been studied by [ITAS 2001]. The weight reduction of the hull leads to additional weight savings because less fuel has to be carried. The overall weight reduction of the take off weight was around 4% which will be used in this study.

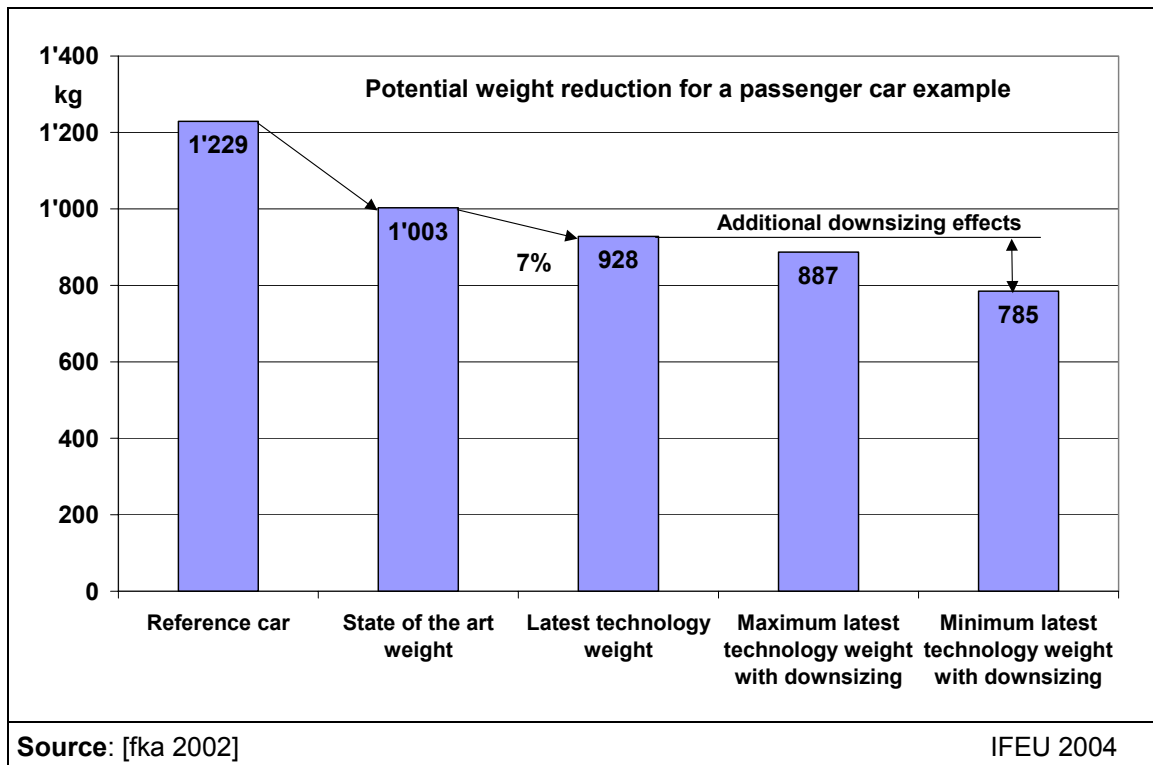


Fig. 25: Potential weight savings for a passenger car

For ocean vessels mainly the superstructure can be weight reduced. A weight reduction of the hull will be difficult due to safety requirements. Therefore the potential for a further weight reduction will be rather limited. As for rail vehicle 2% weight savings potential will be assumed.

Tab. 37: Assumed weight savings potential

Vehicle	Assumed potential weight savings compared to weight of state-of-the-art vehicle
Passenger cars	7%
Light-duty vehicles	7%
Medium trucks	6%
Heavy trucks	5%
Buses	7%
Rail vehicles	2%
Aircrafts	4%
Ocean vessels	2%

Source: IFEU assumptions based on [RWTH 1999], [fka 2002] & [ITAS 2001] IFEU 2004

7.5 Results for potential global energy savings in transport

7.5.1 Comparison of scenarios

A comparison between the transport primary energy consumption in different scenarios of OECD and non-OECD countries shows considerable energy (Fig. 26) and CO₂ (Fig. 27) savings being achieved by the introduction of average new vehicles and additional light-weighting.

Assuming that the entire transport volume is performed by average new vehicles, a 7.5% reduction in energy consumption and CO₂ emissions can be expected in the OECD countries and an 11% reduction in the non-OECD countries. Due to the comparatively older fleet, higher savings can be achieved by the introduction of new vehicles in the non-OECD countries. For an additional weight reduction of all vehicles, a further 3.3% reduction in the OECD and 2.7% reduction in the non-OECD countries can be expected. Slightly higher savings have been achieved in the OECD countries because of the high share of private passenger cars and LDVs.

Assuming a constant transport volume, modal split and no further efficiency improvements for new vehicles, these savings can be expected to occur after a complete substitution of the current fleet. An almost complete replacement of all vehicles will be completed after say 30 to 40 years. For certain vehicles (e.g. road vehicles) and in some regions (e.g. OECD countries) an almost complete replacement of the entire fleet can be expected even earlier.

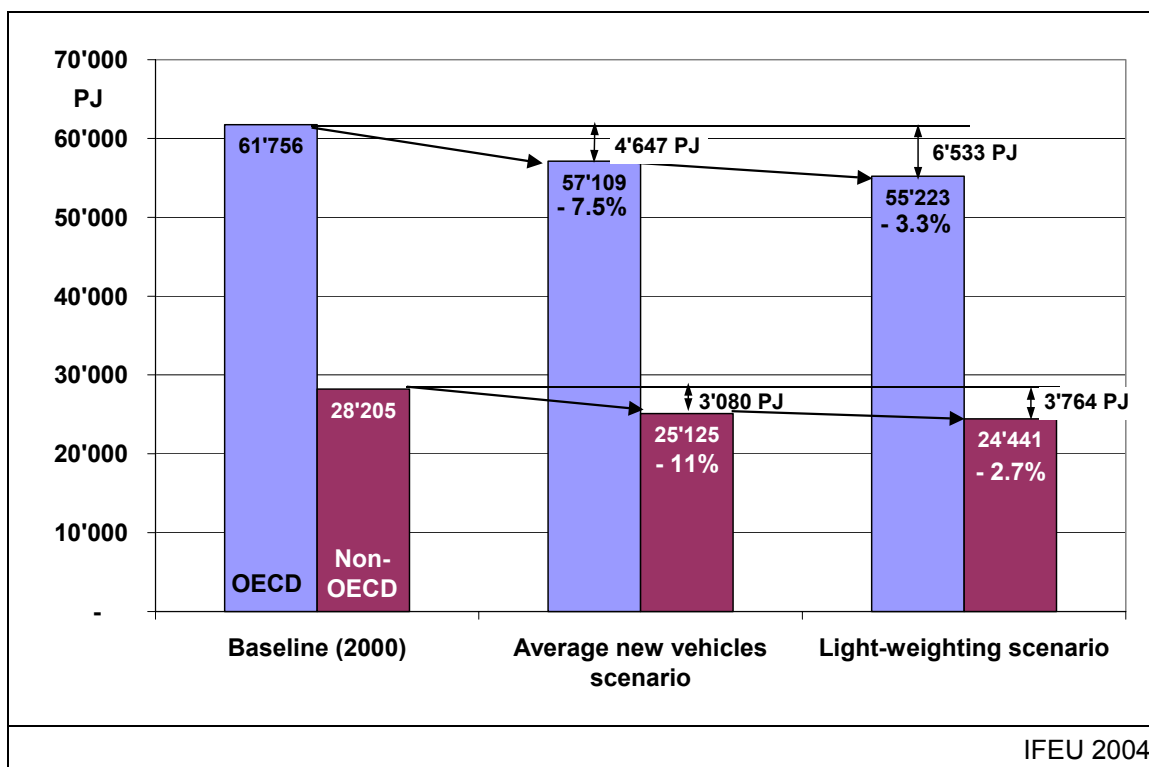


Fig. 26: Transport energy consumption (PJ) by scenario (2000)

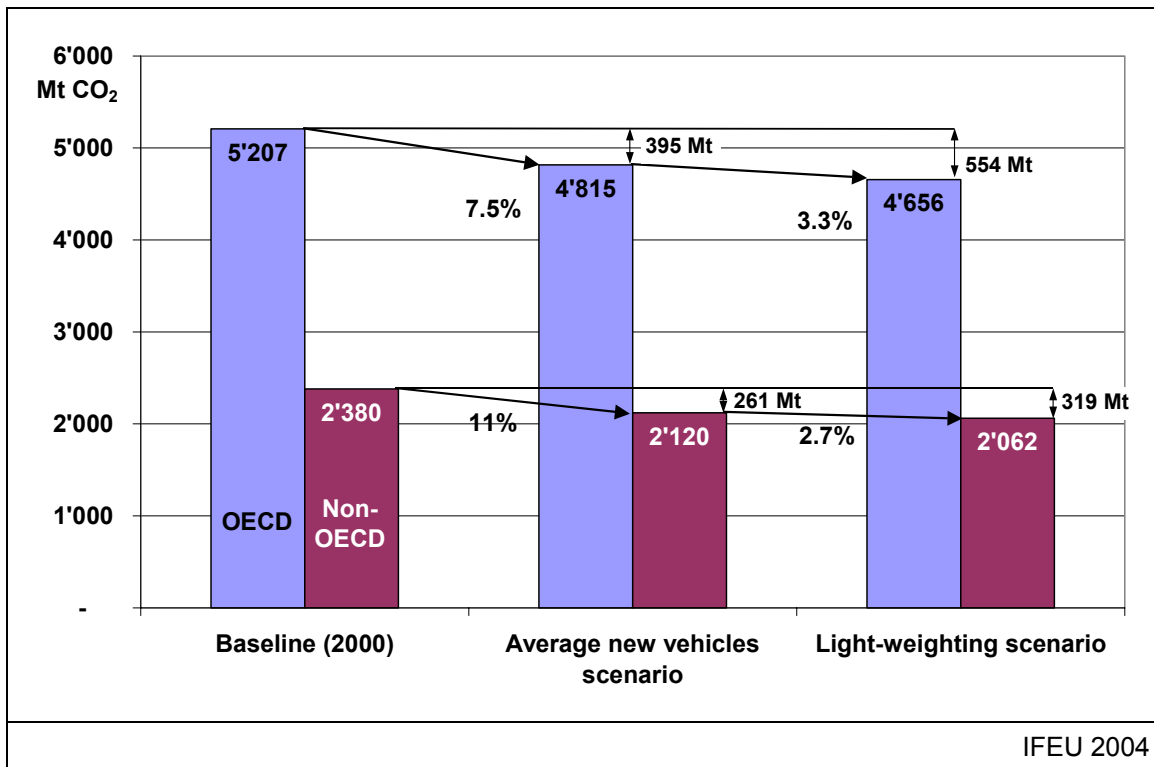


Fig. 27: Transport CO₂ emissions (Mt) by scenario (2000)

7.5.2 Savings by additional light-weighting

Overall energy savings by the maximum utilisation of light-weighting compared to the average new vehicles scenario are in the range of 2'600PJ energy (Fig. 28) or 220 Mt CO₂ (Fig. 29) annually. Almost 2'000PJ account for the OECD countries. This is a share of about 77% which is even higher as the overall transport energy consumption share. This is due to the fact that the OECD countries have a higher share of private passenger cars and LDVs, which show among the highest weight savings and energy savings by light-weighting potential. Passenger cars and LDV also make the greatest overall contribution to the total potential for energy savings by light-weighting, followed by aircrafts and other road vehicles. The total potential for rail and water is rather limited and only relevant in certain countries.

The absolute potential for energy savings mainly depends on the total energy consumption in the region or for the vehicle. Thus North America and OECD Europe dominate the total energy savings potential due to the large fleet of vehicles and high total energy consumption. All other regions show a considerably lower savings potential.

Especially private road vehicles (passenger cars and LDVs) are responsible for the dominance of the OECD regions. For public transport vehicles, a high potential exists also in the non-OECD countries. Energy savings by light-weighting of buses can be mainly attributed to non-OECD countries. Also for medium trucks, about half of the calculated savings can be attributed to non-OECD countries.

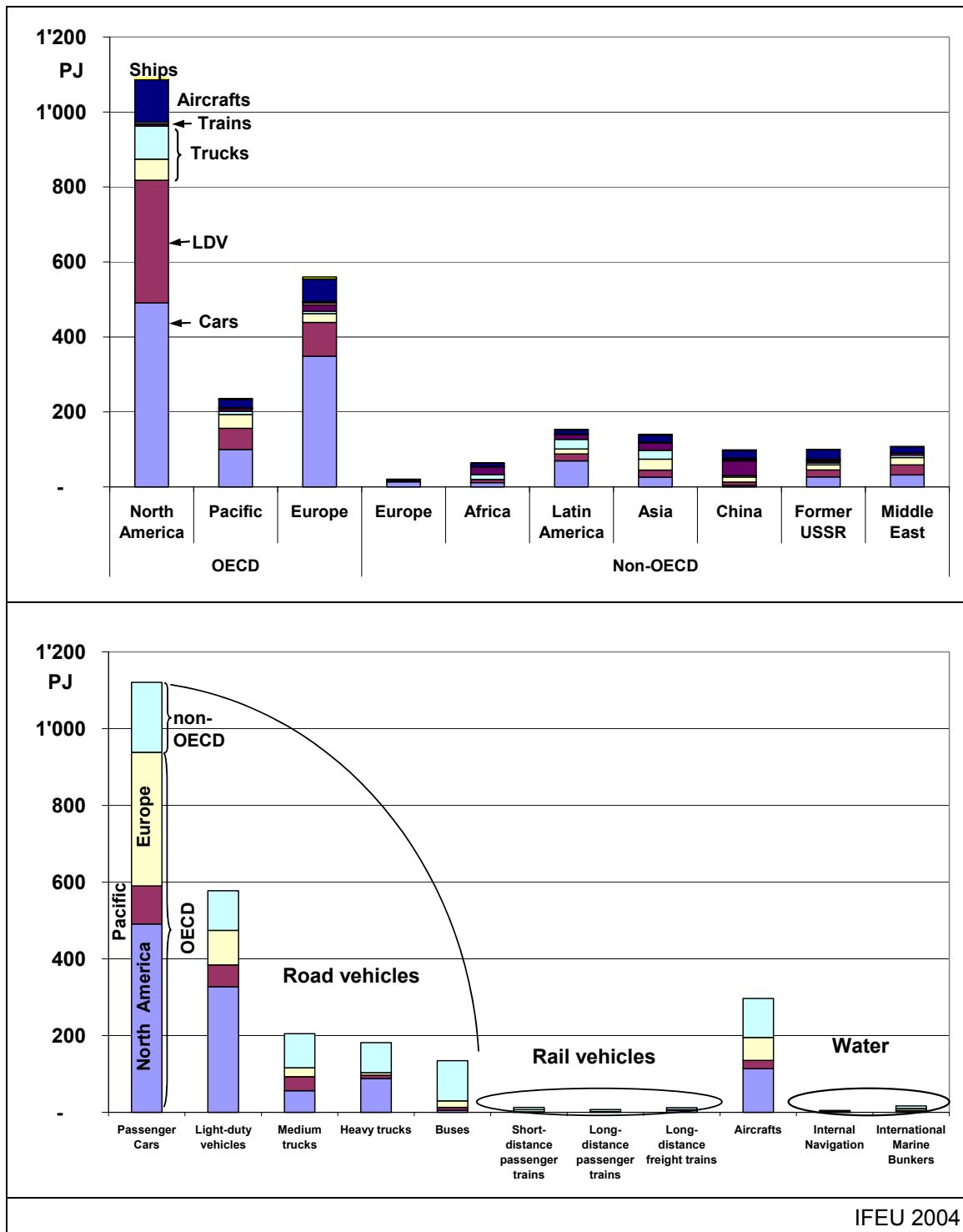


Fig. 28: Primary energy savings (PJ compared to average new vehicles scenario)

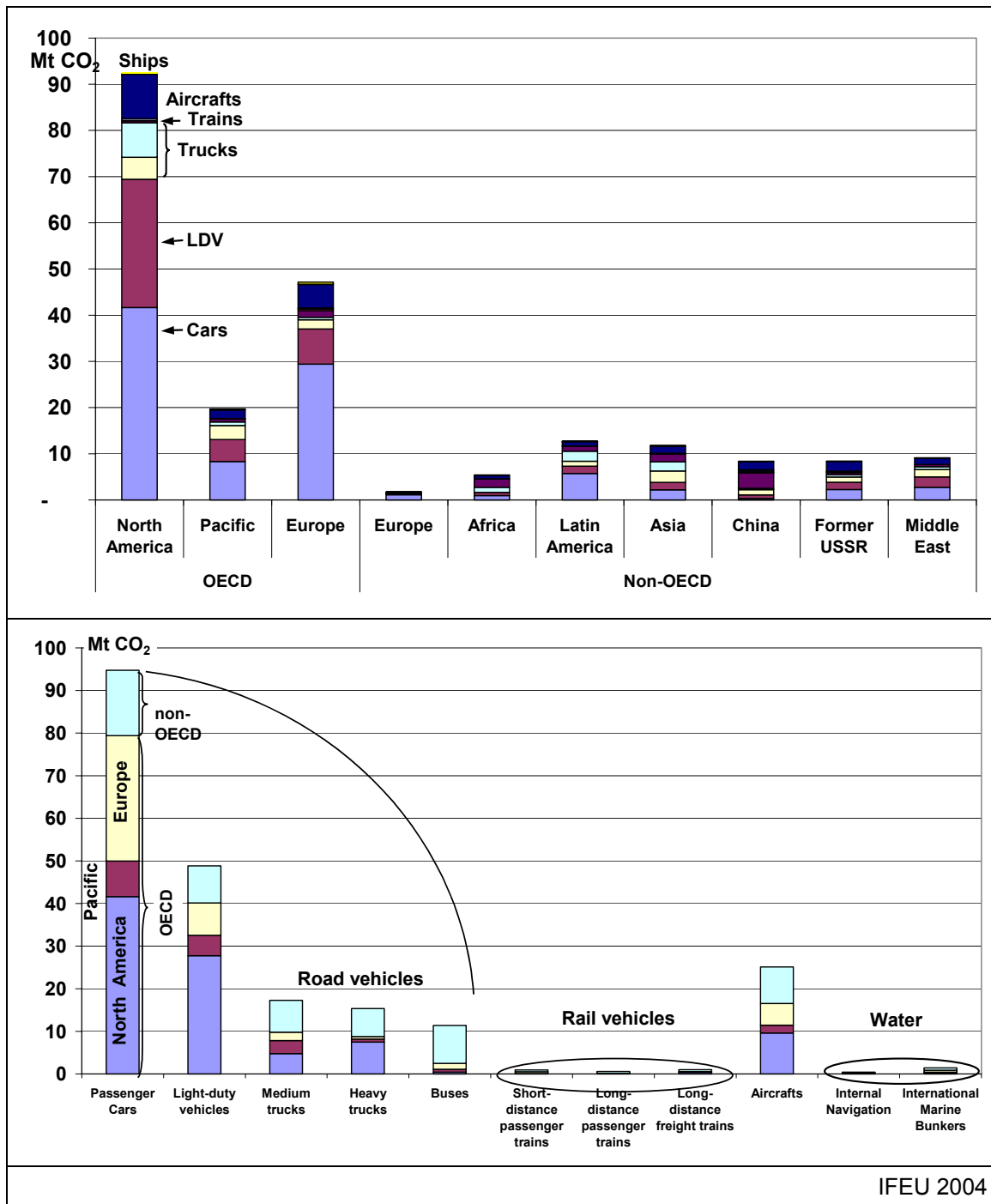


Fig. 29: CO₂ savings (Mt compared to average new vehicles scenario)

8 Conclusions

The potential primary energy and CO₂ savings by a reduction in the weight of transport vehicles have been extensively discussed in this report. Together with the first study ([IFEU 2003a]) a comprehensive overview on this topic has been given on two levels: The operational life of single vehicles has been analysed for the most common vehicle types and the global annual transport energy consumption of all vehicles. The main conclusions which can be drawn from this report therefore depend on the level of the focus.

The life-time primary energy savings for a single vehicle are by far the highest for aircrafts. All other vehicles show roughly 100 times lower life-time savings. Only high speed ferries have a potential for only 10 times lower life-time savings compared to an aircraft. Besides the vehicles, already discussed in the first study, also ocean vessels and passenger ferries show considerable life-time energy savings. In the case of cargo vessels, these can be mainly achieved by an additional payload e.g. for container ships.

The data ranges for single vehicles show the use of vehicles to be even more important than the vehicle type if it comes to life-time energy savings by weight reduction. The data ranges cover an about equal spectrum for most vehicles. Only high-speed ferries and aircrafts show outstandingly high life-time energy savings.

The potential annual energy savings by the maximum utilisation of light-weighting technology are mainly influenced by the baseline energy consumption. Therefore road vehicles, especially cars and LDVs, have a very high potential for energy savings by light-weighting. Most of the potential energy savings can be achieved in the OECD countries, which is also mainly due to their high share of transport energy consumption.

9 Commented Annex

9.1 Matrices for data ranges

In order to show the possible range of life-time primary energy savings for different vehicles, the main input variables have been varied along the estimated data range. The range of possible specific energy savings for a defined vehicle has been considered in the columns and the life-time mileage of the vehicle in the rows of the matrix. This method allows to look beyond the scope of the so called “average vehicles” as defined in the respective sections. All values are stated in GJ per vehicle (-life) for a 100kg weight reduction.

9.1.1 Road vehicles

The considered input data for passenger cars and LDVs leads to results between under 4 GJ to over 185 GJ for a 100kg weight reduction. With extreme input data about 50 times higher energy savings can be achieved compared to a very conservative estimate. The input data in respect to specific fuel savings per 100km for a 100kg weight reduction has been varied between 0.1 litre for a very steady driving cycle with inefficient adjustments up to 0.5 l for an extreme urban driving cycle with efficiency adjustments.

The life-time mileage has been varied between 100'000km and 1'000'000km. The first case would apply to, say a second private car, being used about 5'000 to 10'000km annually for about 10 to 20 years. In the case of a shorter life-time due to an accident or almost no annual use of the vehicle, the mileage can be even lower. Private passenger car use, however, has an average life-time mileage in the range of rather 200'000km, while commercial passenger cars and light-duty vehicles can be assumed in the range between 300'000 and 500'000km. 1'000'000 would be an extraordinary life-time mileage for a passenger car. Generally speaking, light-duty vehicles will be rather used as commercial vehicles, while passenger cars more often are used as private vehicles.

Tab. 38: Data range matrix for passenger cars

	Cycle (l/(100km*100kg))	Steady NEDC			Urban	
Utilisation (km)	GJ/100kg	0.1	0.2	0.3	0.4	0.5
Private use	100'000km	3.71 (1)	7.43 (1)	11.14	14.85	18.57
	150'000km	5.57	11.14	16.71	22.28	27.85
	200'000km	7.43	14.85 (3)	22.28 (2)	29.71 (2/4)	37.14
Commercial	300'000km	11.14	22.28	33.42	44.56	55.71
	500'000km	18.57	37.14	55.71 (5)	74.27 (6)	92.84
Extraordinary	1'000'000km	37.14	74.27	111.41	148.55 (6)	185.68
(1) Second car (2) Average private car (3) Average highway car (4) Average city car (5) Company car (6) Urban taxi						
IFEU 2004						

Tab. 39: Data range matrix for light-duty vehicles

	Cycle (l/(100km*100kg))	Steady NEDC			Urban	
Utilisation (km)	GJ/100kg	0.1	0.2	0.3	0.4	0.5
Private use	100'000km	3.71 (4)	7.43	11.14	14.85	18.57
	150'000km	5.57	11.14	16.71	22.28	27.85
	200'000km	7.43	14.85	22.28 (2)	29.71	37.14
Commercial	300'000km	11.14	22.28	33.42 (1)	44.56	55.71
	500'000km	18.57	37.14	55.71	74.27(3)	92.84 (3)
Extraordinary	1'000'000km	37.14	74.27	111.41	148.55	185.68
(1) Average LDV (2) Average private LDV (3) Urban LDV (4) LDV as second car						
IFEU 2004						

Most buses are used as commercial vehicles and therefore are assumed to generally have a higher mileage. The specific energy savings for a 100kg weight reduction have been found to be lower compared to passenger cars. Again specific energy savings very much depend on the driving cycle which is applicable.

City buses have much higher specific energy savings compared to long-distance buses. Even if long-distance buses are assumed to have a slightly higher mileage, city

buses will have the greater potential for weight induced energy savings. Potential life-time energy savings show a smaller spectrum compared to passenger cars. About 20 times higher energy savings can be achieved for a city bus with high specific fuel savings and an extraordinary high life-time mileage compared to a long-distance bus with a low life-time mileage. For articulated or other heavy trucks lower specific energy savings have been considered, since these vehicles will be rather used for long-distance transport.

Tab. 40: Data range matrix for buses

	Cycle (l/(100km*100kg))	Long-distance bus			City bus	
Utilisation (km)	GJ/ 100kg	0.04	0.08	0.12	0.16	0.20
Low	500'000	8.22 (4)	16.43	24.65 (6)	32.87	41.08
	750'000	12.33	24.65	36.98	49.30	61.63
Average	1'000'000	16.43	32.87	49.30	65.73 (1)	82.17
	1'250'000	20.54 (2)	41.08	61.63	82.17	102.71
High	1'500'000	24.65	49.30	73.95	98.60	123.25
Extraordinary	2'000'000	32.87	65.73	98.60 (3)	131.47	164.33 (5)
(1) Average city bus (2) Average long-distance bus (3) Long living bus (continental transport) (4) Short living bus (regional transport) (5) High performance city bus (6) Low performance city bus						
IFEU 2004						

Tab. 41: Data range matrix for heavy/articulated trucks

	Cycle (l/(100km*100kg))					
Utilisation (km)	GJ/ 100kg	0.02	0.04	0.06	0.08	0.10
Low	500000	4.11	8.22	12.33	16.43	20.54
	750000	6.16	12.33	18.49	24.65	30.81
Average	1000000	8.22	16.43	24.65	32.87	41.08
	1250000	10.27	20.54 (1)	30.81	41.08	51.35
High	1500000	12.33	24.65	36.98	49.30	61.63
Extraordinary	2000000	16.43	32.87	49.30	65.73 (2)	82.17
(1) Average heavy truck (2) Long living truck (continental transport) (3) Short living truck (regional transport)						
IFEU 2004						

9.1.2 Rail vehicles

Tab. 42: Data range matrix for short distance trains

	Cycle kJ/ (100km*100kg)					
Utilisation (km)		1'500	1'750	2'000	2'250	2'500
Low	2'000'000	71.43	83.33	95.24	107.14	119.05
	3'000'000	107.14	125.00 (1)	142.86	160.71	178.57
Average	4'000'000	142.86	166.67 (2)	190.48	214.29	238.10
	5'000'000	178.57	208.33	238.10	267.86	297.62
High	6'000'000	214.29	250.00	285.71	321.43	357.14
Extraordinary	7'000'000	250.00	291.67	333.33	375.00	416.67
(1) Average subway						
(2) Average regional train						
						IFEU 2004

Tab. 43: Data range matrix for long distance trains

	Cycle kJ/ (100km*100kg)					
Utilisation (km)		200	300	400	500	600
Low	5'000'000	23.81	35.71	47.62	59.52	71.43
	7'000'000	33.33	50.00	66.67 (2)	83.33	100.00
Average	9'000'000	42.86	64.29	85.71 (2)	107.14	128.57
	11'000'000	52.38	78.57	104.76	130.95	157.14
High	13'000'000	61.90	92.86	123.81	154.76	185.71
Extraordinary	15'000'000	71.43	107.14 (1)	142.86	178.57	214.29
(1) High speed passenger train						
(2) Average passenger train						
						IFEU 2004

9.1.3 Ocean vessels

Tab. 44: Data ranges for Container ships

	Ship size (DWT)	6'000	10'000	14'000	18'000	22'000
Utilisation (hrs)						
Low	60'000	121.11	102.97	95.20	90.88	88.14
	100'000	201.84	171.62	158.67	151.47	146.89
Average	140'000	282.58	240.27	222.14	212.06	205.65
	180'000	363.32	308.92	285.61	272.65	264.41
High	220'000	444.06	377.57	349.07	333.24	323.17
Extraordinary	260'000	524.80	446.22	412.54	393.83	381.93
IFEU 2004						

Tab. 45: Data ranges for General cargo vessels

	Ship size (DWT)	6'000	10'000	14'000	18'000	22'000
Utilisation (hrs)						
Low	60'000	83.85	62.45	53.28	48.19	44.94
	100'000	139.75	104.09	88.80	80.31	74.90
Average	140'000	195.66	145.72	124.32	112.43	104.87
	180'000	251.56	187.36	159.84	144.56	134.83
High	220'000	307.46	228.99	195.36	176.68	164.79
Extraordinary	260'000	363.36	270.63	230.88	208.80	194.75
IFEU 2004						

Tab. 46: Data ranges for Tankers

	Ship size (DWT)	60'000	100'000	140'000	180'000	220'000
Utilisation (hrs)						
Low	60'000	13.99	10.63	9.20	8.40	7.89
	100'000	23.31	17.72	15.33	14.00	13.15
Average	140'000	32.64	24.81	21.46	19.59	18.41
	180'000	41.96	31.90	27.59	25.19	23.67
High	220'000	51.29	38.99	33.72	30.79	28.93
Extraordinary	260'000	60.61	46.08	39.85	36.39	34.19
IFEU 2004						

9.2 Differentiation of global transport energy consumption

Aircrafts and ocean vessels will be analysed as a homogenous group of vehicles in terms of relative energy savings and light-weighting potential. Road and Rail vehicles, show very different uses and have to be further differentiated.

9.2.1 OECD North America

The OECD countries of North-America, mainly the United States, are the region with the highest transport energy consumption. Road transport is the single most important transport mode in North America (80%), with only air transport also having a significant share (13%). Rail transport (2%) and water transport (5%) are negligible in terms of primary energy consumption.

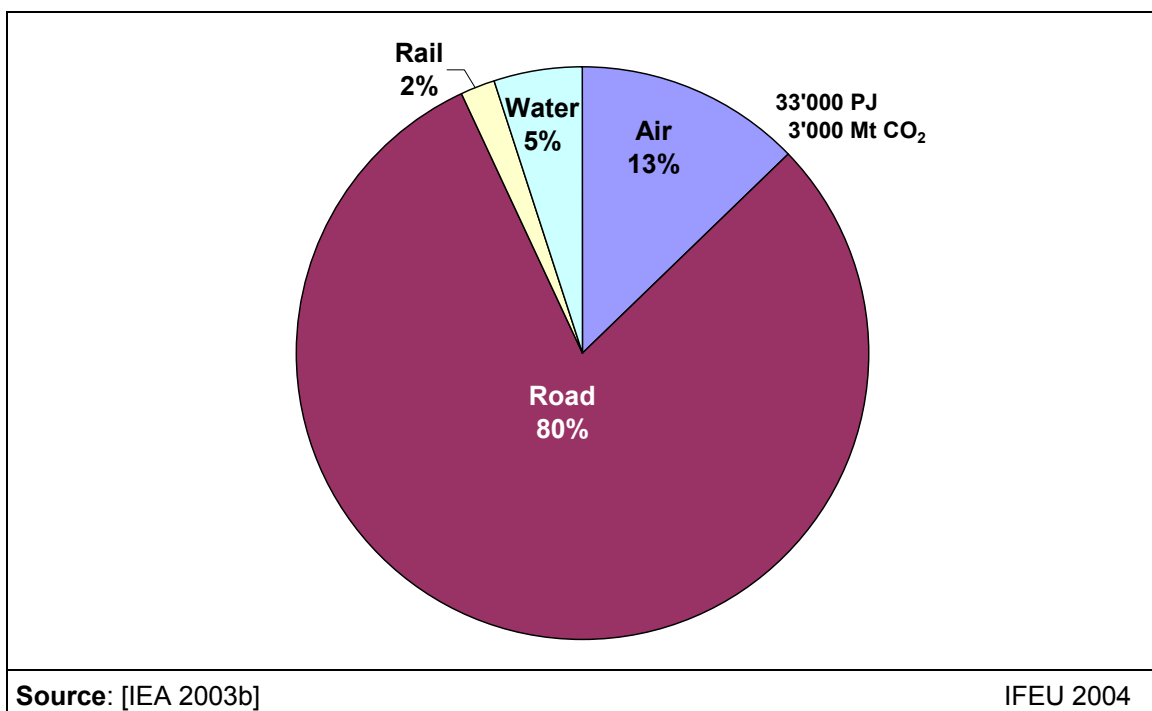


Fig. 30: Transport primary energy consumption in OECD-North America (2000)

The **road transport** energy consumption has been further differentiated according to fuel consumption data from the U.S. Bureau of Transportation Statistics ([BTS 2002a]). The vehicle fleet and usage is assumed to be similar in Mexico and in Canada. The vehicle descriptions have been allocated as in Tab. 47.

Tab. 47: Differentiation of vehicle categories for North American road transport.

BTS Category	Category in this study
Passenger car and motorcycle	Passenger Cars
Other 2-axle 4-tire vehicle	Light-duty vehicles
Single-unit 2-axle 6-tire or more truck	Medium Trucks
Combination truck	Tractor-Trailer
Bus	Busses

IFEU 2004

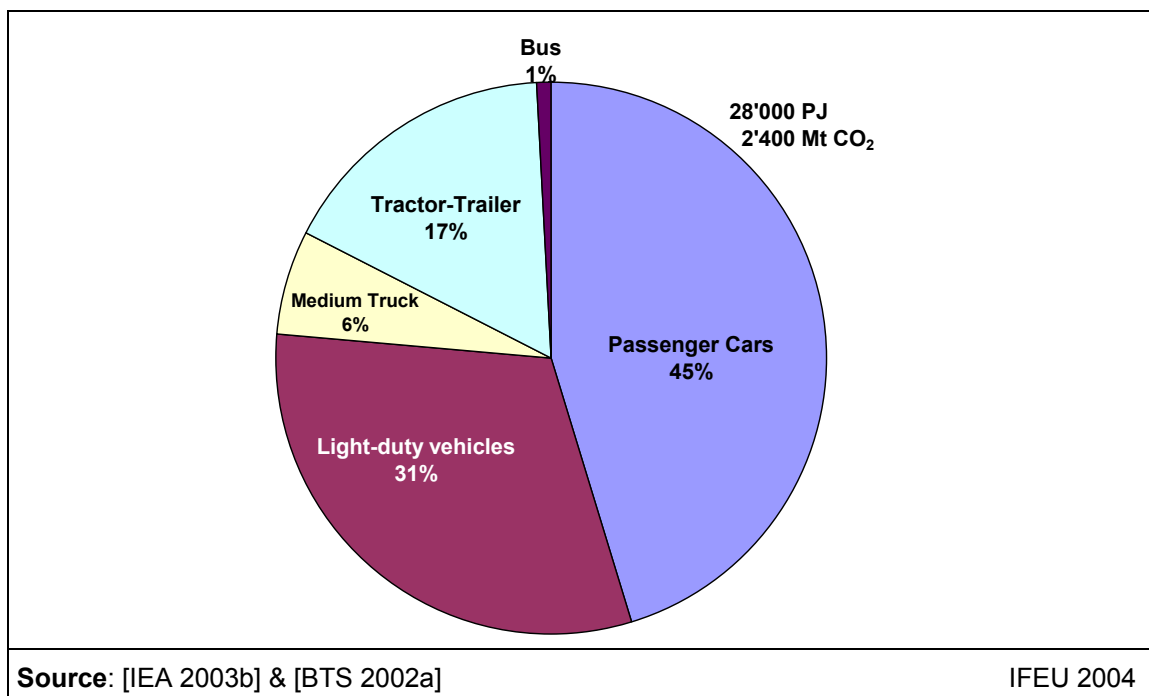


Fig. 31: Road transport primary energy consumption in OECD-North America (2000)

Rail transport energy consumption has been differentiated according to [BTS 2002a] as well. All transit electricity consumption has been allocated to short distance passenger transport (6%), while all Amtrak energy consumption (Electricity and Diesel) has been allocated to long-distance passenger transport (2%). Long distance freight transport (Class I in freight service), however, accounts for about 92% of the rail transport primary energy consumption in the United states.

9.2.2 OECD Pacific

Transport primary energy consumption in the OECD countries of the Pacific Area (Japan, Korea, Australia and New Zealand) is again dominated by road transport (73%), followed by air (10%) and water (14%). Rail transport (3%) has only a minor share of the total energy consumption.

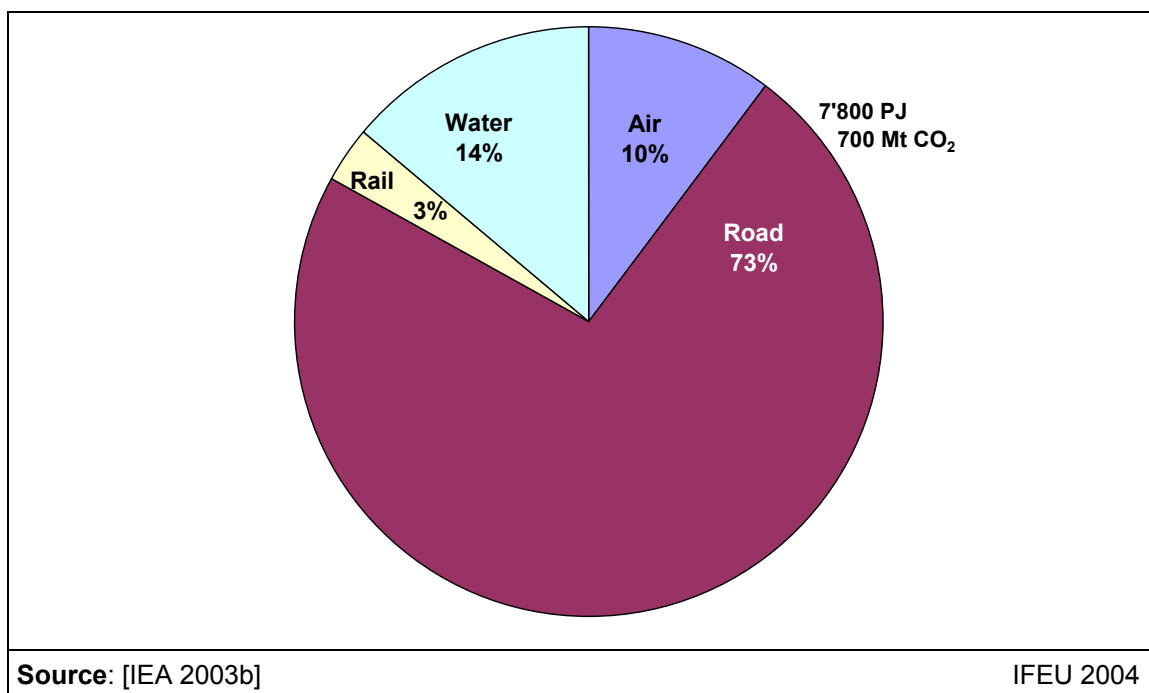


Fig. 32: Transport primary energy consumption in OECD-Pacific (2000)

Road transport energy consumption has been allocated according to motor vehicle statistics from Japan and Australia. Passenger cars and light duty vehicles are dominating followed by medium trucks, while heavy trucks and buses account for only a small share of the primary transport energy consumption.

Tab. 48: Road transport energy consumption in OECD Pacific

	Share of vehicle fleet	Car equivalents	Share of road transport energy consumption	Primary energy consumption
Passenger cars	74.0%	1	45.1%	2,747,849 TJ
Light-duty vehicles	20.0%	2	24.4%	1,485,324 TJ
Medium trucks	5.0%	6	18.3%	1,113,993 TJ
Tractor-Trailer	0.5%	25	7.6%	464,164 TJ
Buses	0.5%	15	4.6%	278,498 TJ

Source: [AusStats 2002] & [JAMA] IFEU 2004

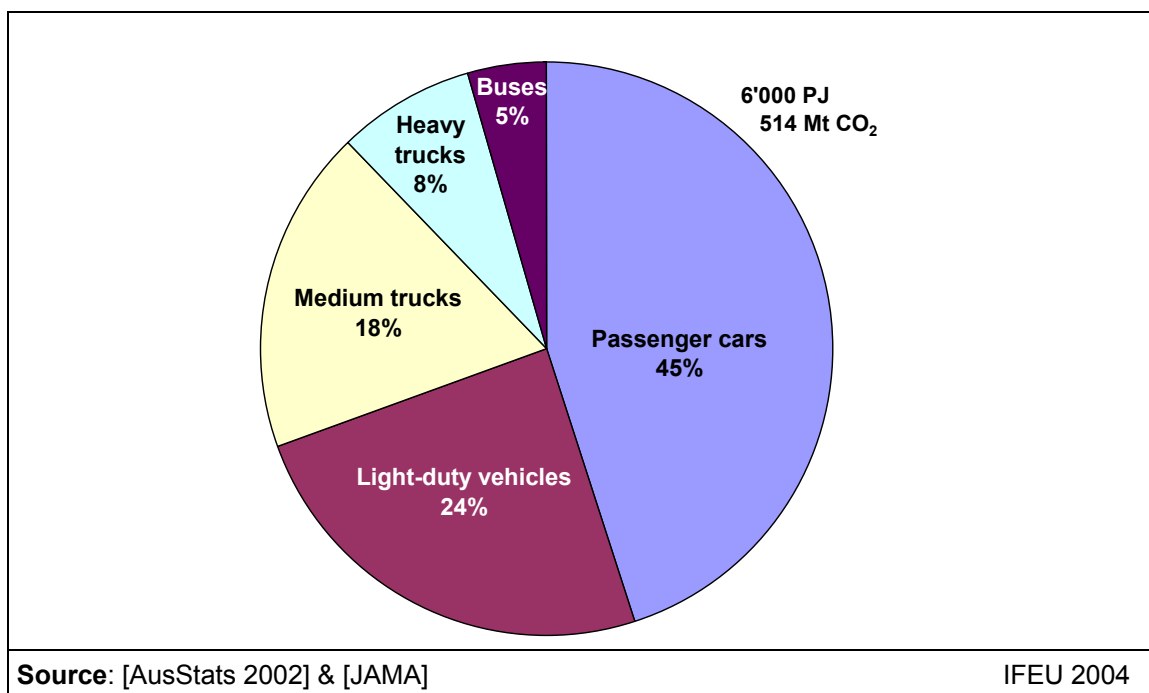


Fig. 33: Road transport primary energy consumption in OECD-Pacific (2000)

In Japan, freight transport accounts for only a small share of the **rail transport** energy consumption (3.5 PJ as opposed to 74 PJ final energy consumption for passenger transport ([ANRE 2003])). In this study the smaller share of diesel fuel consumption is assumed to be for long-distance freight transport. The electricity consumption is allocated to passenger transport and evenly split between short- and long-distance passenger trains.

9.2.3 OECD Europe

Transport energy consumption in the OECD countries of Europe is dominated by road transport, followed by air transport. The rail transport share of 4% is slightly higher as for the other OECD regions.

Tab. 49: Primary energy consumption of rail transport in the EU-15

Transport mode	Energy type	Vehicles	Share TREMOD	Primary energy consumption (TJ)
Rail	Electricity	Short distance passenger trains	52%	330 TJ
		Long distance passenger trains	22%	139 TJ
		Freight trains	26%	165 TJ
	Diesel	Short distance passenger trains	68%	99 TJ
		Long distance passenger trains	8%	11 TJ
		Freight trains	24%	35 TJ

Source: [IFEU 2000] & [EC] IFEU 2004

The **road transport** energy consumption is allocated according to vehicle statistics for the EU-15 ([EC 2002a]). Passenger cars have a very high share of the road transport

primary energy consumption compared to the other OECD regions. The **rail transport** energy consumption (Tab. 49) has been allocated following data calculated for Germany by TREMOD ([IFEU 2000]).

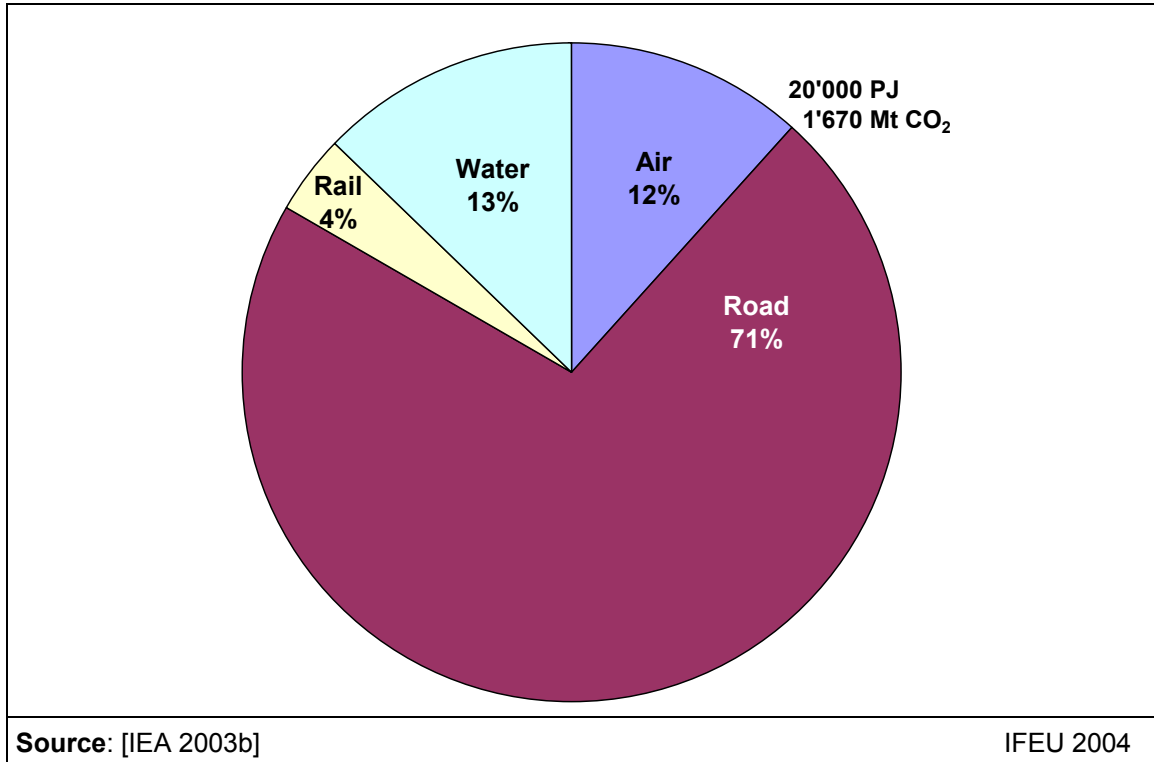


Fig. 34: Transport primary energy consumption in OECD-Europe (2000)

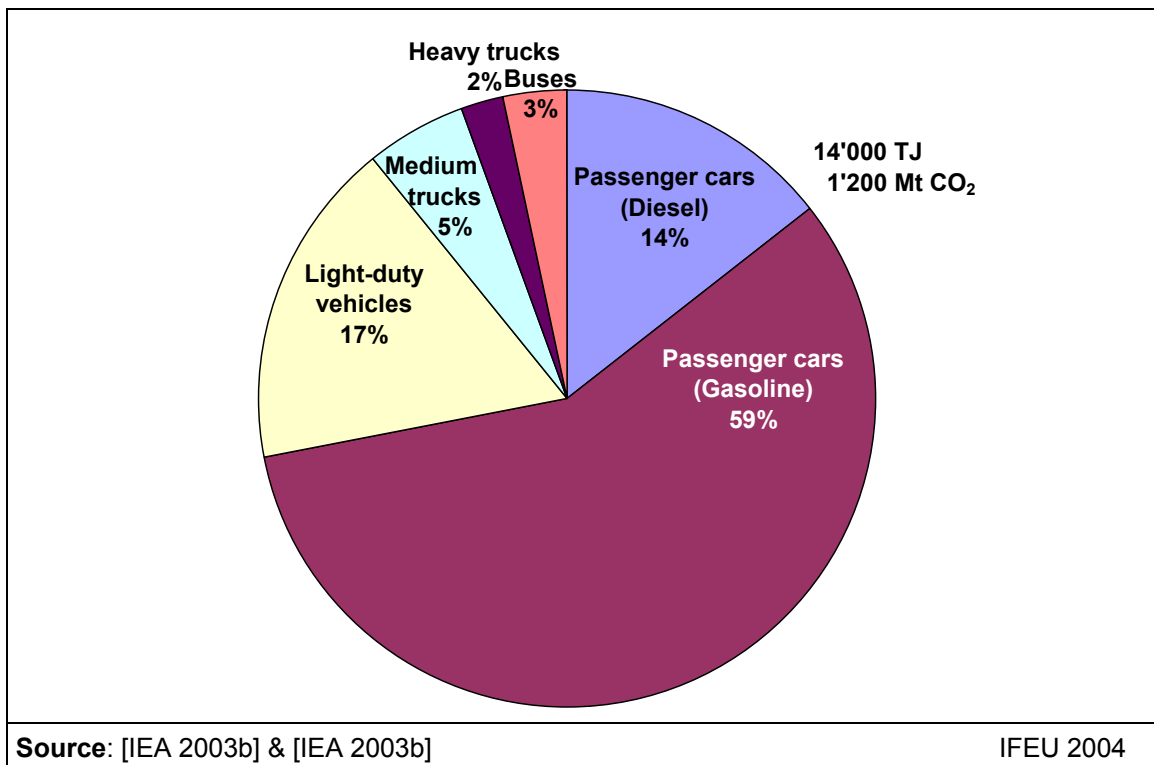


Fig. 35: Road transport primary energy consumption in OECD-Europe (2000)

9.2.4 Non OECD countries

Europe

The energy consumption pattern in the non-OECD countries of Europe (750 TJ/ 62 Mt CO₂) is similar to the OECD countries of Europe, with dominating road transport (71%) but a higher share of rail transport (6%). Due to the low total energy consumption in these countries, the differentiation will be based on the assumption that **Road and Rail transport** energy consumption will be as for the OECD countries of Europe.

Former USSR

A large quantity of the regions electricity consumption (about 37% for Russia) is consumed by pipeline transport not taken into account in this study. The pipeline electricity consumption of Russia is also used for the differentiation in the other Former USSR countries. Road transport in the countries of the Former USSR is less dominated by passenger cars. The Russian passenger cars account for about 66% of the road vehicle fleet compared to 34% utility vehicles in 2000 ([CCFA 2003]). Data for other Former USSR countries indicates that about 75% of the fleet are light-duty and 25% are heavy duty vehicles. The 34% utility vehicles are thus differentiated as in Tab. 50.

Tab. 50: Differentiation of road vehicles (Former USSR)

	Share of vehicle fleet	Car equivalents	Share of road transport energy consumption	Primary energy consumption
Passenger cars	66%	1	33.3%	804'977 TJ
Light-duty vehicles	25.0%	2	25.3%	609'831 TJ
Medium trucks	7.0%	6	21.2%	512'258 TJ
Tractor-Trailer	1%	25	12.6%	304'915 TJ
Buses	1%	15	7.6%	182'949 TJ
Source: [CCFA 2003]				IFEU 2004

Rail transport accounts for a significant share of the total transport energy consumption, with a high share of electricity. About half of the Russian Railway network is electrified ([UIC 2002]), electricity will therefore be used in long distance transport as well as in short distance transport. The railway electricity consumption in the Former USSR countries will be evenly split between long- and short-distance transport. All diesel consumption is assumed to be long-distance transport. Half of the long-distance transport energy consumption in turn is allocated to freight, the other half to long-distance passenger transport.

Asia (excluding China)

Transport energy consumption in Asia is again dominated by **road transport**. Road transport energy consumption has been differentiated by data on the vehicle fleet in India and Indonesia, two large countries in the region. The composition of the road vehicle fleet shows a remarkable share of the fleet (about 70-80%) being two- and three-wheeler vehicles. 25% of the transport energy consumption in Asia can be attributed to Two- and Three-wheeler vehicles and only about 30% to passenger cars

and light-duty vehicles. This may be due to significantly lower private passenger car ownership. Other commercial vehicles in turn, like medium and heavy trucks as well as buses, have a higher share of the transport primary energy consumption.

Tab. 51: Differentiation of road vehicles (Asia)

	Share of vehicle fleet	Car equivalents	Share of road transport energy consumption	Primary energy consumption
Two-/ Three Wheeler	75%	0.4	26.5%	1'532'475 TJ
Passenger cars	15.0%	1	13.3%	766'238 TJ
Light-duty vehicles	5%	2	8.8%	510'825 TJ
Medium trucks	3.0%	6	15.9%	919'485 TJ
Tractor-Trailer	1.0%	25	22.1%	1'277'063 TJ
Buses	1.0%	15	13.3%	766'238 TJ
Source: [GOI 2004] & [BPS 2004]				IFEU 2004

Only a small share of the Asian **rail transport** network (in India about 20% ([CCFA 2003])) is electrified. All electric energy consumption is therefore assumed to be used for short-distance passenger trains. All diesel energy consumption is evenly split between long-distance freight and passenger transport.

China

Road transport plays a much smaller role in China in favour of Rail transport which plays a significant role in Chinese transport accounting for as much energy consumption as air transport. Also Inland navigation has a considerable share of the total primary energy consumption.

The **road transport** energy consumption has been differentiated according to the number of vehicles as stated in [CSEP 2001]. Ownership of private passenger cars is even lower than in other Asian countries. Buses therefore have a much higher share of the transport energy consumption.

Tab. 52: Differentiation of road vehicles (China)

	Share of vehicle fleet	Car equivalents	Share of road transport energy consumption	Primary energy consumption
Passenger cars	28.0%	1	4.7%	117'599 TJ
Light-duty vehicles	28.6%	2	9.5%	240'422 TJ
Medium trucks	16.8%	6	16.8%	423'837 TJ
Tractor-Trailer	1.9%	25	7.8%	197'921 TJ
Buses	24.6%	15	61.3%	1'548'931 TJ
Source: [CSEP 2001]				IFEU 2004

13.5% of the **rail transport** energy consumption in China is based on electricity. This share is assumed to be for short distance passenger trains. 86.5% of the energy consumption is thus for long distance trains, which will be allocated evenly to freight and passenger transport.

Middle East

Transport energy consumption in the Middle East is again dominated by road transport. No energy consumption for rail transport and inland navigation is stated in IEA statistics. No reliable data has yet been found on the vehicle fleet in the middle east countries. **Road transport** energy consumption will therefore be allocated based on the shares for the Former USSR countries.

Africa

African transport energy consumption is clearly dominated by **road transport**. This energy consumption has been allocated according to the vehicle fleet statistics for selected African countries ([AFREPREN 2003]). Passenger cars have a very low share of the energy consumption compared to light-duty vehicles, trucks and buses.

Tab. 53: Differentiation of road vehicles (Africa)

	Share of vehicle fleet	Car equivalents	Share of road transport energy consumption	Primary energy consumption
Passenger cars	60%	1	15.6%	332'529 TJ
Light duty vehicles	25%	2	13.0%	277'107 TJ
Trucks	5%	25	32.5%	692'768 TJ
Buses	10%	15	39.0%	831'322 TJ
Source: [AFREPREN 2003]				IFEU 2004

No data was available for the **rail transport** share of short- and long-distance passenger and freight trains. The energy consumption will therefore be evenly split between passenger and freight transport. Half of the passenger transport is assumed to be short-distance passenger transport.

Latin America

Latin American **road transport** energy consumption has been differentiated according to data for the vehicle stock of Brazil, the largest country in the region. The road vehicle distribution shows passenger cars and tractor-trailers being the dominant vehicles.

Tab. 54: Differentiation of road vehicles (Latin America)

	Share of vehicle fleet	Car equivalents	Share of road transport energy consumption	Primary energy consumption
Passenger cars	82.0%	1	39.6%	1'830'215 TJ
Light duty vehicles	11.0%	2	10.6%	491'033 TJ
Medium Trucks	3.0%	6	8.7%	401'754 TJ
Tractor-Trailer	2.5%	25	30.2%	1'394'981 TJ
Buses	1.5%	15	10.9%	502'193 TJ
				IFEU 2004

For **rail transport**, all electricity (about 23%) is assumed to be consumed in short-distance passenger transport. The remaining consumption of mainly diesel fuel is assumed to be for long-distance transport with equal shares for freight and passenger transport.

9.3 Methodology discussion for the introduction of new vehicles

The relative energy consumption change by the introduction of new vehicles can either be directly compared (specific energy consumption of new vehicles vs. specific energy consumption of fleet) if good data are available or have to be calculated from secondary variables. If comparable statistical data on the specific fuel consumption of the fleet in 2000 as well as data on the specific fuel consumption of new vehicles in 2000 exist, the relative difference could be used to calculate the energy consumption of the assumed fleet of new vehicles. Data for both values, however, may not be comparable. While the specific energy consumption of new vehicles is in many cases derived in test cycles (which may not reflect the real driving behaviour), the specific energy consumption of the fleet is in many cases calculated in a top down approach via the total fuel consumption and estimated mileage.

For a calculation, the relative energy consumption change mainly depends on

- changes in the specific energy consumption of new vehicles, which may be either
 - linear (% annual change) or
 - a function of the model year, and the
- composition of the fleet in respect to the age of the vehicles, which can be either expressed as the
 - average age of the fleet or
 - a detailed age distribution (% of the total fleet for each model year).

Generally speaking, a fleet is composed of more new vehicles than old vehicles. To a lesser degree also the composition of the total mileage in respect to the age of the vehicles is a factor of influence. It can be assumed that new vehicles have a higher average annual mileage than old vehicles. Depending on data availability and quality, several methods could be used to calculate the energy savings of an assumed fleet of vehicles with the specific energy consumption of new vehicles:

- a) If no dependency of the specific energy consumption and the model year of vehicles can be established, no relative changes in the total energy consumption of this vehicle category can be expected by the introduction of new vehicles. This may be the case if technical advancements are counterbalanced by the introduction of new safety and comfort features like air conditioning, etc.
- b) If linear changes in the specific fuel consumption can be established, the composition of the vehicle fleet in respect to age (age distribution or average age) can be used to calculate energy savings by the introduction of new vehicles. For a linear development of the specific fuel consumption the relative energy savings by the introduction of new vehicles can be approximated as

$$RS = \text{Age} \times CR$$

with

RS: Relative savings (%) compared to current fleet

Age: Average age of the current fleet

CR: Annual Change rate of specific fuel consumption

- c) As a more elaborate calculation the detailed age distribution of the fleet in 2000, specific energy consumption by age and the mileage as a function of age could be used to calculate the relative energy savings. The average age of the vehicle fleet in respect to the mileage will in most cases be slightly lower compared to the average age in respect to the stock.

Since no data is available in most cases for an elaborate calculation, the relative energy savings by the introduction of new vehicles will be assessed by the simplified calculated via the average age of the vehicle fleet and the annual specific fuel consumption change of the new vehicles. Differences between the regions will mainly show up in the average age of the vehicle fleet. Also differences in the annual specific fuel consumption changes are possible due to differences in consumer choice and other factors such as taxation:

“Engineering efforts to design low-consumption vehicles depend largely on national price incentives related to existing fuel taxation. ... Therefore

- *countries with very low fuel prices (which are by international standards are subsidised, as in Russia) produce cars with high fuel consumption.*
- *Countries with relatively low fuel taxation (like the US) did not achieve any progress in the reduction of specific fuel consumption in their national markets. It is mainly*
- *countries with high and increasing fuel taxation (as in Europe and Japan) which have developed low-consumption vehicles on a national scale.” [GTZ 2003]*

9.4 Time-frame of scenarios

Energy and CO₂ savings have been analysed in detail in chapter 7.5. The scenario calculation, however, assumes an instant replacement of the old vehicle fleet with average new and additionally weight reduced vehicles. In reality however, the presented annual savings will be achieved only after the complete replacement of the existing fleet with new weight reduced vehicles. The time for a complete replacement of the fleet is different for the considered vehicles and depends on:

- Operational life-time
- Scrappage rate
- New registrations

An almost complete substitution of all vehicles will be completed after 30 to 40 years. For certain vehicles (e.g. road vehicles) an almost complete substitution of the entire fleet can be expected even earlier. The operational life-time of the vehicles analysed in this report is very different. For road vehicles the full proposed annual savings can be achieved earlier, while for long-living planes and trains an almost complete substitution the entire fleet will take about 30 to 40 years.

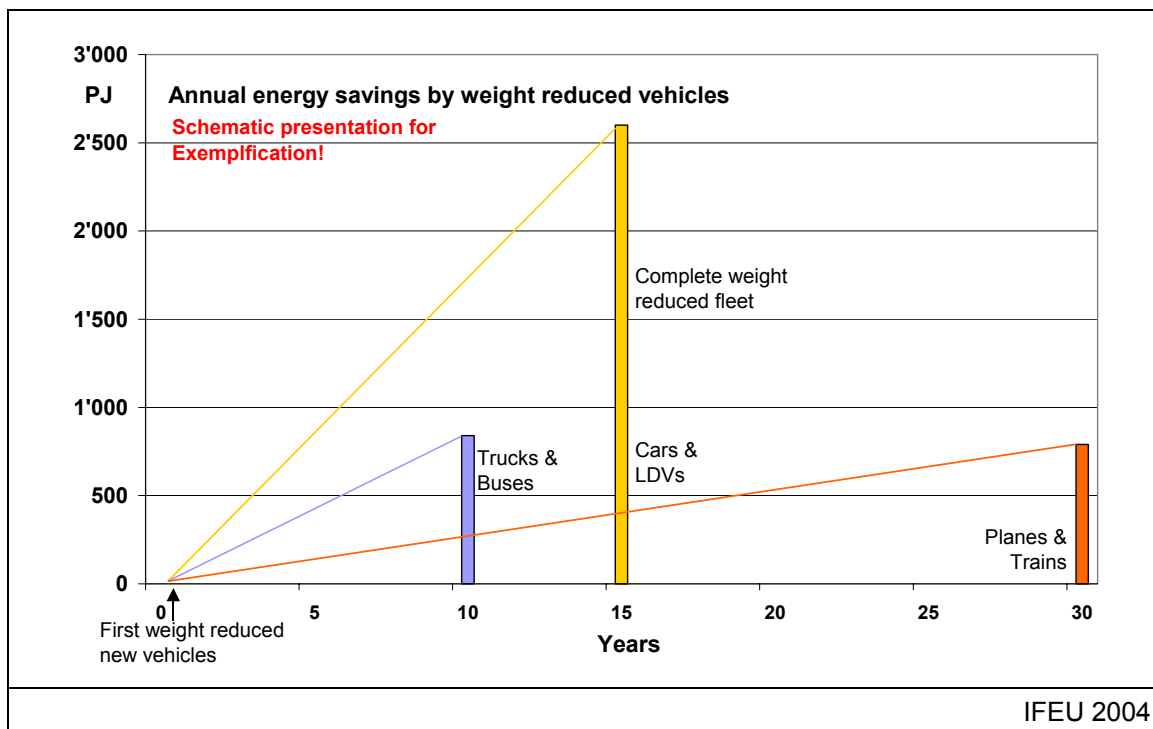


Fig. 36: Time frame of annual energy savings (schematic presentation)

Fig. 36 exemplifies a time frame for annual savings. Assuming a constant transport volume, modal split and no further efficiency improvements for new vehicles these savings can be expected to occur after a complete substitution of the current fleet. The most relevant savings from Cars and LDVs will already be achieved after an almost complete turnover of the passenger car and LDV fleet, after approximately 15 years. At that time only about 50% of the fleet of planes and trains will have been replaced and therefore only about 50% of the proposed annual savings for planes and trains occur. The full annual savings from planes and trains will only be achieved after an almost complete turnover of the respective fleets, say after 30 to 40 years.

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