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IMPLICATIONS OF GLOBALIZATION FOR CO_2 EMISSIONS FROM TRANSPORT

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Transport accounts for about 25% of global CO_2 emissions. Transport activities are on the rise in the coming decades. Would associated CO_2 emissions move upwards as well, and at what rate? The present paper explores the future of these CO_2 emissions, starting from four scenarios for global transport. Considering fuel consumption, energy efficiencies in transport, occupancy rates of transport means, size of cars on the market, and possible environmental policies we find CO_2 emissions are persistently increasing, especially in the less wealthy areas of the world. In Europe, policies that attempt to control mobility and also limit CO_2 emissions may succeed in reducing emissions growth by about 30%. Efforts to increase energy efficiency of transport, in particular road transport, would contribute most to such reduction.

Keywords: Globalization, transport; Scenarios; CO_2 emissions; Energy; Policy

1. INTRODUCTION

Among the sectors of society that contribute to greenhouse gas emissions, transport stands out for two major reasons: transport accounts currently for about 25% of global CO_2 emissions and most emission scenarios [1] state that this share is on the rise. Rapidly rising transport demand is assumed to be one of the main implications of globalization. [2] discuss future transport associated with different scenarios for globalization (cf. [3]). Their work focuses on developments in the magnitude of future transport and on future modal split. They designed four transport scenarios, which capture the future consequences for

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transport to the year 2020 under four sets of assumptions about trends in the world economy [4,5] and trends in transport technology [6].

This article delves into the implications of these transport scenarios for CO_2 emissions and, in addition, attempts to gauge the scope for mitigation of rising CO_2 emissions. The rationale behind this work is the issue of climate change prompted by CO_2 emissions and the international agreements to limit CO_2 emissions, such as the Kyoto Protocol.

This article addresses two major questions:

- What future levels of CO_2 emissions would be associated with the four aforementioned transport scenarios?
- How would policies that focus on the areas of transport, land use planning and environment impact on future levels of CO_2 emissions?

The flow of information – or steps in the methodology – to arrive at future CO_2 emissions from transport scenarios by transport mode is summarized in Fig. 1. The information that constitutes the input is shown in the boxes with text in italics.

This article is structured as follows. After Section 2 – a resume of the inputs highlighted in Fig. 1 – Section 3 presents our assumptions about developments in fuel efficiencies (or carbon intensities) and associated CO_2 emission factors. The results from combining the transport scenarios with the scenarios for carbon intensities are presented and discussed in Section 4 and Section 5 concludes.

2. TRANSPORT SCENARIOS, FUEL EFFICIENCIES AND POLICY PACKAGES

2.1. Transport Scenarios

The origins for the derivation of images of future transport are twofold. The main origin is [4] analysis of the future global economy. He elaborated four scenarios for the global economy using the *Worldscan* model [4,5,7,8], each reflecting different assumptions about trends that underlie economic developments. A second input came from [6], who reviewed future transport technology. Using these studies as starting points, [2] elaborated the world economy scenarios into a series of comprehensive scenarios for future transport covering

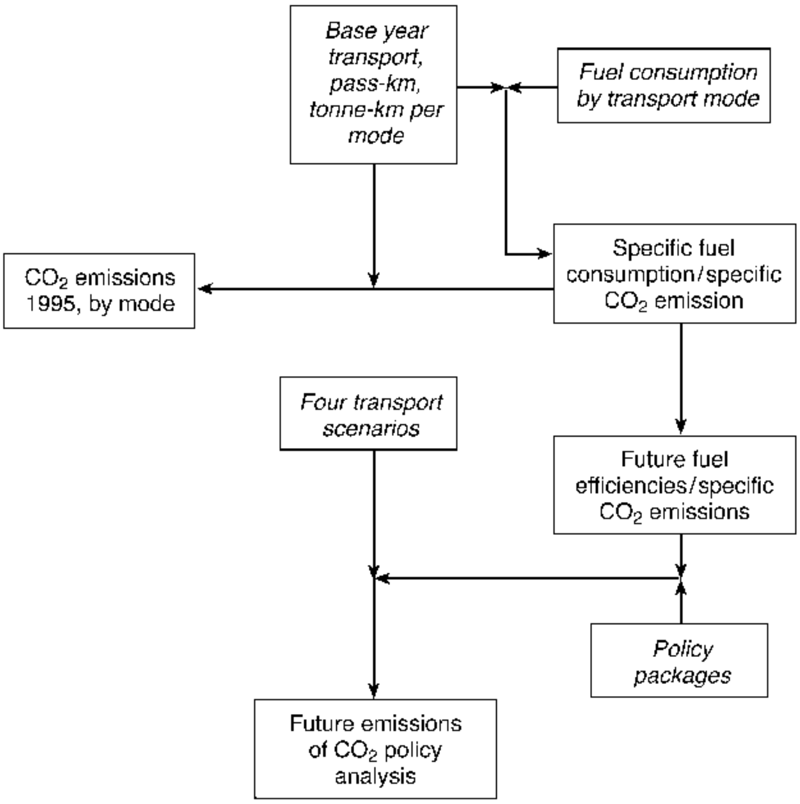

FIGURE 1 Overview of the methodology for estimating future CO_2 emissions

the period 1995–2020. They named these scenarios ‘growth’, ‘core growth’, ‘peripheral growth’ and ‘sustainability’.

The scenarios function at a global, a European and a regional (Dutch) level. In each area there is a distinction between a ‘core’ area – where most of economic activity occurs – and a peripheral area (peripheral in a purely economic sense). So there is a distinction between OECD countries and non-OECD countries (global level), between the EUR-17 countries and the central and eastern European countries (CEE countries) and, at the level of The Netherlands, a distinction between the Randstad and the non-Randstad.

Scenario 1 is entitled ‘growth’. This scenario attempts to demonstrate how transport would evolve in the geographic areas if institutional change would remove various barriers to trade, transport and communications. This development would occur under high economic growth in all regions. Rapid and wide-spread technological development is another major assumption in this scenario. The accelerated introduction of high-speed rail systems, which has an impact on modal split, is part of this scenario.

Scenario 2, ‘core growth’, is similar to the ‘growth’ scenario, for OECD countries. The non-OECD countries, however, will fail to transform their institutional and economic systems and therefore will lag behind in development.

Scenario 3, ‘peripheral growth’, is more or less the opposite of the ‘core-growth’ scenario. It states that the non-OECD countries are able to transform into increasingly efficient economies and therefore exhibit faster growth than OECD countries, where institutional change and economic development stalls.

Scenario 4, ‘sustainable growth’, is rather different. This scenario says that environmental issues will gain in importance and assumes that the outcome of strategies that pursue sustainability, will restrict growth in transport. It also assumes that public transport is desirable over private means of (motorized) transport for environmental reasons.

TABLE I GDP growth rates (%) and growth factors in selected scenarios

	Western Europe		*Randstad*		*Non-Randstad*	
Growth	2.32%	1.4	2.36%	1.5	2.36%	1.4
Core growth	2.33%	1.2	2.37%	1.5	2.37%	1.2
Peripheral growth	0.60%	0.9	0.60%	1.0	0.60%	1.4
Sustainability	0.78%	0.6	0.79%	0.5	0.79%	0.5

Source: [3, 4]

Table I summarizes the principal assumptions for western Europe (EUR-17) and The Netherlands. Transport is assumed to grow with the indicated rates, while on top of that a ‘growth factor’ [9] is applied that account for the conjectured cumulative effect of transport growing harder or slower than GDP. We present figures for western Europe and the Netherlands only since the emphasis of this article is on these areas (see Section 3).

The application of these figures to the transport statistics for 1995 produces four transport scenarios. These scenarios are assumed to reflect developments that would happen if no policies other than business-as-usual policies would be applied ([2] present the details).

2.2 Fuel Efficiencies and CO_2 Emissions

Since CO_2 emissions are essentially proportional to fuel consumption [10], the first step in the methodology (see Fig. 1) involves estimating fuel consumption associated with the transport statistics. The problems in finding fuel consumption data vary according to geographical scale. The UN energy statistics database,[1] gives information on consumption of fuel in the transport sector at a global level, unfortunately without a distinction between fuel consumption in freight and passenger transport. So the question arises: how can fuel consumption be allocated to passenger and freight transport?

There is additional information that can give some guidance in solving the problem. For instance, it is known that heavy fuel oil is not used in aviation. And in many countries petrol is the preferred fuel for passenger vehicles and diesel fuel is mostly used in freight transport. Also engineering studies indicate what one expects in terms of specific fuel consumption (e.g. diesel consumption per t/km); however, these studies also indicate that the range is wide. So to some extent we have to rely on circumstantial evidence for solving the puzzle, especially for those areas where detailed statistical information is scarce and probably unreliable. For this reason, there is uncertainty regarding the estimates presented in this article.

2.3 Policy Packages

The effects of an explicit policy are not taken into account in the transport scenarios of [2]. So the question arises: how do we influence developments in transport? This is the topic of a study [9] that developed three policy packages, which may be summarized as:

- A 'mobility' package that comprises measures that are essentially driven by individual demands. This scenario says that policy making does not aim to restrain individual mobility. Private means of transport are preferred over public transport. Investments in trans-

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[1] We used the United Nations Energy Statistics Database (as available in summer 1998) as the source of information for consumption of fuels. The advantage of this database over other sources of information on fuel consumption is that the scope is global (over 215 countries in 1995), and that the data, with respect to fuel consumption, are rather detailed in regard to transport modes. Also the statistics date back to the 1950s, allowing historical analysis. Unfortunately, there are gaps and discontinuities in the data (e.g. due to political developments). When needed, we estimated the missing data points.

port infrastructure follows demand. Urban planning is not evaluated with respect to the environmental implications of related transport planning.

- The 'ecology' package contradicts this. Environmental considerations have an important say in transport policy. Investments in transport infrastructure constitute an instrument to steer development towards sustainability. Road-pricing is accompanied with expansion of the capacity of public transport. In general, policies aim to promote environmentally friendly modes of transport and attempt to inhibit polluting modes of transport.
- The 'socio-economic' policy package attempts to strike a balance between economic (in a narrow monetary sense) and environmental interests.

For each of these policy packages [9] estimated future transport production (pass.km, t.km) by mode (road, air, rail, water) of transport. These policy packages were developed for western Europe and for The Netherlands, but not at a global level. Table II illustrates some of the key results of these policy packages for transport in western Europe. This shows that the policy packages have, for passenger transport, relatively the greatest impact on the 'sustainability' transport scenario. In addition each package implies different assumptions about energy efficiencies (and carbon intensities) in transport. The next section develops these assumptions, which deal mainly with energy efficiencies, since the latter determine CO_2 emissions.

3. DEVELOPMENTS IN FUEL EFFICIENCIES OF TRANSPORT

This section discusses developments in energy efficiencies of various modes of transport. Since CO_2 emissions (or carbon intensities) are proportional to fuel consumption, energy efficiency is the key parameter that determines CO_2 emissions. We deal with road transport, aviation, rail transport and maritime and inland water transport respectively. For each sector we estimate a base case or 'business as usual' scenario, then we attempt to assess the implications of the policy packages for developments in fuel efficiencies.

TABLE II Selected elements of European transport under different policy packages

	Passengers road (G passenger.km)		*Passenger rail (G passenger.km)*		*Freight road (G t.km)*		*Freight rail (G t.km)*	
	Mobility	*Ecology*	*Mobility*	*Ecology*	*Mobility*	*Ecology*	*Mobility*	*Ecology*
Growth	7999	7873	606	749	2576	2060	386	530
Core-growth	7351	7316	646	686	2151	1596	450	536
Peripheral	4396	4363	333	370	274	1215	266	276
Sustainability	4303	3839	361	886	1223	1112	268	287

3.1. Road Transport

For the energy intensity of road passenger transport (defined as fuel consumption per vehicle/km or fuel consumption per passenger/km), there is a suite of possible explanatory variables, including: personal income, lifestyles, fuel costs, vehicle purchasing costs, government policies (e.g. taxes), environmental policies (e.g. catalytic converters) and occupancy rates. Energy intensities vary by country. In the affluent USA, where there are no fuel taxes and limited public transport, energy intensities are the highest, in contrast with Poland, for instance. A number of studies [11,12,13] have shown that over the last 25 years energy intensities fell, but that in the beginning of the 1990s this trend halted. They show that the increases in the purchase of more luxurious, more powerful and larger cars offset the impact of technological developments towards more fuel-efficient engines. Dutch analysts came to a similar conclusion for The Netherlands [14].

For road freight, analysis [11,12] shows that energy use in road freight varies greatly between countries and that historical data (1970–1990) do not show an overall trend towards increased energy efficiency (cf. [15]). A more detailed analysis of energy efficiency in Denmark [16] shows a deterioration of energy efficiency in the period 1975–1985, an improvement in the period 1985–1990 from 3.0 MJ per t.km to 2.2 MJ per t.km, and a continuation of this trend from then onwards. The explanation of the recent development is that the average load factor did not fall. One of the reasons would be that the specific weight of cargo decreased, for instance because the share of light weight cargo (e.g. computers, flowers) increased at the expense of the transport of heavy weight cargo (e.g. building materials). Per t/km, the transport of high-volume/low-weight cargo requires relatively more fuel. A second factor in this explanation is the rising share of light vehicles (e.g. vans) in the transport vehicle fleet. The indications are that, despite improvements in logistic operations, energy efficiency in transport is not increasing, at least not in OECD countries. It seems likely that in non-OECD countries there is scope for improvement in energy efficiency with the introduction of modern freight vehicles and scrapping of older vehicles. A 0.1% annual increase in energy efficiency would be the quantitative representation of such a tentative assumption.

So, on the basis of the policy packages, what would be the corresponding options for reduction of CO_2 emissions? To begin with, we would want to know what the potential for improving road transport energy intensity is. One may distinguish two types of improvements: (i) incremental changes in current car technology and (ii) changes to 'new' automotive concepts (e.g. electric power). The latter are called 'new' since they follow a different technological trajectory, while the former would fit 'seamlessly' into the current societal and technological context of road transport. With respect to the potential for CO_2 emission reduction, the first route seems most promising for the scenario period (1995–2020). It is true that new automotive concepts such as the electrical car are being developed. The rationale behind this development, however, tends to be local air pollution, problems due to nitrogen oxides (NO_x), volatile organic compounds (VOC) and particulate matter, rather than global pollution problems. These problems occur in densely populated urban areas (e.g. city centres) with unfavourable meteorological conditions. With respect to CO_2 (which is a global pollutant), the electric car does not have a real advantage over the internal combustion engine powered car [17]. Another reason for not considering new concepts (e.g. fuel cell powered cars) is that the scenario period is 25 years, which is short compared to likely lead times for marketing new transport concepts.

[12] reviewed studies on possible incremental changes in conventional automotive technologies. These studies indicated that, according to current technological capabilities, cars up to 50% more energy efficient than the 1990 types could be marketed. However, there are costs. [12] summarized these studies in two statistically estimated functions that relate purchasing, or car cost increases (CCI), to energy intensity reductions (EIR). These functions range from $CCI = 6.489 \times EIR^{2.6381}$ to $CCI = 0.001 \times e^{10.203*EIR}$. For example, at a cost increase of 10%, these functions suggest that energy intensity reductions are estimated to be somewhere between 21% and 45%. So, with CO_2 emissions being proportional to fuel consumption, there is a substantial potential for CO_2 emission reduction for passenger vehicles within the conventional technology regime.

OECD analysts [12] concluded that without changes in government policies – the 'business as usual' scenario – the energy intensity of light vehicles (cars and vans) was not likely to fall. We assume that under current government policy the energy efficiency of light vehicles improves by 0.5% annually. This is an improvement in terms of fuel consumption per vehicle.km of new, but otherwise equal, cars. However, our transport scenarios have the passenger.km as the metric for the explanatory variable for passenger transport. Consequently, there is a question about what future occupancy rates will be. If these fall faster than 0.5% annually, energy efficiency in terms of energy consumption per passenger.km is on the rise. For The Netherlands, [18] assumed that in the period 1990–2030 occupancy rates decreased by slightly over 0.5% annually, in a 'business as usual' scenario. There is also the trend towards bigger cars, which offsets improvements in energy efficiencies of specific vehicles. Our assumption for passenger cars is that energy efficiency related to passenger.km will not change.

These observations refer mainly to OECD countries. Non-anecdotal information and analyses of trends in non-OECD countries appear to be even scarcer than in OECD countries. Therefore, the assumption on developments of energy efficiencies in non-OECD countries has a highly tentative character. We assume that energy improvements will be 0.1% per year in the period 1995–2020. Table III summarizes these assumptions for road transport.

With regard to the first of the three policy packages, the 'mobility' package presumes policies that aim at removing barriers to individuals' mobility and improving accessibility. We interpret the mobility package somewhat as a policy scenario, which assumes that the CO_2 issue will not constitute a barrier to development: energy consumption is not an issue in itself within the mobility scenario. [9] also assumed a shift in modal split, towards road transport. For fuel efficiency, this policy package would infer that passenger cars would become larger, implying a relative deterioration of fuel efficiency. Another implication would be that the number of road vehicles would increase and that two cars per family might become even more normal than it is at present. A major effect would be that occupancy rates would decrease, so energy efficiency per average passenger/km would decrease. Overall the average speed of travel would increase, implying higher energy consumption. On the other hand, car manufacturers would improve their products with respect to fuel consumption, but primarily for marketing considerations.

What the net result would be can only be guessed; however, contemporary history might give some indication. So we note that for light vehicles the energy consumption per car has been more or less constant in the period 1980–1993 [11] in countries such as the USA, Japan, France, Denmark and Italy. We assume that this trend will persist. In addition we assume that occupancy rates of cars will decrease, and that the trend towards bigger cars will also persist. The net result might be an increase in the specific fuel consumption of 0.25% per year. We assume that for freight transport there is a similar increase.

TABLE III Assumptions for energy efficiency and CO_2 emissions in road transport (1995–2020)

Area		*Annual change (%)*	*Reason*
OECD	Freight	0%	Historical (1975–1999) evidence. Improvements in technology (engines, load factors) are off-set by the relative increase of the transport of lightweight goods (e.g. computers, flowers), which is, in terms of fuel consumption per t.km, less efficient compared to transport of heavy goods (e.g. building materials).
Non-OECD	Freight	− 0.1%	Non-OECD countries will experience an improvement similar to that in the period 1975–1990 in the OECD. There will be technical and organizational changes and there will be a change in type of cargo. Therefore a slight improvement.
OECD	Passengers	0%	Historical (1975–1999) evidence. Trends that determine energy consumption per passenger.km are: (1) cars sold become bigger and have larger engines; (2) engine and other vehicle technology becomes more energy efficient; (3) occupancy rates decline.
Non-OECD	Passengers	− 0.1%	A slight improvement of 0.1% annually.

TABLE IV Policy package assumptions for energy efficiency in road transport

Area		*Base case*	*Mobility*	*Ecology*	*Socio-economic*
EU/The Netherlands	Freight	0%	+ 0.25%	− 0.5%	− 0.352%
CEE countries	Freight	− 0.1%	+ 0.15%	− 0.5%	− 0.303%
EU/The Netherlands	Passengers	− 0%	+ 0.25%	− 2.5%	− 1.125%
CEE countries	Passengers	− 0.1%	+ 0.15%	− 2.6%	− 1.175%

The ‘ecology’ policy package scenario would attempt to discourage the number of cars, to promote the sales of energy efficient cars. Several studies [12] indicate that under concerted policy action energy consumption of new light vehicles could decrease up to 2.7% annually. We assume 2.5% (in vehicle.km rather than passenger.km). For freight transport, Michaelis notes that little information is available with respect to energy efficiency. The indication is that the potential for improvements in energy efficiency is lower than that for light vehicles. Moreover, in the freight sector, an increase in the share of lightweight high volume goods increases energy consumption in terms of fuel consumption per t/km. We tentatively assume that in freight transport the potential for energy improvement is limited to 0.5% annually.

The third scenario, the ‘socio-economic’ policy package, assumes that the rise in mobility is restricted by environmental considerations in a balanced way. In relation to energy efficiency, we assume this balanced way lies somewhere between the ‘mobility’ and ‘ecology’ scenarios (Table IV).

We note that the scenarios have a simple analytical structure. The model used is strictly linear, and any interaction between different phenomena such as would be captured in an equilibrium model is not taken into account. For instance, we did not account for the so-called feedback effect [12,19] that says that when cars are more energy efficient, driving becomes less expensive and part of the energy gain is lost since owners tend to drive more.

3.2. Aviation

For the calculation of future fuel consumption and associated emissions, we also need an assumption about the developments in energy

TABLE V Assumptions for developments in CO_2 intensity of aviation (1995–2020)

Area		*Annual change (%)*	*Reason*
All areas	Passengers & freight	− 2%	Historical trends (1970–1997). Improvements in energy efficiency are the result of improved technology with respect to engines, aerodynamics, air traffic control, size of aircraft and airline operations.

TABLE VI Policy package assumptions for developments in energy efficiency of aviation

Area		*Base case*	*Mobility*	*Ecology*	*Socio-economic*
All areas	Passengers & freight	− 2%	− 2.5%	− 2.5%	− 2%

efficiency of aviation. We assume an annual improvement in efficiency (fuel consumption per passenger/km) of 2%. This is a conservative estimate compared to historical rates of 3.5% over the period 1970–1995 and 2.1% over the period 1985–1995 for US air transport [20]. Note that this trend differs from the trend in energy consumption of road passenger transport. In that case, there is no trend in the direction of better energy efficiency (and less CO_2 emissions). In our analysis shown in Tables V and VI we do not make a distinction between geographical area since aviation technology and operations are determined by developments in a global market.

In the first policy package, the ‘mobility’ scenario, this would imply giving way to various measures that facilitate aircraft operations. Investments in aircraft (probably to be more energy efficient) would increase. Also air traffic management would be improved. In sum, energy efficiency would be enhanced. We assume an additional 0.5% rate of improvement in energy efficiency. The ‘ecology’ scenario also assumes technological progress but this progress is forced by public policy. Measures would result in an acceleration of the introduction of ‘quiet’ engines and also in improved air traffic control. If the introduction of new engines would be promoted it is likely that these engines will also be more energy efficient. In sum we assume an additional 0.5% rate of improvement in energy efficiency. The third

TABLE VII Assumptions about current emission factors for rail transport

	OECD	*Non-OECD*
Passenger transport (g CO_2 per pass.km)	50	70
Freight transport (g CO_2 per t.km)	30	35

policy package, the ‘socio-economic’ scenario, would not imply any extra incentives consequently we assume no implications for energy efficiency in aviation.

3.3. Rail Transport

Rail transport differs from all other modes of transport since electricity is often used as the source of energy, implying that emissions depend on the share of electric traction and on the technology of power production. This is part of the reason why emission factors vary so greatly in the literature. An OECD document [21] showed data for freight transport CO_2 that range from 41 to 102g CO_2 per t.km. [22] estimated 38g CO_2 per t.km as the aggregate emission factor for Dutch rail freight under the assumption that 80% of the energy consumed is electric. A recent Dutch study [23] suggested 28g CO_2 per t.km for specific Dutch diesel–electric freight trains. A Danish study [16] indicated that the energy intensity of aggregate rail transport declined from about 1.6 MJ per t.km to about 0.9 MJ per t.km. These intensities correspond to about 35g to 18g CO_2 per t.km respectively, if the actual source of energy is fossil fuel. For The Netherlands, electricity production (about 80% fossil fuel based) of 1 kWh corresponds to an emission of about 620g CO_2.

For passenger trains and trams, the literature also shows disparate data:

- 1.0 to 0.8 MJ per passenger.km [16] corresponding to between 20g and 16g CO_2 per passenger.km;
- 0.11 kWh per passenger.km (0.15 kWh [commuter train], 0.068 kWh [full high speed train], 0.24 kWh [Amsterdam tram], 0.245 kWh [Amsterdam Metro] [23] [Table VII]).

With respect to rail transport we assume that occupancy rates are the main factors that determine emission factors (kg CO_2 per passenger.km). We assume that the stronger the growth in passenger rail trans-

TABLE VIII Assumptions for developments in energy efficiencies in rail transport (1995–2020)

Area		*Annual change (%)*	*Reason*
OECD	Freight	0%	Capital goods (locomotives) have long lifetimes.
Non-OECD/ CEE countries	Freight	0%	Developments unknown.
OECD	Passengers	0% −0.25%	Much depends on occupancy rates. In low scenarios annual change is 0% and that in the high scenarios −0.25%.
Non-OECD	Passengers	0% −0.25%	Much depends on occupancy rates. In low scenarios annual change is 0% and that in the high scenarios −0.25%.

port the stronger the growth in occupancy rates, and the faster the rate of improvement in energy efficiency. In the lowest scenario we assume 0% improvement, in the highest scenario −0.25%, while in the intermediate scenario the improvement lies in between by linear interpolation. Table VIII summarizes the assumptions.

These highly tentative estimates are given primarily to make the overview of transport emissions comprehensive with respect to the range of transport modes. However, we note that the share of rail transport-related emissions is small. So conclusions with respect to the environmental impact of transport overall are not sensitive to errors in the estimates of rail emissions.

For freight transport we do not have indications for noticeable effects of policy packages on energy efficiency. For passenger transport one could argue the following differences. Under the ‘mobility’ package market forces have a relatively large impact on the eventual rail operations. This would imply that economic efficiency of rail operations would be important, which in turn would imply that occupancy rates would be relatively high. For instance, new high-speed rail connections will be highly successful economically. Consequently, energy efficiency would improve faster than in any other scenario – tentatively 0.5%. The ‘ecology’ policy package assumes rail transport to be environmentally more acceptable than road transport and accepts lower occupancy rates. The trade-off would be that rail transport would not improve in terms of energy efficiency because of low

TABLE IX Policy package assumptions for energy efficiency in rail transport

Area		*Base case*	*Mobility*	*Ecology*	*Socio-economic*
OECD	Freight	0%	0%	0%	0%
Non-OECD	Freight	0%	0%	0%	0%
OECD	Passengers	0% – 0.25%	0% – 0.5%	0%	0% – 0.25%
Non-OECD	Passengers	0% – 0.25%	0% – 0.5%	0%	0% – 0.25%

occupancy rates. Under the 'socio-economic' policy package some improvement would be found. Table IX gives emission factor developments for the transport scenarios. Again, the values for the intermediate scenarios are found by linear interpolation.

3.4. Maritime and Inland Water Transport

Improvement of energy efficiency is the result of the introduction of more efficient technology and better organization leading to higher load factors. Given the long lifetime of vessels (25 years and more), technological development will hardly be effective in reducing fuel consumption by the year 2020. Organizational changes may occur at a faster pace. A trend that leads to higher fuel consumption would be that the share of container transport increases. This type of transport is less energy efficient than that of bulk cargo because the weight–volume ratio is expected to decrease and container ships navigate faster than bulk carriers. Meanwhile, energy efficiency links up directly with oil prices since speed of navigation is an important economic parameter for shipping operations. Tentatively, we assume a 0% increase in energy efficiency for OECD countries and for non-OECD countries an improvement of 0.5% annually (Table X).

For inland waterway transport we assume that in the 'high' scenario energy efficiency decreases by 0.25% per year, since much of the increase in transportation is effected by faster (and more energy intensive) shipping (e.g. container shipping on the Rhine and Mississippi). There is also a trend towards a higher share in low weight/high volume goods that require relatively more energy for transport. In the 'lowest' scenario energy efficiency does not change. For the 'intermediate' scenarios, energy efficiency is determined by interpolation.

For The Netherlands we anticipate no changes in energy efficiency efficiency since inland waterway infrastructure does not allow the use of large fast ships (Table XI).

TABLE X Assumptions for developments in fuel efficiencies in shipping

Area		*Annual change (%)*	*Reason*
OECD	Freight	0%	Ships have long lifetimes.
Non-OECD	Freight	0%	Developments unknown.

TABLE XI Assumptions for developments in fuel efficiencies of inland waterway transport

Area		*Annual change (%)*	*Reason*
The Netherlands	Freight	0%	Within The Netherlands little infrastructure allowing high speed transport.
OECD	Freight	0% + 0.25%	Barges have long lifetimes. The fuel consumption of ships increases with increasing speed, while increase in size results in improvements in energy efficiency. Net result to vary. Under high growth, transport energy efficiency worsens, but only at a European level.
Non-OECD	Freight	+ 0.25%	No difference between developments in EU and CEE countries.

TABLE XII Policy package for changes in fuel efficiency in inland waterway transport

Area		*Reference*	*Mobility*	*Ecology*	*Socio-economic*
The Netherlands	Freight	0%	0%	0% + 0.25%	0% + 0.125%
WEU	Freight	0% + 0.25%	0% + 0.5%	0% + 0.5%	0% + 0.25%
CEE countries	Freight	+ 0.25%	0% + 0.5%	0% + 0.5%	0% + 0.25%

Under the ‘mobility’ policy package scenario the result would be faster ships operating at higher rates. The assumption is that for the ‘high’ transport scenario this would result in a 0.5% increase in CO_2 emissions (0.5% decrease in energy efficiency). This assumption does not hold for The Netherlands. In the ‘ecology’ scenario we assume the same developments; in this case inland waterway transport is preferred over road transport for various environmental reasons. However, in terms of CO_2 emissions per t.km, inland waterway transport will become less environmentally friendly because of the increase of the share of high volume goods. This will also affect The Netherlands. The 'socio-economic' policy package will result in energy efficiencies and emission factors somewhere in between (Table XII).

For sea transport we assume none of the policy packages will have appreciable effects on energy efficiency or emission factors.

4. RESULTS AND DISCUSSION

This article has reported the results of a research project, of which the present study was the final piece of work, aimed to assess the implications of globalization – the process of a growing and intensifying global network of economic, institutional and cultural linkages – for international transport and eventually for the global environment. The analysis is on three geographical levels: the global, European and regional (The Netherlands). The assessment is made in the form of scenarios for future transport – passenger/km and t/km – and associated CO_2 emissions, while the basic assumption is that transport can be derived from scenarios for global economic development that capture the implications of different rates of globalization. Below we present the base case emissions followed by the results for the policy packages.

4.1. Base Case Developments

For the global application we only developed a base case scenario, assuming no application of policy packages. Fig. 2 summarizes the results under such an assumption [34].

In the preceding section we indicated that, with the exception of aviation, the changes in emission factors are minor. So the pattern of future emissions reflects mainly the assumptions on developments in transport (and underlying economic developments [4]). For instance the growth in road transport emissions in non-OECD countries in the 'growth' and 'peripheral growth' scenarios is due entirely to the assumed growth in road freight transport.

How do these estimates relate to other outlooks for future global CO_2 emissions from transport? We may compare our scenarios with those developed for the IPCC's Second Assessment Report (SAR) [1]. These are shown in Table XIII. Our base year emissions for road transport (about 3200 Mt) are slightly lower than the IPCC 1990 estimate. For the year 2020 the range of emissions from road transport

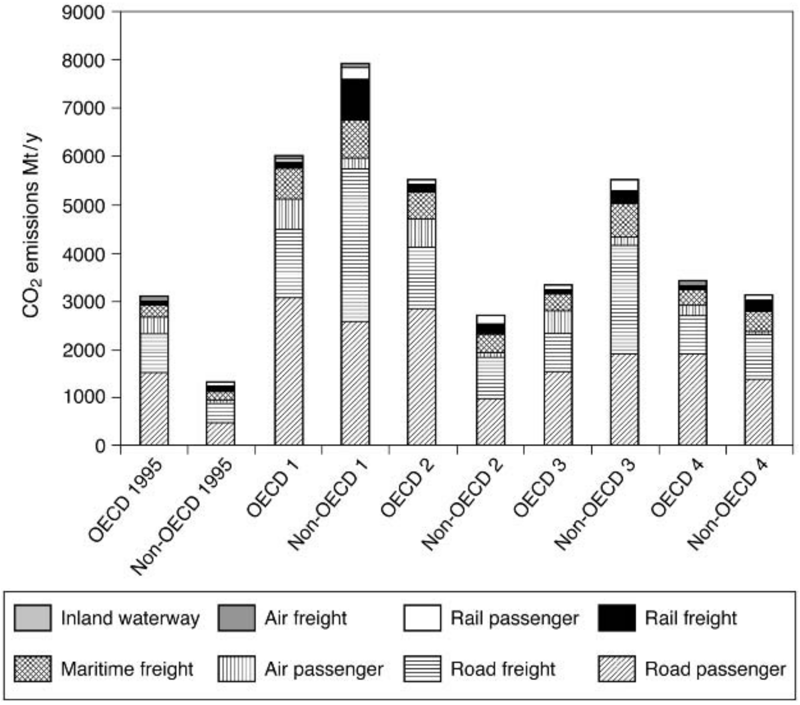

FIGURE 2 CO_2 emissions scenarios (2020)

Note: The suffixes 1, 2, 3 and 4 refer to 'Growth', 'Core-growth', 'Peripheral growth' and 'Sustainable growth' scenarios respectively.

is 4100–7900 Mt. Our estimates are higher (4500–9500 Mt) but in the same range.

The IPCC scenarios for aviation range between 1600 and 700 Mt of CO_2 emissions, higher than our scenarios. Part of the explanation would be that the IPCC scenarios include emissions from military aviation. Fig. 3 shows the emissions associated with these scenarios for western Europe and for the CEE countries. Again these estimates show that road transport is and will remain the principal source of CO_2 emissions.

Conclusions can be drawn from these results that pertain to all geographical levels:

- CO_2 emissions from transport seem to be on the rise under all conceivable futures that do not encompass explicit CO_2 reduction policies. In the more wealthy areas of the world (OECD or EU

TABLE XIII Scenarios for CO_2 emissions of transport developed under the IPCC process (SAR)

Transport mode	*1990 Energy (EJ)*	*1990 CO_2 emitted (Mtonne)*	*Traffic growth (%)*	*Energy intensity (%)*	*2020 Low*	*2020 High*	*2050 Low*	*2050 High*
Car, other personal and light goods vehicles	30–35	2035–2376	1.4–2.1	− 1.0–0.0	2244	4484	2471	8470
Heavy goods vehicles and buses	20–23	1357–1562	1.9–2.7	− 0.5–0.0	1943	3421	2779	7506
Air	8	543	3.2–4.0	− 2.0–0.6	770	1628	1089	4877
Other (rail, inland waterway)	4	271	0	− 0.3	249	293	227	319
Total		4260–4752			5207	9827	6567	21171

Source: [1]

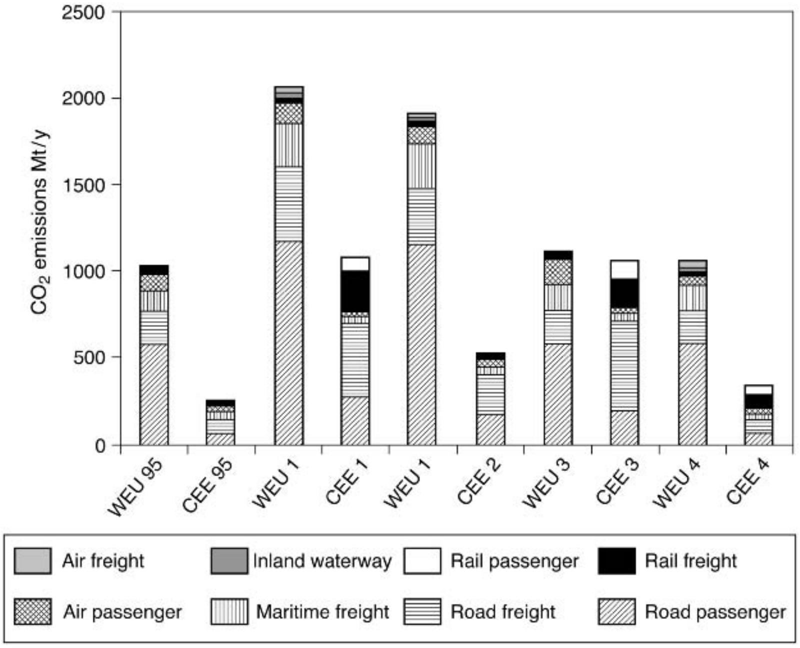

FIGURE 3 Base case CO_2 emission scenarios (2020) for EUR-17 and CEE countries
Note: The suffixes 1, 2, 3 and 4 refer to 'Growth', 'Core-growth', 'Peripheral growth' and 'Sustainable growth' scenarios respectively.

countries) emissions may double between 1995 and 2020. If economic developments in non-OECD/CEE countries catch up with the rest, emissions from transport in these countries could quadruple.
- Road transport is the main source within all transport, typically accounting for 75% of all emissions. Within this source road passenger transport accounts for over half of CO_2 emissions. In non-OECD/CEE countries the share of freight transport may rise.
- The expectations of technological developments with respect to improvements in energy efficiency are highest for aviation.
- Even under scenarios that assume low economic growth and decreasing transport intensity of economies, CO_2 emissions would rise in OECD countries. For non-OECD countries all scenarios, except for the 'sustainability' scenario, indicate strong growth and an increase in CO_2 emissions seems unavoidable, except perhaps in CEE countries under sustainability conditions. Extensive de-

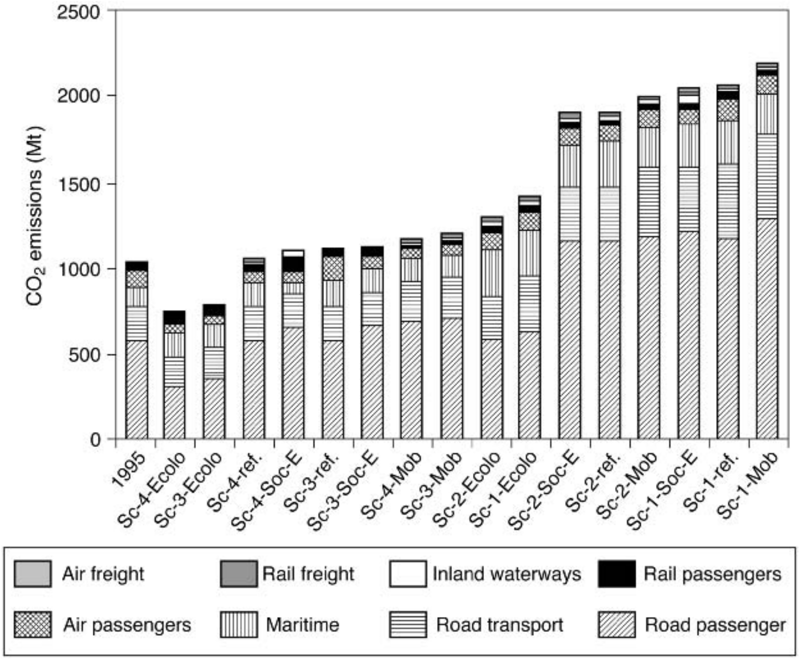

FIGURE 4 CO$_2$ emissions in 2020 by scenario and policy package (Western Europe)

coupling of transport from GDP growth is a major assumption behind the forecast that in OECD areas emissions would not grow.

4.2. Emissions under Different Policy Packages

The implementation of the policy packages would imply that in the future modal split would be different (Table II) and that energy efficiencies would be affected. When the four transport scenarios are combined with the three policy packages, 12 outcomes for emissions emerge. Fig. 4 illustrates these results for western Europe together with the base case (no policy packages) and base year (1995) emissions. (In the legend 'Sc' stands for scenario and the number for the underlying scenario (1: growth, 2: core growth, 3: peripheral growth and 4: sustainability). 'Ref' stands for the reference or base case scenario with respect to emission factors, and 'mobil', 'socio-E' and 'ecolo' for the three policy packages.)

Table 14 gives selected outcomes of these calculations. (Because the

TABLE XIV Selected outcomes of CO_2 emission calculations

	Western Europe (Mtonne)	*Randstad (ktonne)*	*Non-Randstad (ktonne)*
Emissions 1995	1033	14516	14040
Growth – mobility	2181	27497	37463
Growth – ecology	1412	22003	30877
Sustainability – mobility	1162	13822	19623
Sustainability – ecology	746	11253	16164

pattern of outcomes for the Randstad and the rest of The Netherlands look quite similar to those for Western Europe as a whole, they are not shown here for the sake of brevity.) This selection emphasizes the assumptions that are most influential on the range of outcomes on the basis of ‘growth *versus* sustainability’ and ‘mobility *versus* ecology’. The table suggests that:

- The combined effects make a difference of about 100% for both types of scenario: CO_2 emissions under ‘Growth-mobility’ are about twice the emissions under ‘Sustainability-ecology’.
- The extreme policy packages make a difference of about 30% in the results for Europe and 20% for The Netherlands.

Within the policy packages the effect of assumptions about changing modal split (Table II) may be compared with the effect on energy efficiency assumptions. This indicates that:

- Energy efficiency in road passenger transport is the main variable and constitutes the principal leverage for reducing CO_2 emissions. We have assumed that the ‘ecology’ policy package would attempt to use all technically feasible opportunities to improve energy efficiency. Under the ‘mobility’ policy package, energy efficiency would worsen slightly. Most (625 kt) of the difference (769 kt) between the European ‘growth–ecology’ and the ‘growth–mobility’ scenarios results from differences in energy efficiencies. For the ‘sustainable growth’ scenario, the difference between both extremes (746 kt and 1162 kt) is accounted for by 250 kt less emissions that would be the result of a policy that exploits the technical potential for improving energy efficiency in road vehicles. The rest of these differences are explained by differences in energy efficiencies in other transport modes. The effects of differences in modal split are minor.

- For road freight transport the potential for emission reduction is about 70 and 40 kt, respectively. However, it is a complex activity – many technologies, many different actors – and little empirical information is available to support a more detailed analysis. For this reason, there is more uncertainty regarding these figures.
- For aviation, there is a persistent trend of improvement in energy efficiency over the years. If this trend continues, CO_2 emissions will grow less than may be expected. Maximum growth of 25% is found in the 'growth–socio-economic' scenario policy package.

How sensitive are these conclusions to the main assumptions? [2] assume (see Table I) that the rate of development of transport would depend on the nature of the scenario for economic development. For instance, in Europe, under the 'Growth' scenario transport would grow 40% cumulatively over 25 years on top of economic growth. This would correspond to an annual growth in transport of about 3.7%, economic growth being 2.32% annually. Under the 'sustainability' scenario the cumulative growth in transport would be 40% less than economic growth. On an annual basis transport would decrease to about 1.2%, while the economy would grow 0.78% annually. This is a strong assumption, since studies of elasticities with respect to GDP [25] indicate values over 1. We note, however, that the transport elasticities of [2] are not quite comparable to the data in this literature (since elasticities are contingent on the actual transport context) and that historical evidence is not conclusive for the future. So one could estimate -1.2% as conceivable. However, we do not know how; we do not know what sustainable development would actually imply for the development of an economy's structure and transport pattern.

Assumptions are also made on the modal split of goods and passenger transport [2]. The conclusion of these assumptions about the eventual CO_2 emissions depends on the difference in overall carbon intensity of different modes of transports. Emission factors for road vehicle transport tend to be consistently higher than for rail transport, but the differences are clearly less than a significant order of magnitude. Noting that the scope for improvement is highest for road transport, we presume that this assumption is not critical to our conclusions. Of course the latter judgement depends on our assessment of the feasibility of improvements in energy efficiency in road transport. However, it seems that the scope for technical improvements is hardly disputed.

4.3. What Policies Would Enhance Energy Efficiency? And Who Could Pursue Them?

The policy analysis says that, if future transport CO_2 emissions would have to be below 1995 levels, three requirements should be met simultaneously:

- Sustainability should pervade economic development and policies. This would mitigate those economic drivers that push economies into transport intensive directions. A similar environmentally beneficial effect on transport would result from, for different reasons, faltering economic development in the OECD countries.
- Transport and complementary land-use policies would be directed at limiting transport activities for ecological reasons, the 'ecology' policy package.
- The 'ecology' policy package should include measures that harvest the technical potential for improvement in energy efficiencies of road transport in particular.

The first requirement would have the greatest impact. How to make sustainability a major desire of people is a question beyond transport policymaking and the present analysis. With respect to passenger road vehicles, there is a range of feasible technical options to improve fuel efficiency. Basically, three policy instruments could bring about such technical change. First, set technical standards to the fuel efficiency of cars. Such policy is pursued at a European level; however, these standards are relative and pertain to certain categories of cars. There are no absolute standards. So large cars will continue to be sold, and if consumer preferences develop as they have developed historically, these will be sold in increasing numbers. A policy that would counter such trends is the fostering of environmental awareness among the public and the introduction of energy labelling in the automobile sector. Such policy could be conducted at a country level, and several EC countries have introduced or plan to introduce such a scheme. The EU plans a Directive on consumer information regarding fuel economy (COM 98 489 final). However, since energy efficient cars would be costly, one may wonder whether there will ever be (in say 10 years) a demand for highly energy-efficient cars without additional policies in place? It seems that the car industry should be forced either directly (regulatory enforcement by fuel efficiency standards) or indirectly (market forces induced by fuel taxes). For instance, a tax on the sales of new cars that is proportional to engine size, or, as is also advocated

[14,26] proportional to the size of cars. A fuel tax would also be an even more appropriate instrument.

In aviation the situation is different. If it were true that market competition in the aviation industry is the main driver behind improvement in efficiency, we may expect little from additional pressure from governments. However, there is an indirect influence on energy efficiency in aviation, if environmental legislation with respect to aircraft noise and NO_x emissions fosters the purchase of new aircraft (e.g. equipped with more energy efficient engines).

Maritime transport ranks third in the list of sources of CO_2 emissions (for Europe), higher than aviation. We have assumed little change in the energy efficiency of maritime transport. The effects of technological progress in propulsion systems and hull design were assumed to be off-set by the advent of high speed transport, while it also is recognized that lead times of technological change in shipping are frequently compared to the scenario period (25 years). It is likely that possible growth in maritime transport will be associated with the growth in (high-speed) container shipping, rather than with the transport of bulk cargo. A similar development would occur in inland navigation. As in aviation, developments in energy efficiency are the result of market mechanisms. So far it seems that speed of transport and transport reliability are more important than transport fuel costs. We note that, as in the case of domestic aviation, fuel sold to international shipping is exempted from tax by international treaties. This makes the idea of putting a charge on these fuels less feasible [27].

For an assessment of the impact of a new technology over a period of 25 years, one needs an impression of the possible pace of the introduction of such technologies. For instance, for maritime transport and aviation we have already noted that aircraft and ships have lifetimes of over 25 years. So, it would take more or less the scenario period before a new generation of aircraft and ships would fully manifest itself in reduced CO_2 emissions. For changes in land transport technology that require new types of transport infrastructure (presumably with lifetimes beyond 25 years, and which require large capital investments), the impact of new technologies will be felt even later. So we do not assume a significant role for new vehicle propulsion technologies such as fuel cells, which may be significantly less carbon intensive than the conventional car. Electric vehicles pose no large advantages over conventional vehicles with respect to carbon intensity, under the assumption that electricity is produced from fossil fuels. Also we do not expect an appreciable share of electric vehicles in the market since we assume that the market niche for electric cars is limited.

5. CONCLUSION

Outlooks have been constructed for future CO_2 emissions for OECD and non-OECD countries, for eestern-European and central and eastern European countries, and for The Netherlands. These were built on scenarios for global economic development, on assumptions about the development of transport intensities of economies and on base case 'business as usual' assumptions for technological development (energy efficiency) in transport. The scenarios pertain to the period 1995–2020.

The scenarios that capture high-economic growth and an associated increase in the transport intensities of economies show a doubling of emissions in the wealthy areas and a quadrupling of emissions in the less-wealthy areas of the world. Under conditions of low economic growth and a reduction of transport intensities, CO_2 emissions in the wealthy areas grow slightly. In non-wealthy areas emissions may still double.

CO_2 emissions may develop differently under specific policies in the areas of transport and environment. We analysed the implications for CO_2 emissions of three policy packages, for western Europe and The Netherlands. The difference between CO_2 emissions associated with the extreme policy packages ('mobility' and 'ecology') is about 30% for western Europe. About 80% of this difference results from an improvement of fuel efficiency in transport under the 'ecology' package, mainly in road transport. This improvement would be attained by currently available technology.

European and Dutch transport emission levels can only be limited to around 1995 levels if, simultaneously, economic growth is limited, if transport intensities of economies decline and if all technical opportunities for reduction of CO_2 emissions are exploited.

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