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Environmental Aspects of Inter-City Passenger Transport

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Summary

Many governments in different parts of the world are investing in high speed rail. Some of them do so thinking that it will be an important part of climate change mitigation. Intercity traffic over medium distances is particularly interesting in the environmental context as it constitutes the only transport segment where aircraft, trains, coaches and cars naturally compete for market shares.

This report calculates the effect on emissions from building a new high speed link that connects two major cities located 500 km apart. It assumes that emissions from new vehicles and aircraft in 2025 can be used as a proxy for the emissions during a 50 year investment depreciation period. The emissions from the marginal production of electricity, used by rail and electric vehicles, are estimated to amount on average to 530 gram per kWh for the entire period. Fuels used by road vehicles are assumed to be on average 80 percent fossil and 20 per cent renewable (with a 65% carbon efficiency in the latter case).

Traffic on the new line after a few years is assumed to consist to 20 per cent of journeys diverted from aviation, 20 per cent diverted from cars, 5 per cent from long-distance coaches, and 30 per cent from pre-existing trains. The remaining 25 per cent is new generated traffic. Under these assumptions would the investment result in a net reduction of CO_2-emissions of about 9,000 tons per one million one-way trips. Assuming 10 million single journeys per year, the total reduction would be 90,000 tons.

When the price of CO_2 is $40 per ton, the socio-economic benefit of the reduction would amount to $3.6 million, which is very little in the context of high speed rail. The sensitivity analysis shows that alternative assumptions do not significantly change the outcome. One may also have to consider the impact on climate change from building the new line. Construction emissions for a line of this length may amount to several million tons of CO_2.

There is no cause to prohibit investment in high speed rail on environmental grounds so long as the carbon gains made in traffic balances the emissions caused during construction. However, marketing high speed rail as a part of the solution to climate change is clearly wrong. Investment in infrastructure for modal shift should only be considered when traffic volumes are high enough to carry the cost. The principal benefits of high speed rail are time savings, additional capacity and generated traffic, not a reduction of greenhouse gases.

Background

Intercity passenger transport is growing fast to meet demand for mobility from private citizens and the business community. A shift to fast modes of transport makes it possible to travel longer annual distances within restrained time budgets. Aviation and high speed trains are the fastest among modes. Although high speed comes at the price of negative environmental impact, many environmentalists claim, along with the companies and interest organizations of the rail sector, that high speed trains are environmentally benign and should be allowed to form an important part of climate change mitigation.

de Rus and Nash (2007 take another view; "Decisions to invest in high speed rail have not always been based on sound economic analysis. A mix of arguments, besides time savings – strategic considerations, environmental effects, regional development and so forth – have often been used with inadequate evidence to support them."

Intercity traffic over distances between 400 and 600 km is particularly interesting in the environmental context as it constitutes the only transport segment where aircraft, trains, coaches and cars naturally compete for market shares. Among the parameters that influence modal choice are price, travel time, frequency, comfort and personal safety. Environmental considerations may also play a role although rather few appear to be willing to make any larger sacrifice in terms of cost in order to contribute to a better environment.

The objective of this paper is to analyze whether the difference in environmental impact between passenger transport modes is large enough to justify government investment in modal shift. As investment in new infrastructure usually has to be written-off over 40 to 60 years, the perspective in this paper is long-term. Limiting the analyses to current differences in environmental impact between cars, buses, trains and aircraft would clearly be wrong.

A distinction is made in this paper between fast passenger trains and high speed trains. The former travel at a maximum speed of 150-200 km/h, while the latter are capable of top speeds in the excess of 250 km/h. Average speeds, however, may be lower due to track restraints.

Intermodal competition

The author assumes that few people find it acceptable to travel between cities located 400 to 600 kilometers from each other at average speeds below 90-100 km/h when infrastructure that allows such speeds or more exists. Therefore the potential environmental benefits from travelling at average speeds below 100 km/h are disregarded in this paper.

The willingness-to-pay for high speed varies among people and is closely connected to income (or having someone else pay ones bill). The fact that some customers prefer low-speed intercity trains to fast trains or high-speed trains is a sign of this. This means that investment in rail for high-speed trains will have only an insignificant effect, if any, on those customers who currently prefer local trains (with many stops) to existing fast trains. Presumably the effect on those who today prefer to travel by car will also be small, although perhaps not insignificant. The reasons for taking the time to travel by car may be reduced cost (e.g. several people travelling in one car) or that the traveler needs a car on his arrival to the destination.

Table 1 shows the time that it takes to travel from city center to city center by different modes. It is assumed that the air passenger on average has to devote a total of 70 minutes on ground level connections to and from airports and needs to check in 30 minutes earlier than a train passenger. Passenger who check-in luggage may need an additional 10 minutes. Aircrafts are assumed to spend 10 minutes on waiting and taxing. People travelling by car are assumed to need a 30 minutes break for a fast meal when the distance is 600 km.

From the table it is evident that conventional trains can compete with air traffic up to a distance of a little less 400 km. However, at 500 and 600 km it takes a high speed train to beat aviation. The fact that some people nevertheless choose to travel by aviation may be explained by several factors among them frequency of connections, price and personal preferences.

Table 1. **Travel time between city centers (point-to-point) by different modes of passenger transport, accounting for access and waiting times, and for cars at 600 km stopping for a short meal**

Mode	**Average speed, km/h**	**Distance city center to city center**		
		400 km	**500 km**	**600 km**
Passenger car	100	4:00	5:00	6:30
Coach	85	4:43	5:53	7:34
Fast train	150	2:40	3:20	4:00
High speed train	280	1:26	1:47	2:09
Aircraft	800	2:20	2:28	2:35

As most central stations are located down-town, an advantage of travelling by rail is that the journey takes you from city center to city center. However, all passengers to not have a down-town location as their point of departure or a final destination that is located in or close to a city center. For them the total travel-time may be shorter by a combination of aviation and a rental car or a taxi. A shift from fast to high-speed train may or may not make a difference for this type of customer. The difference in travel time is small already when travelling from city center to city center.

Environmental aspects

Transport affects the environment in numerous ways. The most important parameters in the context of intercity passenger traffic are exhaust emissions (NO_x, SO_x, PM and VOC), noise, and climate change. Land-use, including intrusion and barrier effects, may also be important. Calculating the environmental effects of different ways of moving people must in the context of infrastructure planning and investment take account of the anticipated technological development during the depreciation period and the step-wise enforcement of more stringent environment standards. The correct way of doing this would be to calculate the cost of emissions year-by-year and to translate future costs to present day value by a discount rate. In a world of fast technological development, the outcome to a large extent depends on the length of the depreciation period and the choice of discount rate. A long period in combination with a low discount rate (e.g. 60 years and 2 or 3%) gives a high weight to future, more environmentally benign technologies, while a high discount rate, say 4-6 per cent, means that the results are much influenced by the current, relatively large, differences between the modes. The general expectation among experts is that these differences will diminish over-time as all modes need to become cleaner and more energy efficient.

However, no expert can tell us what new vehicles and engines will look like 30 or 50 years ahead. At best they can forecast with some degree of accuracy what designs and engines that will dominate the production of new vessels and vehicles 10 or 15 years from now. Given that trains and aircraft tend to become 25 to 30 years before being scrapped, most vessels produced in, say, 2025 will still be used in 2045, which is 36 years from now. However, by then these vessels will only make up a small part of the total fleet. The life of cars and buses are shorter but newly produced passenger cars may on average become 15-20 years old before being replaced. Electric vehicles, that have very durable engines and transmission systems, may in future become even older.

One way around the problem with unknown future technologies and the choice of discount rate may be to base the evaluation of the long-term environmental performance of the different modes on what might be the best available technology in 2025, 16 years from now. The assumption would then be that these technologies will dominate transport at mid-term of the depreciation period and may be taken as a proxy for the environmental impact of a mode over an entire period of 50-60 years. In the following sections this simplified method is used for producing a rough picture of the long-term differences in environmental impact per passenger kilometer.

Tailpipe emissions

Regulated exhaust emissions occur from all types of internal combustion engines as well as from power plants that use fossil fuels or biofuel. The maximum permissible tailpipe emissions from cars and buses have been drastically reduced over the last 15 years and will continue to decline. By 2025, new vehicles may be expected to emit so little that the aggregated impact from the entire new fleet is negligible. However, as cars and buses have operating lives of 15-20 years, it will take until about 2035 for the total fleet to be clean. By then the share of electric road vehicles and plug-in electric hybrid cars may also be substantial.

The electricity used by trains, and in the future by a growing number of cars, is marginally produced in coal-fired power plants, and in most countries such plants dominate the grid. Some power plants still emit huge quantities of sulphur and NO_x. Several European power plants, most of them located in Eastern Europe currently emit more than 100,000 tons of SO_2 at thermal capacities ranging from 800 to 12,000 MW, and a number of plants, most of them British, emit more than 20,000 tons of NO_x per year (Entec, 2008). This means that the worst emit more than 20 gram SO_2 and 3 gram NO_x per kilowatt-hour produced. However, by 2025 such power plants will either have been decommissioned or have had to clean up their operations. Thus in the longer term also the regulated emissions from power plants will have been reduced to sustainable levels.

The assumption here is therefore that the remaining tailpipe emissions, if any, as well as those originating from power production can be disregarded in a long-term comparison between the land-based modes.

For aviation, the situation is more complicated. The emissions of NO_x from aircraft are a major long-term concern, however, primarily because of their contribution to climate change. Emissions of NO_x from airplanes will therefore be addressed in the below section on greenhouse gases.

Noise

Problems associated with noise from vehicles and vessels are sight-specific. It is therefore difficult or impossible to calculate average noise costs for different modes. However, a few general observations can be made. Intercity journeys by car or bus usually takes place on motorways or other high-standard roads that allow speeds of 90 km/h or more. At such speeds the tire-to-surface noise dominates over engine noise, which means electrification of road vehicles will have limited impact on equivalent noise levels. On the other hand, motorways and other major roads are often built as to avoid crossing through minor towns and other settlements. That means fewer people are victims of such road noise compared with noise from railway lines which for historical reasons were often designed to go through the heart of towns. However, new high speed lines may also avoid crossing through smaller towns where no stop is made anyway.

A 50 per cent reduction of external noise from trains and aircraft appears to be technologically possible. Additional improvement can be achieved by using noise-absorbing road surface materials or install absorbents close to the railway track. Shielding by noise-protection walls may significantly reduce the impact but only relatively close to the barrier. People living further away will be affected by the diffuse background noise that barriers cannot stop. Where aviation is concerned, the only way of shielding is by improved insulation, particularly of windows.

The noise created by large carriers amount to less per passenger kilometer compared with an equally high sound from a smaller vehicle or vessel. Trains that can seat hundreds of passenger therefore create less noise per passenger kilometer than cars even when making much more noise when passing. However, in the road environment noise is dominated by trucks. The marginal contribution of an additional car to an already busy road is small.

The conclusion is that the social marginal cost caused by traffic noise cannot be included in a generalized comparison of the different modes. A shift from one mode to another may increase or decrease the impact on human health depending on local circumstances.

Land use and landscape

The use of land and the impact on landscape is also to a large extent site-specific. However, some general observations can be made.

Aviation, for natural reasons, consumes much less land per passenger kilometer than other passenger transport modes. An additional flight generally does not cause any extra damage in this sense while growing traffic volumes may after a while require an additional runway or even a new airport.

Intercity traffic by car, bus or traditional intercity trains share infrastructure with vehicles bound for other destinations and to some extent with local traffic. The marginal impact on land-use is usually zero. It is only when congestion calls for additional infrastructure capacity to be built that more intercity traffic will make a difference. If new capacity is created simply by adding a new lane or track, the marginal effect on land-use is limited and no new barrier is formed.

Introducing high-speed trains where no previous infrastructure for such trains exists requires a new railway especially designed for this type of traffic. High speed traffic requires a layout with large radius curves and limited gradients.[1] The horizontal curve radius must be at least 5.5 kilometers to accommodate speeds of 300 km/h, and should ideally not be less than 7 kilometers (UIC, 2008a).[2] For these reasons high speed tracks are often built in new corridors although partial location to existing railway or motorway corridors is sometimes possible. This means new land is occupied and new barriers are created.

A potential side-effect of building a new line for high speed trains is that more room is left for other types of train on the pre-existing rail infrastructure. Proponents of high speed rail often claim that the creation of new corridors makes an expansion of goods transport by train possible in otherwise congested railway systems. An indirect effect of this may be that a shift from road to track will reduce the overall environmental impact of freight transport. However,

[1] However, high speed trains can tolerate somewhat steeper gradients than conventional trains.

[2] For speeds of 200 km/h a curve radius of 2.5 km is sufficient (and 3.5 ideal).

for this to happen there must be a latent demand for transport by rail that could previously not be met for lack of capacity.

Theoretically, rail because of the high capacity of trains require much less land for a given number of passenger than roads (although buses require less space than cars). However, to be able to make maximum use of this advantage all trains should run at the same speed and stop at the same stations. Mixing fast and slow trains with each other, and passenger trains with freight trains, may significantly reduce the actual capacity of a railway corridor.

Climate change

The transport sector's contribution to climate change appears to be the only environmental parameter of great concern in a long-term perspective. The remaining part of this paper will therefore be devoted to the question of whether modal shift in intercity passenger transport would do the climate any good. It starts with providing current data and assumptions concerning the future energy-efficiency of the various modes. It then discusses the issue of how to calculate the short-term marginal effect on greenhouse gas emissions, and finally goes on to analyze the impact on actual emissions of load factors.

Calculating carbon emissions well-to-wheel is a complicated matter. In this short paper the comparison between emissions, direct or indirect, from rail, road and aviation are based on tank-to-wheels for diesel and gasoline cars and on fuel-to-electricity for electric trains and cars. This means that for road and aviation fuels, the extraction, refining and delivery of fuels to gas stations have been omitted, and for electricity, the extraction and transport of coal to the power stations as well as any grid-losses. In both cases these emissions amount to 10-15 per cent of the well-to-wheel emissions.

Electric trains

Modern fast passenger trains travelling at a medium speed of 150 km/h use 0.031 to 0.045 kWh per seat kilometer (Lukaszewicz and Andersson, 2006), while high speed trains at service speeds of around 250 km/h require 0.041 to 0.065 kWh per seat kilometer (RSSB, 2007). The Japanese Shinkansen 700 consumes as little as 0.029 kWh due to a wide-body and large train length which results in more seats per length meter and a very high total number of seats. As the gauge in many countries, notably in most of Europe, does not allow wide-bodies that can seat 2+3 passengers, the following sections focus on trains that seat 2+2 passengers.

Passenger trains need energy for:

- accelerating up to speed
- overcoming resistance to movement
- climbing gradients
- powering control systems
- lighting, heating, cooling and ventilating the carriages

The energy needed for accelerating up to speed is defined by the weight (mass) of the train and the speed. This kinetic energy increases with the square of the speed and so does the aerodynamic resistance, i.e. the drag needed to push the train through the air (UIC, 2008b). Therefore moving the train at 300 km/h will require four times the energy needed for a trip in 150 km/h (all else equal).

The rail sector is committed to reducing the average electricity consumption by different types of trains by investing in new technologies and by making operations more fuel-efficient. CER, the Community of European Railway and Infrastructure Companies has committed to an overall reduction of 30 per cent in CO_2 emissions per passenger and ton kilometer between 1990 and 2020. The companies will make use of new or improved technologies as well as "Eco-driving", active traffic management and efficient timetabling (UIC, 2008b).

Some railway companies have already achieved reductions of this magnitude. In the UK the specific primary energy consumption in passenger rail transport fell by 25 per cent between 1995 and 2006, and Deutsche Bahn reports reductions by one third between 1990 and 2007 for both freight and regional passenger traffic (UIC and CER, 2008). However, the primary energy consumption in passenger long distance traffic was not reduced at all, presumably reflecting a shift to higher average speed.

Actual consumption per seat kilometer depends on:

- Train length
- Number of seats per length meter
- Aerodynamics
- Weight
- Tunnel length and tunnel diameter
- Average speed and top speed
- Number of stops and accelerations/decelerations due to changing speed limits
- Engine efficiency and degree of regenerative braking

Reducing air drag is the single most important measure for cutting electricity consumption at high speeds. Nose and tail need to be adequately streamlined. Bogie shielding, removal or shielding of roof-based equipment and closing inter-car gaps are other measure of importance. Much of this is cost-effective already at speeds between 150 or 200 km/h and should be demanded by any cost-conscious operator and delivered by all train manufacturers. However, the fact that energy consumption (all else equal) rises dramatically with speed indicates that there may be some very expensive measures that pay-off only in high speed trains.

The impact of tunnels on aerodynamic resistance depends on the narrowness of the tunnel area and is larger for single-track than for double-track tunnels. If tunnels make up 10 per cent of the distance of a high speed line they may increase overall air drag by around 8 per cent and the overall energy consumption by 5 per cent.

The number of seats per length meter is also highly relevant for energy consumption (at any speed).Travelling at high speed over medium distances may allow the operator to save some space by substituting a bistro or restaurant car by trolley catering.

As shown in Table 2, the estimates of the difference in energy consumption between conventional intercity trains and high speed trains vary considerably. High speed trains are said to require anything from 9 to 150 per cent more energy per seat km.

Table 2. **Literature statements on the difference in energy consumption between conventional and high speed rail**

Source	**Unit**	**IC**	**HSR**	**Difference, %**
van Essen et al. (2003)	MJ/seat km	0.22	0.53	+141
Kemp (2004)#	Litre/seat km	46 (225 km/h)	88 (350 km/h)	+91
Rail White Paper (UK, 2007)	Energy/seat km	200 km/h	350 km/h	+90
Kemp 2007 (Figure 27)		200 km/h	300 km/h	+45
Network Rail (2009)	g CO_2/seat km	11.7	12.8	+9
Network Rail (2009) *	kWh/seat km	0.028 (200 km/h)	0.033 (300 km/h)	+18
Lukaszewicz and ¤ Andersson (2009)	kWh/seat km	0.022 (180 km/h) Θ	0.027-0.031 (250 km/h),	+32

Approximate figure, taken from graph
* Future trains, Hitachi Super Express vs. Alstom AGV (both 650 passengers)
¤ Future high speed train
Θ Evert Andersson, personal communication.

This range is clearly much too big. According to Network Rail (2009), running resistance accounts for 68 per cent of the energy consumed by an intercity train, while inertia and comfort functions make up respectively 10 and 22 per cent. The two latter will not change much with increasing speed for a point-to-point service. As running resistance at speeds above 200 km/h is dominated by drag, which increases with approximately the square of the speed, it seems reasonable to assume that increasing the service speed from 200 to 300 km/h should raise electricity consumption by about 85 per cent, all else equal. This is close to figures given by Zängl (1993), who says that a German ICE running at 300 km/h (constant speed) would require 83 per cent more energy per seat km than when the same train travels at 200 km/h.

The author of this paper has searched, in vain, the literature for marginal cost curves for technical measures that improve the fuel-efficiency of passenger trains, and he has in addition consulted experts without getting an answer to his question concerning how much more could be done on high speed trains compared to new conventional trains. However, the marginal cost curve for reducing air drag most likely is rather flat.[3]

[3] Evert Andersson, Royal Institute of Technology, Stockholm, personal communication, and Network Rail (2009), p. 9.

The difference between what can be done to reduce the consumption of a high speed train compared to conventional fast trains will be a result of the former being able to accept a higher marginal abatement cost and/or of a difference in train length or seats per length meter. However, the latter, assuming that operators attempt to maximise profits, would only be a result of substituting a restaurant by a trolley service, assuming that passengers can content themselves with the latter when the travelling time is short. Where train length is concerned, operators can choose to meet the higher demand for the high speed train compared to traditional services either by adding cars or by offering more frequent services (or possibly a combination).

Based on the above argumentation, it is assumed that the difference in seat km energy consumption between future 200 km/h IC trains and 300 km/h high speed trains may be in the order of 40 to 50 per cent, assuming the same number of intermediate stops. The assumption is that most of the reduction compared with the all-else-equal case comes from making the high speed train longer than the conventional train. In the sections below it is assumed that trains with such top speeds will on average run at respectively 150 and 280 km/h due to track restraints.

Diverting traffic from an existing line where the service speed is 150 km/h to a new high speed line that allows an average speed of 280 km/h would make energy use per seat km increase by at least 60 per cent (assuming use of modern technologies in both cases). The effect on air drag from 10 per cent tunneling is also considered in this choice of mark-up for high speed electricity consumption. In the calculations below, the new 2025 fast train is assumed to consume 0.018 kWh per seat km (150 km/h), while the high speed trains uses 0.029 kWh (280 km/h).

The issue of how electricity consumption affects CO_2 emissions is discussed in a later section.

Aviation

Modern commercial aircraft use on average between 0.029 and 0.039 liters per seat km.[4] Short-range aircraft, however, burn significantly more than long distance flights.

Substantial improvements in airframe design and engine efficiency as well as wide-scale use of composite materials to reduce weight is expected to take place in the next few decades. “Clean Sky” is a R&D program under the European Commission's Seventh Research Framework Program. According to the Advisory Council for Aeronautical Research in Europe (ACARE), the greening of air transport means developing technologies to reduce the environmental impact of aviation with the aim of halving the amount of CO_2 emitted by air transport, cutting specific emissions NO_x by 80 per cent. Reducing soot, water vapor and particulates emissions will also be tackled. These targets are to be reached in 2020.

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4 http://sasgroup.net (Airbus A321-200, A319-100, Boeing737-400/500/600/700/800, and MD90).

The International Air Transport Association (IATA) is much less optimistic but believes that it should be possible to reach 1.5 per cent average annual improvement in fuel efficiency to 2020.[5] The difference between ACARE and IATA can probably be explained, at least partially, by ACARE's focus on new technologies. IATA's target appears to concern fleet averages.

Based on Easyjet's Corporate Responsibility Report 2006, ATOC (2009) estimates that flying a new Airbus A319 causes CO_2 emissions of about 115 g per seat km for a 300 km flight and 85 g for a flight twice that long. This corresponds to 0.046 and 0.034 liter of kerosene respectively. Boeing claims that the new 7E7 "Dreamliner" will require only 0.017 liters per seat km, while Airbus says the A380 will consume less than three liters per 100 passenger km (RSSB, 2007). Assuming a 70 per cent load factor, the latter means 0.021 liter per seat km. However, these figures are for long flights. One might have to multiply by 1.5 to arrive at figures that correspond to the fuel consumption of short-hauls (RSSB, 2007)

ATOC (2009), referring to work done for the British Committee on Climate Change, thinks that CO_2 emissions from short-haul flights can be reduced by 35 per cent by 2025 compared with 2006, resulting in 62 g CO_2 per seat km. This corresponds to 0.025 liters per seat km and is the value that will be used in this report. It should be recognized that shifting from jets to turbo-props would reduce fuel consumption further, however, at the price of lower speed.

Aircraft emit several other gases and substances that contribute to global warming, among them NO_x, water vapor and particles that form ozone and contrails and may contribute to the formation of cirrus clouds. To take account of this contribution, the aggregated impact of aviation is sometimes calculated by multiplying the radiative forcing of the aircraft's CO_2 emission by a factor of 1.5-2.5. An earlier study by the IPCC (1999) even suggested a factor of 2.7. However, technological development will reduce these emissions substantially until 2025, where NO_x is concerned probably more than CO_2. Of relevance in the context of short-distance flights is also that the aircraft cruises at high altitude during a relatively short part of its journey and often does not reach the tropopause at all. Therefore it makes sense to use a relatively low factor. Econ (2008) suggests factor 1.3 but this report will use factor 1.5.

Passenger cars

New cars sold in Europe in 2008 on average emitted 154 gram CO_2 per kilometer when driven according to the official EU test cycle. Emissions in real traffic are probably higher, in particular in areas plagued by congestion. An EU directive limits emissions from new cars of average size (weight) in 2015 to 130 g/km and indicates that the limit may be as low as 95 g/km by 2020. The assumption here is thus that new fossil-fuelled cars, including electric

5 *Airlines present climate change proposals to heads of governments*. Press release 22 September 2009.

hybrids, may on average emit 85 gram in 2025 when driven as prescribed by the European test cycle. However, emissions in intercity traffic may differ a bit from those resulting from the test.

Speed has a large impact on fuel consumption, not only in trains, but in any type of vehicle or vessel. Tests made by the Swedish National Road Administration (2000-2001 models) indicate that emissions at constant speed are 30 per cent higher at 110 km/h compared to 70 km/h. Nevertheless, today´s cars emit more in the urban part of the test-cycle than in the part that represents driving in rural areas. This, however, may change when most cars are equipped with start-stop functions and systems for regeneration of braking energy. The use of full hybrids will have a much greater impact on fuel consumption in urban driving than on the highway. In the long-term the difference in average fuel consumption between the urban and the rural part of the test cycle is likely to be small.

In addition, one should be aware that the rural part of the cycle does not include much of motorway speeds. On the other hand, modern future cars will be equipped with cruise control and other assists that help the driver to keep the speed constant, thereby avoiding the efficiency losses associated with variations in speed. Therefore the assumption here is that the average new fossil-fuelled car will in 2025 emit 105 gram CO_2 per km when driven on non-congested motorways where the speed-limit is 120 km/h and the average speed is around 110 km/h. This represents a level 24 per cent above the assumed emission limit when new cars in 2025 are driven according to the test cycle and equals 21 gram per seat km.

Plug-in electric hybrids and all-electric battery cars that are charged from the grid may become common by 2025. Provided that air drag and rolling resistance are similar to those of the fossil-fuelled cars of the same vehicle generation, one may expect these electric vehicles to consume on average around 0.15 kWh per km when driven according to the European test cycle (King, 2007, and Hacker et al, 2009. Under motorway conditions the specific consumption may increase to 0.19 or 0.20 kWh per km. Thus, this paper assumes that the average consumption when used for intercity journeys will be 0.2 kWh per vehicle km and 0.04 kWh per seat km. The issue of how grid electricity affects CO_2 emissions is discussed in a later section.

Long-distance buses

Megabus, a British company, reports an average fuel consumption of 0.577 liter per km for its double-deck Stagecoach Megabus, presumably under rather mixed traffic conditions (no details provided).[6] This equals 0.0063 liters per seat km. Norges Naturvernforbund (2008), based on data from Volvo, says that an annual average for the Volvo 9700 when used in intercity traffic is 0.28 liters per vehicle km. This corresponds to 0.0054 liters per seat km.

[6] http://www.megabus.com

The current long-term potential for improvement appears to be in the order of 25 per cent.[7] This translates into 0.21 liters per vehicle km for a new bus in 2025 when travelling on motorways with little variation in speed and making few stops. This means 0.0040 liters per seat km and 10.5 gram CO_2 per seat km. Eco-driving may reduce fuel consumption further but is not accounted for here.

Emissions indirectly caused by electricity consumption

When comparing the impact of different modes, studies often use average power production emission figures for electric trains assuming that they run on that mix. This may be correct when wanting to illustrate the actual impact of traffic during a given (historical) year. However, when the task is to analyze the consequences of investments made to facilitate modal shift, it is necessary to base the assessment on the marginal effects on production and emissions from growing or declining demand.

Growing demand for electricity may coincide with a growing number of windmills and other carbon-free means of power production, but in most countries and regions coal-fired condensing stations will remain the marginal form of production for the foreseeable future. That means under normal conditions that any change in demand will either increase or decrease the use of coal or lignite. A successful and large scale introduction of Carbon Capture and Storage (CCS) may in the long term change this, but it is currently impossible to know to what extent this method will be used by 2025. In the absence of CCS that covers all fossil-fuelled power stations connected to a grid, any increase in demand will, in the short to medium term, slow down the replacement of coal by more environmentally benign sources of electricity.

In this context it is also necessary to note the outcome of shrinking demand for electricity on emissions of CO_2, regardless of whether demand is declining as a result of a recession or because of energy efficiency improvements. Short term, the power plant with the highest variable production cost would be the unit to close first. This will, especially under emissions trading, normally be plants that use lignite or hard coal. Wind mills and hydro power stations would not reduce production in a situation of diminishing demand. For this reason the European Union's Directive on Energy End Use Efficiency and Energy Services (2006/32/EC) recommends that the effect of electricity efficiency improvements should be multiplied by 2.5 to reflect the reduction in primary energy consumption.[8] It would be very strange, indeed, to use marginal figures when demand is shrinking, and average figures in situations of increasing demand. However, this is what the rail industry sometimes does.

From the above it is obvious that in a system-perspective a shift from aircraft, cars and buses to electric trains would reduce demand for kerosene, diesel and gasoline and increase the use of coal and gas.

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7 Edward Jobson, AB Volvo, personal communication.

8 2.5 equals an electricity efficiency of 40% which is normal in coal-fired condensing power stations.

Some argue that the introduction of carbon dioxide emissions trading means that taking the marginal effect into account has become obsolete. The emissions will not be allowed to exceed the cap no matter how much demand for electricity increases. The only effect would be that scarcity will make the price of allowances rise. This way of arguing would be reasonable if the cap was set to reflect the final target of cutting the carbon emissions of Annex 1 countries by 80 or 90 per cent below their 1990-levels. However, the caps under discussion in Europe and the United States are intermediate targets for 2020 that are only the first steps on a long journey to sustainability.

If scarcity leads to a fast increase in the equilibrium price of carbon, there is reason to fear that politicians may deviate from their current long-term plans. A high or fast rising price may make them hesitate about the future of the cap-and-trade systems, and the caps of the next stage might be set higher than would have been the case at a lower price of carbon (WWF, 2009).

Another difficulty in the context of emissions trading is that the European Emissions Trading System (EU ETS) covers CO_2 emissions from power production but not emissions caused by cars and buses. Aviation will be included from 2012. In contrast, the proposed American scheme (The Waxman-Markey Bill)[9] covers not only fossil energy used in power production but also emissions from fuels delivered to any mode of transportation (by an up-stream approach). As all emissions from transportation are subject to the scheme, one could argue that any expansion of demand for road fuels could not alter the cap. If so there would be no need to worry about gas-guzzling SUVs. However, also in this case there is an evident risk that a high price will prevent future politicians from following the route outlined in the bill, which says emissions should be cut by 80 per cent by 2050 from 2005 levels.

A claim that cap-and-trade systems reduce the marginal climate effect to zero can under no circumstances be used on only one mode of transport (rail), and if used on all, there would be no ground for the rail sector to claim that high speed rail has an environmental advantage over road and aviation as the effect of modal shift on greenhouse gases would by definition always be zero. The conclusion here is therefore that the marginal long-term effect on greenhouse gases is the most suitable way of comparing the environmental performance of transport by different modes.

In power production the marginal emissions may differ somewhat depending on whether hard coal or lignite is used and whether coal is sometimes replaced by natural gas as the marginal source of production. In some systems other means of production may temporarily replace coal, for instance during periods of low demand or periods of high production in hydro power stations. The efficiency of marginally used coal-fired power plants may also differ from time to time and from grid to grid.

A successful climate change mitigation policy will require that coal-fired power plants are gradually phased out or alternatively equipped with CCS. In this paper the use of lignite is assumed to have been terminated by 2025 (or equipped with CCS). In the even longer term,

9 The American Clean Energy and Security Act of 2009.

natural gas may have replaced hard coal or all hard coal-fired plants may have installed CCS. In a successful climate change policy, aiming at 80 per cent reduction by 2050, hard coal (without CCS) may have been phased out by 2035 and replaced by renewable energy, nuclear power and natural gas. The latter would then be the new marginal production fuel.

In order to reflect emissions during an entire depreciation period of 50 years for investment in new rail infrastructure one might assume hard coal to be the marginal production fuel during the first two decades and natural gas during the last three. Electricity produced in a coal-fired condensing station with 40 per cent production efficiency gives rise to an emission of about 800 gram CO_2 per kWh electricity produced, while natural gas used in a plant with 58 per cent efficiency emits 350 gram per kWh electricity. This gives an average of 530 gram per kWh for the entire period. This figure disregards the fact that one may have good reasons to give higher weight to emissions in the near future compared to those produced 30 or 40 years from now.

Alternative estimates may be plausible and should, of course, be applied equally on both electric trains and road vehicles that use grid electricity.

Marginal effects of increasing demand for fossil fuels

Carbon free fuels and low-carbon fuels are also in limited supply. The global potential for producing first and second generation biofuels is much smaller than current demand for conventional fuels. This means any change in demand for road fuels will either increase or decrease the use of fossil fuels such as gasoline and diesel. Aviation is even more dependent on petroleum-based fuels. As fossil fuels are more easily substituted in other applications, they are under emissions trading (or equal taxation) bound to be the last to be phased out.

However, the European Community requires all Member States to deliver 10 per cent of the demand for road fuels in 2020 in the form of biofuels or electricity. Most States are expected to respond by making the oil companies market diesel or gasoline that is blended with renewable fuels such as biodiesel or ethanol. This low-blend may over time increase somewhat. The assumption here is therefore that a mandatory blend of 20 per cent biofuel and 80 per cent diesel or gasoline is the typical marginal road fuel during the depreciation period. The below calculation is based on the assumption that the biofuels will reduce well-to-wheel emissions by 65 per cent (i.e. 0.65 x 0.2 = 0.13). The fact that some cars and buses may run to 100 per cent on biofuel is disregarded as focus is on the marginal effect on a system level.

In the longer term there is an obvious risk, from a climate perspective, that scarcity pricing of oil products will provide incentive for ventures in production of un-conventional oils from tar sands and shales. The Economist reports a continuing high investment in Canadian tar sand despite the financial crises.[10]

[10] *The Economist*, 5th September 2009.

However, in countries and states where the government has adopted regulations that force the oil companies to reduce the overall carbon intensity of the entire production chain, unconventional oil is very unlikely to get a foothold. Gradually lowering the caps of trading schemes will also make it difficult for these fuels to enter the market. They are therefore disregarded in the context of this paper.

Future emission factors

Table 3 summarizes the results of the previous sections of this report and provides estimates for the direct or indirect emissions of greenhouse gases from new vehicles and vessels by 2025.

Table 3. CO_2 emissions from new vehicles/vessels in intercity traffic 2025. Gram/seat-km

Mode	Emission
Cars with internal combustion engines	18.3
All electric cars	21.2
Long-distance buses	10.5
Fast trains (150 km/h)	9.5
High speed trains (280 km/h)	15.4
Short range aircraft	93.8

It may be surprising that the conventional car emits less than the electric car. This is due to the assumption that it runs on 20 per cent biofuels. With 100 per cent diesel/gasoline the emission would be 21 gram/seat km.

The reader should be aware that the above figures and the calculations carried out below disregard emissions to and from airports and train stations.

Load factors

To be able to compare passenger modes with each other one has to take account of differences in load factors. Today, on average 45-70 per cent of the seats are occupied in intercity trains with no or few stops at intermediate stations. Traditional airlines appear to have cabin factors around 70 per cent. Where high speed rail is concerned, Network Rail (2009) reports load factors for 12 different services in four countries, ranging from 42 to 88 per cent, with a median value of 64. Regional trains and long-distance buses that stop at many stations have difficulties filling vehicles over the entire distance. They seldom reach load factors above 50 per cent (de Rus and Nash, 2007) although Swebus, in fierce competition with regional and fast trains, reports 56 per cent (2008) for its Stockholm-Gothenburg service.

However, new strategies are gathering ground. Low-cost airlines achieve high occupancy rates by varying their prices, and traditional airlines and train operators are gradually learning how to improve yield management. The below calculations are based on the assumption that the average load factor in 2025 is 80 per cent for regional aircraft, 75 per cent for high speed trains, 65 per cent for conventional intercity trains and 55 per cent for long-distance coaches.[11] The conventional intercity train is assumed (in the absence of a high speed service) to make the same number of intermediate stops as the high speed train. The lower load factor compared to high speed is explained by the fact that the latter will attract more passengers, which will partly be used for offering more frequent services (see above) but will also to some extent improve the average passenger density.

The differing load factors for conventional trains (150 km/h) and high speed trains (280 km/h) means that the latter would only consume 41 per cent more energy per pkm, down from a difference of 60 per cent per seat km.

In many countries, on average only 1.2-1.5 people occupy the five seats of a passenger car. However, the occupancy rate is higher for long-distance journeys than for daily commuting and other local trips. Colleagues tend to share cars when traveling to far away business meetings, and families often choose cars before trains and aircraft when on holiday trips. Studies of the effect on car travel of introducing high speed rail use average car occupancy rates in the range of 1.5-2.2 persons (CCAP & CNT, 2006, Econ 2008a, ATOC, 2009). Thus, this paper assumes that on average 2.0 persons travel together in cars on intercity journeys (= 40% occupancy rate).

Table 4 shows the emissions from intercity journeys by new vessels and vehicles in 2025 when account has been taken for the average load factor.

Table 4. **CO_2 emissions from new vehicles/vessels in intercity traffic 2025. Gram/pkm**

Mode	**Emissions**
Cars with internal combustion engines	45.8
All electric cars	53.0
Long-distance buses	19.1
Fast trains	14.6
High speed trains	20.6
Short range aircraft	117.2

Effects on greenhouse gas emissions from modal shift

Politicians all over the world invest public money in new transport infrastructure and to the extent that they do so in order to cut emissions of greenhouse gases they favor investment in rail, including high speed lines. Making road transport shift from cars to buses would also cut emissions but does not require new infrastructure. So it is really about rail. When considering the effects on emissions of greenhouse gases from investing in new rail one must take account of the following changes that may result from the investment:

[11] RSSB assumes 60 per cent for point-to-point services.

- Diminishing emissions due to shifts from aviation and road transport to rail
- Increasing emissions due to higher train speeds
- Additional emissions resulting from new journeys that are generated by new and faster services
- The use of free capacity on pre-existing tracks when a new line is built

The last issue concerns the opportunities of reducing emissions by using the old tracks for extended freight transport and regional passenger traffic and will not be discussed here but in a later section of report.

It may be worth observing that the generation of new journeys means that passengers now spend their time and money on something that in the absence of high speed rail they would have used for some other purpose. However, there is no way of knowing what they might have done and what the carbon intensity of that activity would have been. It is therefore disregarded.

The relative importance of the first three factors will depend on the circumstances in each case. A high speed line that replaces a very inefficient line that only allows average speeds of 80 km will attract more new traffic than a line that is a supplement to or replacement for an existing service in, say, 150 km/h.

The high speed line between Madrid and Seville (471 km) attracted 5.6 million travelers in 2000, seven years after it was opened. The market share for trains rose from 14 per cent in 1991 to 54 per cent, while aviation shrank from 11 to 4 per cent, cars from 60 to 34 and buses from 15 to 8 per cent (Nelldal et al, 2003). However, at the same time the number of journeys grew by an annual average of approximately 5 per cent, and as a consequence, the number of trips by aviation, car and bus declined much less. The figures indicate that opening the new line must have attracted a great deal of new journeys that would not in its absence have taken place. High speed in combination with modest prices allows people to make trips that they under previous circumstances would not have contemplated, for instance seeing friends more often, having meetings instead of talking over the phone or attending football matches.

In the case of Madrid-Seville, travel time by train was cut by half, from 5 to 2.5 hours (UIC, 2008). Investment in high speed rail does not always result in such reduction. High speed lines between Stockholm and Gothenburg (460 km) and Stockholm and Malmoe (615 km), Sweden's three largest cities, are expected to cut travel times by respectively 27 and 44 per cent (from 2:45 to 2:00 hours in the case of Stockholm-Gothenburg). An investigation on behalf of the Swedish government (UOH, 2009) nevertheless thinks that the investment (a combination of the two new lines) would result in:

- 7.7 billion more pkm by rail;
- 1.6 billion pkm less by aviation;
- 3.1 billion pkm less by car;
- 0.1 billion pkm less by bus.

This means deviated traffic would amount to 4.8 billion pkm per year, and that the high speed links would generate 2.9 billion pkm in the form of new intercity trips. The latter constitute 38 per cent of the total expected increase in passenger transport by rail. However, the high figure for traffic diverted from cars could be put in question. Why would so many prefer rail because of higher speed when the existing rail services between the three cities are already substantially faster than the cars?

In a study for the Norwegian Government, VWI (2007) estimates that building a high-speed link between Oslo and Trondheim (464 km) would result in the changes shown in Table 5. Interestingly in this case, travel diverted from cars to rail is expected be quite small, and the share that consists of new traffic is also smaller despite a more substantial travel time reduction than in the Swedish case.

Table 5. **Diverted and generated traffic after the completion of a high speed link between Oslo and Trondheim**

	Share of total traffic, %
Diverted from aviation to train	38
Diverted from car to train	7
Diverted from bus to train	6
Total shift	**51**
Generated new traffic by train	26
Total increase in train traffic	**77**
Pre-existing train passengers	23
Total passenger traffic by train	**100**

CCAP and CNT (2006) expect diversion from cars to on average account for 47 per cent of total traffic on 12 future American high speed lines, with aviation contributing only 19 per cent and current trains 20 per cent. Such high figures for cars is presumably explained by the fact that cars have a dominating position over medium distances in the United States and that rail services in some cases do not really exist.

To be able to calculate how modal shift may affect emissions of greenhouse gases it is necessary to make an assumption concerning the split between cars with internal combustion engines and electric cars and plug-in hybrids. As the methodology of this paper is based on the emissions from new vehicles in 2025, one must base the assumption on how new sales in 2025 may be divided on different types of engines. It is assumed that traditional cars (including electric hybrids that cannot plug-in) make up 40 per cent of the market, plug-in electric vehicles 40 per cent and all-electric cars 20 per cent. The plug-in cars are assumed to run half of their annual mileage on grid electricity but as they can store only a limited amount of electricity on board, one must assume that only a tenth of an intercity journey by such a car is in electric mode. Presumably many of the battery cars will be bought for local and regional use rather than for long-distance journeys (some families will own more than one car). It thus makes sense to suppose that these cars will represent less than 20 per cent of the intercity traffic. We assume that the share is 10 per cent. That means that the share of grid electricity will only be 14 per cent for new cars in 2025 and that the average emission per pkm will be 46.8 gram.

In order to get an idea of how investment in new rail infrastructure may affect emissions of greenhouse gases a fictitious example is shown in table 6. It shows the result on emissions some years after the inauguration of a new high speed line when the service speed increases from 150 km/h on an existing line to 280 km/h. The example is based on the assumption that traffic consists of 30 per cent pre-existent train travelers, 20 per cent diverted from aviation, 20 per cent from cars and 5 per cent from buses. The remaining 25 per cent are assumed to be newly generated. The table shows the result per 1 million one-way trips between cities located 500 km apart.

Table 6. **An example of changes in direct and indirect greenhouse gas emissions from opening a 500 km high speed link that replaces an existing passenger train service**
Ton $CO_{2equiv.}$ per 1 million one-way trips

	Share of total traffic, %	**Effect on emissions, ton $CO_{2equiv.}$**
Diverted from aviation to high-speed train	20	- 9,660
Diverted from car to high-speed train	20	- 2,620
Diverted from bus to high-speed train	5	+ 38
Total shift	**45**	
Generated new traffic by high-speed train	25	+ 2,575
Total increase in train traffic	**70**	
Pre-existing train passengers	30	+ 900
Total passenger traffic by train	**100**	**- 8,767**

A reduction of about 9,000 tons per 500 one-way trips is not much of improvement. It would not even add much to climate change mitigation in a case where the total number of annual (one-way) journeys was 10 or 20 million.

The calculations behind table 6 disregard the fact that in some countries the existing rail infrastructure can accommodate higher, wider or longer trains than normal in other parts of the world. For instance, in Japan and Scandinavia the distance between the tracks is wide enough to allow for wide-body cars, which is generally not the case in Britain and continental Europe. However, reducing high speed rail energy by 15 or 20 per cent would not change the overall picture much.

Valuing CO_2

The positive effect on climate change of investing in modal shift depends to some extent on the value put on carbon.

Provided that cap-and-trade systems become a favored method for limiting the emissions of greenhouse gases and that these systems are linked to each other, there will in future be a (more or less) global price on CO_2. The economic value of achieving net reductions by investing in modal shift will thus depend on the future price of carbon. Depending on the stringency of the caps and technological development the long-term price may fall anywhere in the range of $30-80 per ton. However, by 2025 it is less likely to be much higher than $40-50 per ton CO_2. That means that the socio-economic benefit from reducing emissions as indicated in Table 6 would only amount to $7.0-8.8 million when total annual traffic amounts to 20 million journeys per annum.

Sensitivity analysis

Varying some of the main parameters 10 per cent up or down does not provide results that differ enough from the main calculation to justify a differing conclusion. Not even combining several optimistic assumptions in favor of high speed rail makes much difference. Reducing the marginal climate effect from electricity consumption by half and raising the share of total traffic that is diverted from aviation to 30 per cent (and reducing the car share to 10%) would in combination reduce emissions for every one million trips to 16,167 ton CO_2. Assuming very high figures for air traffic diversion does not make sense. It is not possible to replace more than 100 per cent of aviation and in most cases airlines will be able to keep 20 or 30 per cent of their customers. Assuming fewer generated journeys means emissions will fall somewhat, but at the same time an important part of the market for high speed rail disappears.

Not even disregarding completely the environmental impact of electricity consumption (as the Swedish Rail Administration wants it) would reduce emissions per one million single journeys by more than 16,000 to 20,000 ton, depending on whether the share diverted from aviation is set at 20 or 30 per cent. Multiplying the highest figure by 10 or 20 to get the annual contribution from a high speed line does not add up to more than approximately 0.2 to 0.4 million tons per year.

Calculating the emissions year by year throughout the entire depreciation period of the new infrastructure and discounting the cost to present day net value might produce a differing result, especially at a high discount rate. The marginal CO_2 emissions from electricity production will probably be higher in the short term but the price of carbon will, on the other hand, be lower. Using a shadow price on carbon may argue in favor of a rather high discount rate as it is essential to start cutting emissions soon in order to avoid the earth from warming up too much. This rationale means that the environmental benefit of high speed rail diminishes compared with the above example.

The calculations have been based on tank-to-wheel emissions and overhead wires-to-wheels, plus the emissions from electricity production (disregarding emissions from coal and gas extraction and grid losses). A well-to-wheel approach would not have produced significantly different results, not even in a case when the well-tank/well-to-wire emissions were twice as large for fuels than for electricity.

An important parameter that was disregarded in the above calculations is the impact on short-term emissions of building a new railway line. Building a 500 km long high speed line may cause emissions of several million ton $CO_{2eqv.}$ (Norges Naturvernforbund, 2008, and Network rail, 2009), and even if these emissions are balanced by reduced overall emissions in the longer term, they do have a short-term impact on the atmospheric concentration of greenhouse gases. There is thus an obvious risk that investment in high speed rail will add to the difficulties of keeping the atmospheric content of greenhouse gases at a level that prevents the mean global temperature from exceeding its pre-industrial level by more than 2 degrees Celsius. From a climate point of view it might be better to up-grade existing lines and to try to make people use modern telecommunications rather than investing lots of money in making us travel more.

Make your own calculation

The author of this paper has made his best to provide detailed information concerning all of the assumptions on which his calculations and conclusions are based. This allows the reader to vary the assumptions according to his or her own beliefs and make his/her own calculation.

Freeing space for freight transport - the Swedish case

Building a completely new high speed line means traffic will be diverted from the pre-existing rail network. Thus capacity on those tracks can be used for other types of trains, provided, of course, that demand for such services exist. The situation is often complex and the optimal solution may differ greatly from case to case. The Swedish case discussed below should just be seen as one example.

In Sweden, freeing capacity for freight transport is a major argument for constructing new high speed lines between Stockholm and respectively Gothenburg and Malmoe. However, before taking the step to invest in these high speed rail lines, there is cause to investigate whether capacity problems in rail freight transport can be overcome by other and less expensive measures. Improved signaling systems and investment in passing siding may increase substantially the capacity of an existing track (Nilsson and Pydokke, 2009).

In the Swedish case, part of the congestion on the Stockholm-Gothenburg line is caused by containers being transported across the country from the Port of Gothenburg. Most of the containerized goods transported to and from the greater Stockholm area travel via

Gothenburg, despite the fact that most of it comes from or is destined to far-off places like China. The Port of Stockholm in now investing in a new container port, located close to the open sea, in order to compete for this market. Hutchinson Port Holdings will run the terminal in connection with its operations in Rotterdam.

In addition a greater part of goods entering or leaving northern Sweden could use short-sea shipping. Improving the Swedish rail infrastructure at high cost does not make much sense so long as the freight trains cannot continue through Denmark to destinations on the European continent. There will be limited rail capacity over the Sound and Fehmarn Belt even after the completion of the Fehmarn Belt Bridge (Rødby-Puttgarten) in 2018.

However, one restraint on short-sea shipping is that the government enforces fairway dues on all ships calling at Swedish ports, and that these fees recover not only the short-term marginal costs but also the fixed infrastructure costs. Freight trains, on the other side, enjoy Europe's lowest track fees that do not even cover the short-term marginal cost, much less the costs associated with expanding the infrastructure. Sweden could level the playing field by enforcing the same principle of liability on all modes. This implies raising the track fee for trains and introducing kilometre-charging on heavy goods vehicles, which several Member States of the EU have already done or are in the process of doing.

The Swedish example does not apply to other countries or regions, unless they have similar conditions. In other parts of the world other alternative solutions may be more relevant, for instance increasing the use of inland-waterways and/or pipelines. "Gigaliners" fuelled by grid electricity might be an option in regions where the motorways are not crowded. Electrifying a motorway would not involve excessive cost or high emissions of CO_2.

Conclusions

There is no cause to prohibit investment in high speed rail on environmental grounds so long as the carbon gains made in traffic balances the emissions caused during construction. The rail sector, however, often claims that investment in rail infrastructure will bring large environmental benefits (Banverket, 2008, UNIFE 2008, UIC 2008). Independent research, on the other hand, concludes that these benefits are not so important (de Rus, 2008, WSP and KTH Järnvägsgruppen, 2008, Nilsson and Pydokke, 2009). The results of this report support the latter view.

Investment in high speed rail cannot be expected to contribute much to climate change mitigation. Investment in conventional fast trains may in some circumstances be significantly more beneficial. It may be time for many environmentalists to reconsider their attitude to high speed rail. While in some cases calling for huge investment in high speed rail, the environmental organizations want speed restrictions for road vehicles to be tightened, aircraft to be designed for lower speeds and ship operators to involve in slow-steaming.

The cost of building high speed lines is high, €9-40 million per km according to de Rus (2008), and 12-30 million according to UIC (2008). de Rus puts the average cost at €18 million. Huge traffic volumes appear to be the only way to recover these costs. The principal benefits of high speed rail are time savings, additional capacity and generated traffic. Wider economic benefits may also be important, however, difficult to estimate. The strongest case for high speed rail is where traffic volumes are high (de Rus and Nash, 2007).

"Only under exceptional circumstances (a combination of low construction costs plus high time savings) could a new HSR line be justified with a level of patronage below 6 million passengers per annum in the opening year; with typical construction costs and timer savings, a minimum figure of 9 million passengers per annum is likely to be needed" (European Commission, 2008).

The conclusion of this paper is that investment in high speed rail is under most circumstances likely to reduce greenhouse gases from traffic compared to a situation when the line was not built. The reduction, though, is small and it may take decades for it to compensate for the emissions caused by construction. However, where capacity restraints and large transport volumes justify investment in high speed rail this will not cause overall emissions to rise.

In cases where anticipated journey volumes are low it is not only difficult to justify the investment in economical terms, but it may also be hard to defend the project from an environmental point of view as it will take too long for traffic to offset the emissions caused by building the line. Under such circumstances it may be better to upgrade an existing line to accommodate for somewhat higher speeds as this would minimize emissions from construction and cut emissions from train traffic compared to high speed rail.

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