

RAIL AS THE SUSTAINABLE BACKBONE OF THE ENERGY EFFICIENT TRANSPORT CHAIN – A WORLD VIEW

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Abstract: The transport sector in 2010 was responsible for 23% of total CO₂ emissions from fuel combustion in the world. In the same year road transport was responsible for 72% of total CO₂ emissions caused by the transport sector globally. This high emission level was created transporting 34% of people and goods. Railway moved 9% of passengers and freight with an impact of just 3% of total transport CO₂ emissions. Worldwide, CO₂ emissions per passenger-km went down by 32% in the period 2000-2010. In the same period, CO₂ emissions per freight tonne-km shrunk by 18%. In the European Union, railways have already largely exceeded the target of 10% renewables in the energy mix. In 2010 renewables used in the rail sector were at 18% compared with only 5% in the transport sector as a whole.

This paper highlights sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change. The target is to mitigate their environmental impact through improved energy efficiency and development and deployment of low-carbon technologies. The paper considers rail energy and emissions statistics and presents aggregate data on a worldwide rail activity and energy use basis. The paper looks closely at railway electricity mixes in Europe as well as options to provide renewable electricity to railway operators. Moving towards sustainable mobility requires both integrated and efficient transport systems as well as secure and clean energy. Modal shifts to rail can be a major driver for decarbonisation of the transport sector, and the set of data presented illustrates this potential.

Keywords: emissions; energy; environmental protection; rail; renewables

INTRODUCTION

This paper shows how shifting to rail would benefit sustainable mobility: worldwide, railways generate only 3% of transport CO₂ emissions, while sustaining more than 9% of total transport activity. Rail energy efficiency and emissions are also constantly improving: worldwide rail energy consumption and CO₂ emissions per passenger-kilometre shrank by more than 30% between 2000 and 2010 [1]. This is partly due to the continued electrification of railways as more than one-third of energy consumed by railways in the world is now electricity. The sources of the energy are also discussed.

In Europe the railway sector has surpassed the EU directive target set for 2020 which requires that transport should use 10% of renewable energy. In fact in 2010 railways used just under 20% of renewable energy. Despite this success the rail industry is still very keen to improve and one example of this is the MERLIN project, (EC Contract No. FP7-314125), which is part-funded by the European Commission. MERLIN focuses on energy management as a key issue for railway systems though the development of suitable and sustainable smart energy management solutions. The target for the project is to contribute to further reduce rail energy consumption by 10% and reduce CO₂ emissions thereby contributing to a sustainable rail system. Similarly OSIRIS (Grant Agreement Number: SCP1-GA-2011-284868) is a European project that focuses on a holistic approach to the reduction of energy consumption for urban rail systems looking at the system and including vehicles, infrastructure and operation. The project has determined key performance indicators and standard duty cycles to measure energy consumption in urban rail. Solutions were then proposed and their full potential investigated by simulations and pilot tests for the most promising solutions.

Fig. 1 shows the share of CO₂ emissions from fuel combustion by sector in 2010. The transport sector in 2010 was responsible for 23% of total CO₂ emissions from fuel combustion in the world. In the same year road transport was responsible for 72% of total CO₂ emissions caused by the transport sector globally. This high emission level was created transporting 34% of people and goods. Railway moved 9% of passengers and freight with an impact of just 3% of total transport CO₂ emissions. Overall, railways generate less than 1% of the total energy-related CO₂ emissions.

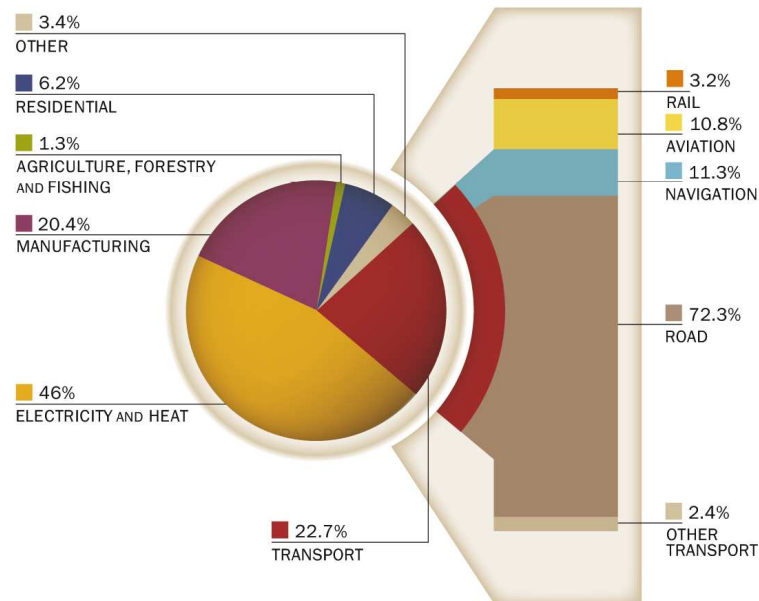


Figure 1 Share of CO₂ emissions from fuel combustion by sector in 2010, showing that transport is a significant polluter but also that rail is the least polluting. Source Elaboration by Susdef [2]

ROLE OF POLICY

Fig 1 clearly shows that fuel combustion should be a topic of interest for the transport sector and despite the good performance by the rail sector the rail industry is targeting clean European Rail Diesel. CleanER-D, (Grant No. 234338) is a European Commission partly-funded project that aims to develop, improve and integrate emissions reduction technologies for diesel locomotives and rail vehicles. Furthermore it uses innovative methods and hybrid solutions for the best possible contribution to reductions in CO₂ emissions. This research was a response of industry and stakeholders to the introduction of new legislation setting tighter GHG emission levels for European Railways. The so called Stage IIIB legislation follows the strategy established by policy makers in using regulation as a driver for innovation to reduce emissions in the transport sector e.g. Euro V (European automotive). A comparison between road and rail legislation in the EU and US targeting CO emissions is shown in figure 2

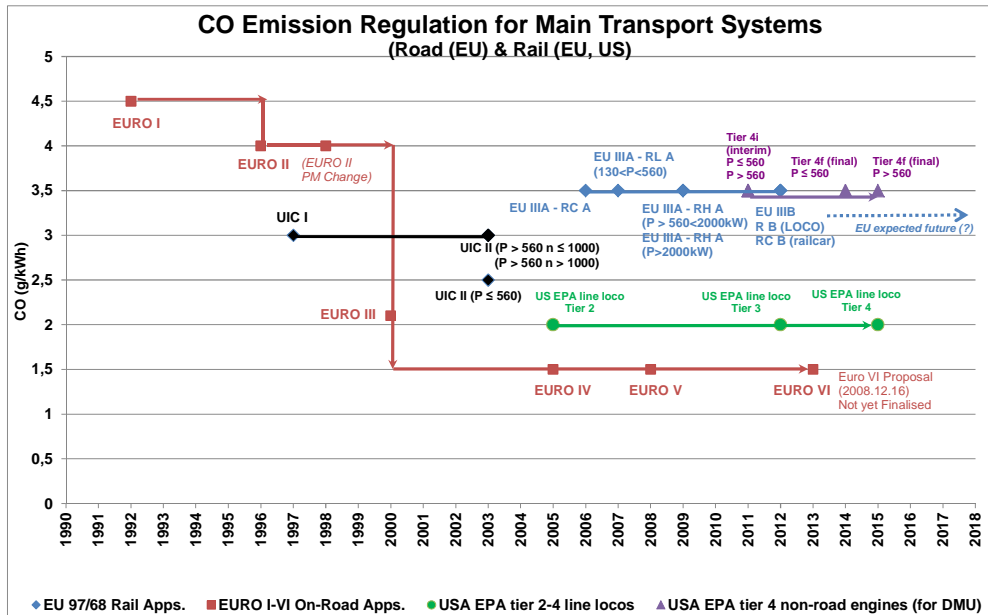


Figure 2 Carbon Monoxide Emission Regulations Compared for Rail and Road transport [3]

WORLD RAIL STATISTICS

Table 1 shows the world transport modal share in 2010. It shows that road dominates passenger transport as measured in passenger km and navigation (shipping) dominates freight in terms of tonne kilometres. For the rail sector to have an impact in terms of transport and energy efficiency the sensible target is the passenger market dominated by road. A significant modal shift for passengers from road to rail would be a very energy efficient move and would enhance the sustainability credentials of rail. The transport of bulky and heavy goods by ships is already energy efficient and these should not be targeted by rail. However the 10% of freight carried by road should certainly be considered as a target for modal shift, reducing congestion and taking trucks off the road [4]

Table 1: World transport modal share in 2010 showing the dominance of road in passenger transport and navigation (shipping) in freight transport [4]

	Passenger PKM	Freight TKM	Total TU
ROAD	83.1%	10.0%	33.7%
NAVIGATION	0.3%	79.3%	53.8%
RAIL	6.5%	10.4%	9.2%
AVIATION	10.1%	0.3%	3.3%

Fig. 3 shows the rail passenger transport activity by geographic area between 1975 and 2010. It highlights that India and China move more railway passenger-kilometres than the rest of the world combined and together they account for 61% of the total. In Russia and the US passenger traffic is not a priority. In contrast Fig. 4 shows that for freight 52% of railway tonne-kilometres are moved in North America and Russia.

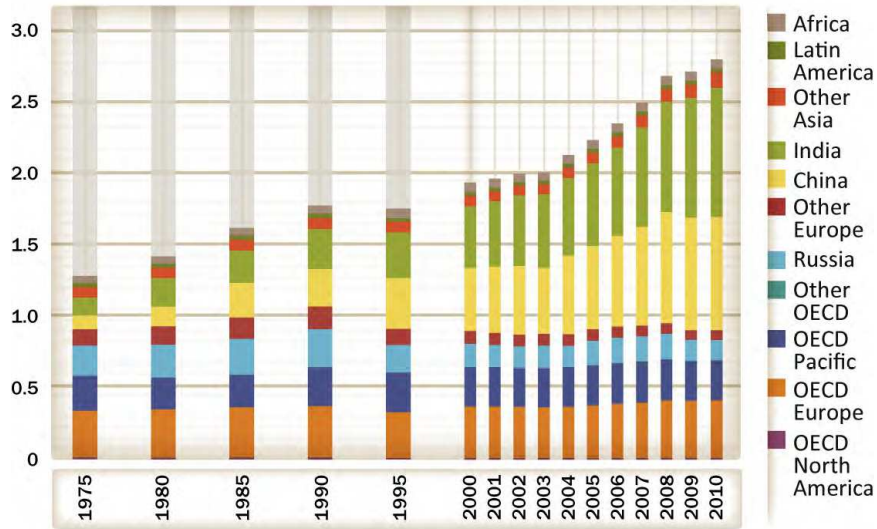


Figure 3: Railway passenger activity from 1975 to 2010 in trillion passenger kilometres showing the domination of rail passengers in India and China and the unpopularity of rail as a passenger transport option in the US: Source UIC (2012)[4]

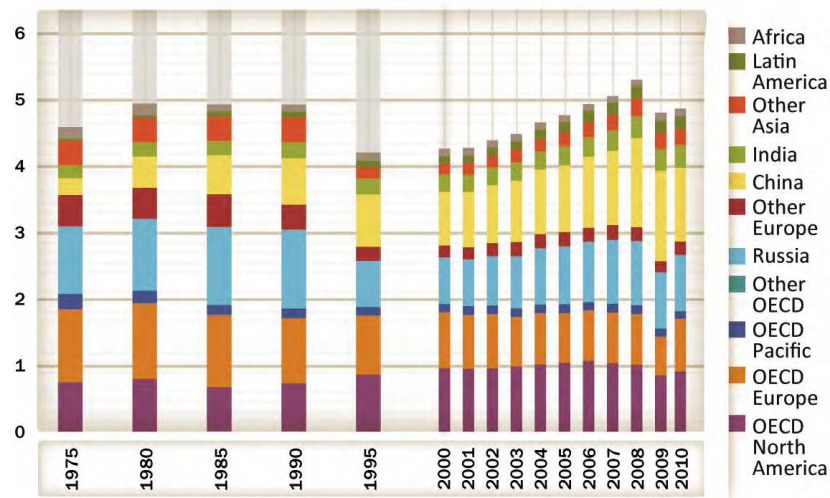


Figure 4: Railway freight transport activity from 1975 to 2010 in billion train kilometres showing the importance of rail freight to Russia and North America: Source UIC (2012)[4]

Interestingly nearly 50% of the world’s railway lines are in North America and the European Union, and although the passenger numbers are high in India and China together they only have 12.5% of the world’s railway lines. This indicates that the passenger routes have a high load factor and in turn this means less energy consumption and CO2 emissions per passenger-km. This shows the sustainability in energy use terms in China and India for rail passenger transport i.e. the figures suggest that efforts are being made to maximize the number of passenger-km using electrified railways although the sustainability of the energy mix is not considered in this particular assessment. Also in Figure 5 it can be seen that the rail sustainability credentials of India and China are enhanced when taking into account the efforts being made to electrify their rail network, India has 30% of its network electrified and China has 50%, which is particularly relevant given that 4 decades ago electrification in China was non-existent.

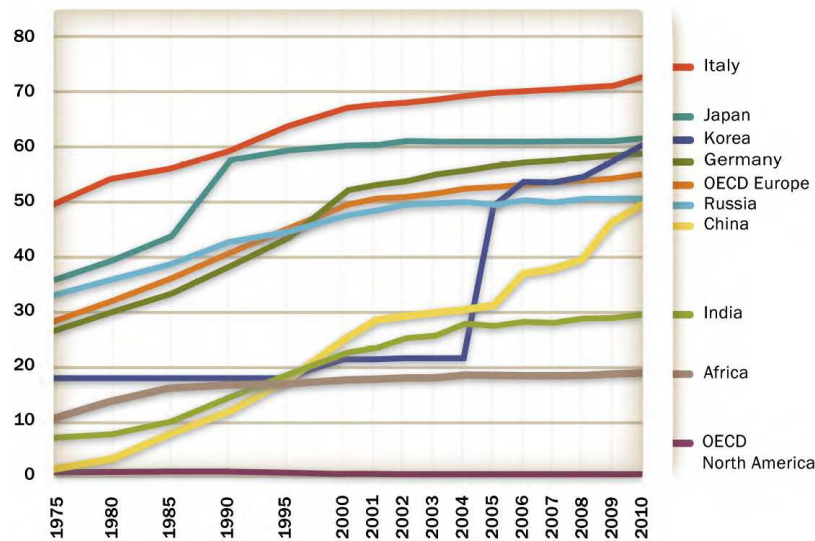


Figure 5: Share of electrified lines in different geographical areas showing that India and China have an impressive proportion of their large network electrified and North America has electrified hardly any of its substantial network: Source UIC (2012)[4]

RAIL ENERGY MANAGEMENT AND SUSTAINABILITY RESEARCH: THE URBAN RAIL EXAMPLE

The urban environment is a clear example of railways being or aspiring to be the backbone of a sustainable transport chain. A high proportion of the urban movement of people and goods requires the use of two or more transport modes and here lays the opportunity for railways to become the backbone of this chain. A wealth of research has been conducted on urban mobility and the choices we make to travel. Railway research is focusing on technologies and strategies than can enhance the energy efficiency of the system and thus enhance sustainability.

A first step in this process is gaining an understanding of how energy is used in the system, any transport system, but in particular the railways given their complexity. Fig. 6 shows the specific case of London Underground [5]. Here, stations consume about 37% of the total energy destined for non-traction purposes, while operations in depots account for 12.5% and tunnel ventilation fans for 6%. Especially noteworthy is the high energy consumption of ground water pumps, about 23% of the non-traction energy demand.

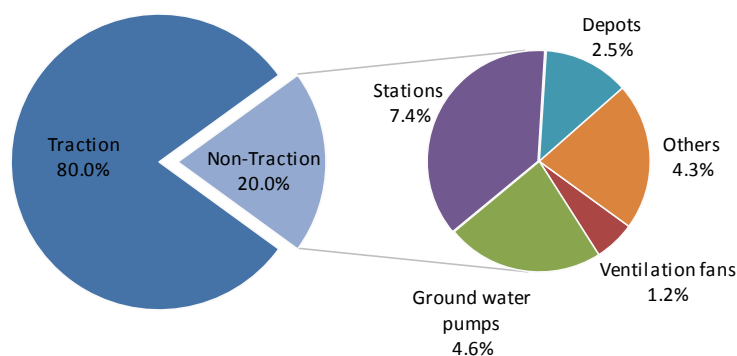


Figure 6: Distribution of non-traction energy in London Underground: Source [5]

Fig. 7 shows a typical traction energy flow chart for urban rail, a result of the amalgamation of measured and estimated consumption data for different urban rail systems within Europe, [9-17]. This diagram should therefore be considered as illustrative rather than as a representative example of the proportion of energy consumed by different traction subsystems in urban rail, as there is significant variation between different systems. Despite the excellent sustainability credentials of rail the rail sector continues to improve the energy performance of the mode by

considering the research needed to improve the situation with respect to energy losses identified in Fig. 7. For example the infrastructure losses refer to the electric losses occurring from the point of common coupling to the pantograph (or collector shoes); that is, the electric losses in the substations and the distribution network, the latter being significantly higher [18].

As seen in Fig. 7, auxiliary systems consume an important share of the total energy entering the rolling stock. HVAC equipment is generally responsible for the most significant part of this consumption, which is strongly influenced by the climate conditions [19]. For instance, it has been reported that heating systems account for 28% of the total traction energy in Metro Oslo [14], whereas all auxiliary systems represent about 10% of the total vehicle consumption in London Underground [15].

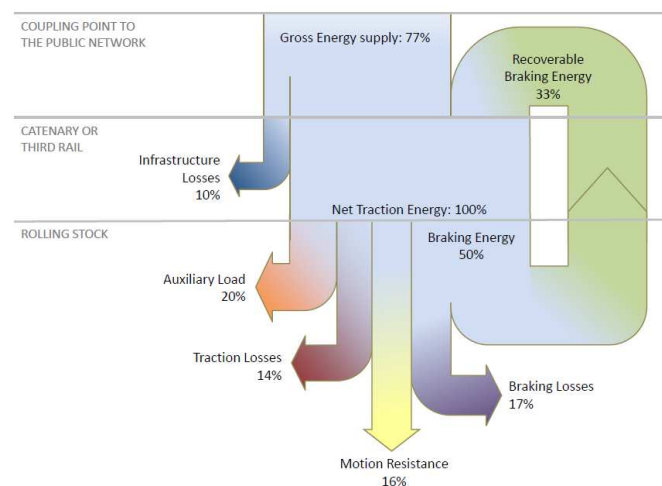


Figure 7: Comparison between measures for energy saving in existing urban rail systems: Source [5]

Another major share of the traction energy is dedicated to overcoming the motion resistance of the rolling stock. This comprises both aerodynamic opposition to the vehicle advance and mechanical friction between wheels and rails. Aerodynamic drag increases with the square of velocity, therefore its influence is more noticeable in commuter trains than in tramways, for instance.

In turn, mechanical resistance plays a more decisive role in low-speed services, the mass of the rolling stock being the main parameter to take into account for reducing its effect. It can be concluded from the available literature that, on average, motion resistance is responsible for approximately 16% of the traction energy used in urban rail services [9, 10, 14, 15], as illustrated by Fig. 7.

Energy losses in the traction chain itself mainly consist of inefficiencies in the converters, the electric motors and the transmission system. The efficiency of these components may significantly vary across the speed and power ranges, and so the overall values will depend on the duty cycle. The greatest portion of traction energy is wasted in braking processes, see Fig. 7. The amount of energy dissipated in braking strongly depends on the kind of urban rail system, but generally speaking it accounts for half of the energy entering the rolling stock. This rate clearly increases with the frequency of stops, being higher in tramways and metros than in commuter rail, for instance.

Provided that electric motors can act also as generators while braking, it is possible to recover and reuse a significant proportion of the braking energy [20]. In contrast, about one third of the braking energy is irreversibly lost because of the use of friction brakes and the losses occurring in motors, converters and transmission system during dynamic braking.

Once the energy consumption is understood and mapped out, a combination of technologies and strategies is being investigated as the most promising approach to optimise energy usage. Fig. 8 presents a non-exclusive list of the main initiatives proposed and implemented so far to minimise energy consumption in urban rail. As seen, these energy efficiency actions are classified into operational and technological measures. Operational measures aim at using both existing rolling stock and infrastructure more efficiently, which can be achieved with minor changes to

the facilities. In contrast, the introduction of new technologies requires higher investment costs and implies major modifications in the system equipment.

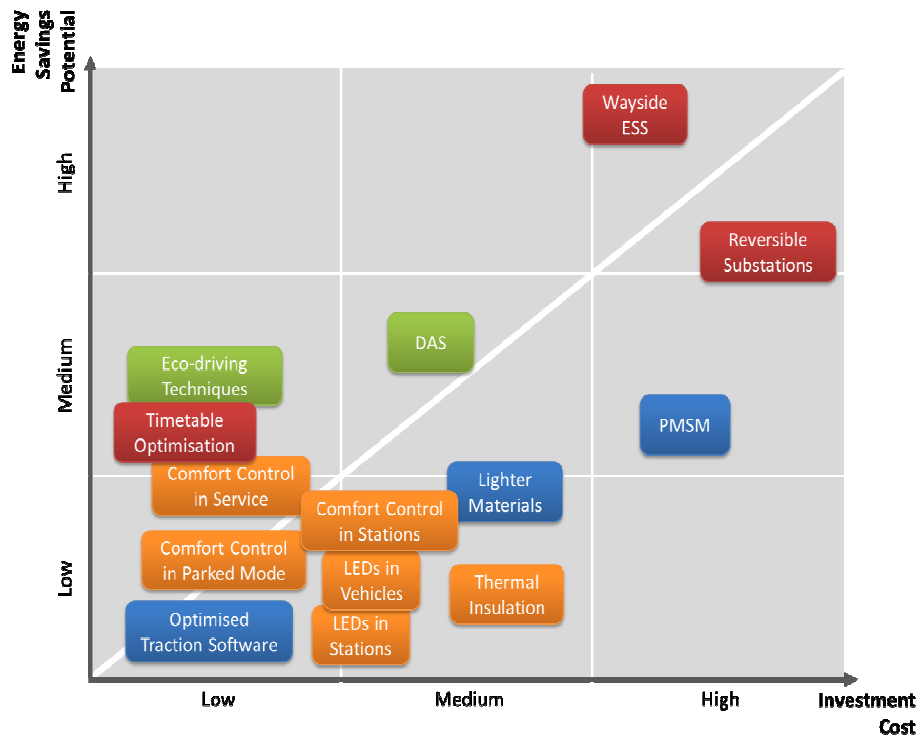


Figure 8: Strategies to optimise energy in urban rail: Source [5]

Additionally, Fig. 8 tabulates the measures according to their level of application; that is, the rolling stock, the infrastructure or the whole system. Five clusters of actions have been considered, namely: using regenerative braking, implementing eco-driving strategies, minimising traction losses, reducing the energy demand of comfort functions, measuring and managing the energy flows efficiently.

As illustrated in Fig. 9, an improved traffic flow control helps to apply energy-efficient driving strategies. Besides, before implementing driving assistance tools, a careful study determining the best driving techniques and optimal traffic control strategies are needed. In general, eco-driving measures minimise resistive losses in the power supply line as they contribute to reduce current flow in the network. They may also lower the thermal load in tunnels and stations because they reduce the intensity of the braking processes. Interestingly, the use of efficient traffic control systems may facilitate better interchange of braking energy between vehicles. Moreover, deceleration profiles that match the characteristics of the traction motors will lead to fewer losses in braking energy recovery.

Synergies must be expected from the combination of measures aimed at reducing energy consumption of comfort functions in vehicles and stations; that is, reducing the thermal load in tunnels and stations will lower the cooling demand in vehicles, and vice versa. In turn, some measures like upgrading the HVAC systems of vehicles (e.g. heat pumps) may increase their mass and, therefore, the traction energy consumption.

In addition, actions to increase energy efficiency of the traction system are fully interconnected to each other, as shown in Fig. 9. Thus, reducing traction energy consumption through enhanced drives will lead to less resistive losses in the line. Moreover, improvements in traction equipment will generally imply a mass reduction, and any mass reduction in vehicles will result in reduced traction consumptions and fewer losses in the line. Minimising the losses of traction equipment will enhance braking energy regeneration and reduce the thermal load in both tunnels and stations.

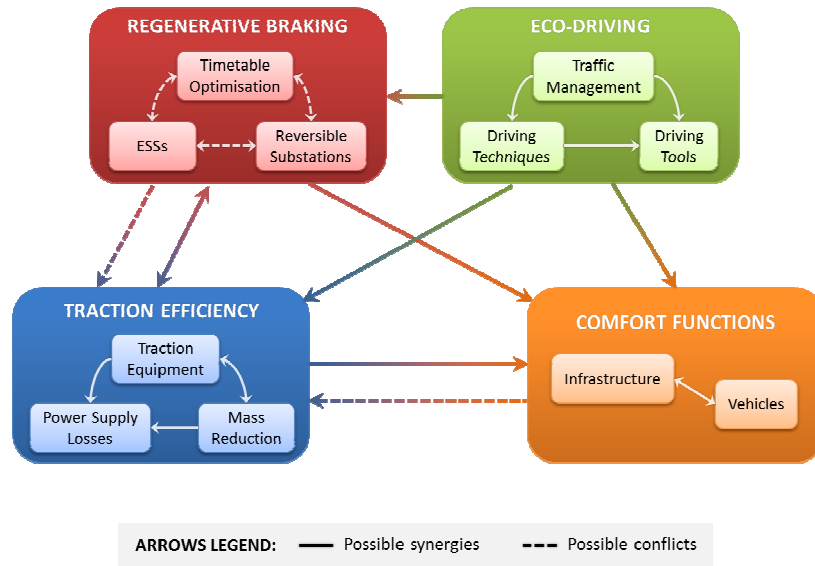


Figure 9: Interdependencies between energy efficiency measures: Source [5]

RAIL IN THE TRANSPORT CHAIN

Research undertaken by the eco-alliance (Allianz pro Schiene) in Germany has shown that rail is most environmentally sustainable for passengers (Fig. 10) and freight (Fig. 11) although as mentioned previously shipping is an excellent option for long distance freight.

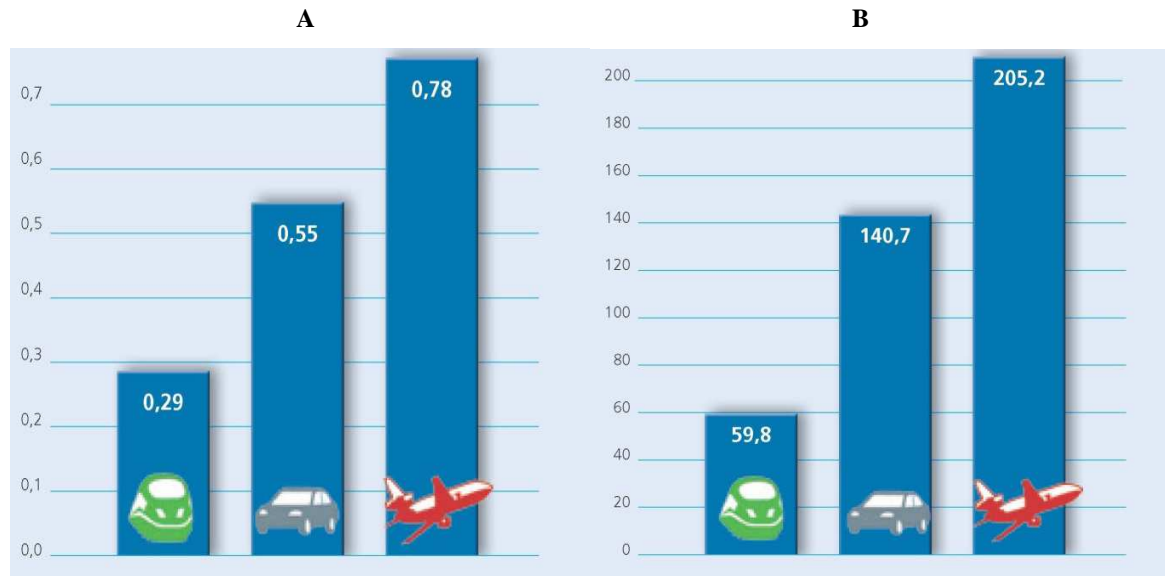


Figure: 10 showing the environment credentials of passenger rail travel, compared to the motor car and flights (inland) Figure 10(A). shows the energy consumption in kWh per passenger km and Figure 10(B) is the CO2 emissions in grams per passenger km. Source: [6]

Germany is an excellent example as it has a high proportion of electrified line (Fig. 5). Countries that import oil and gas are economically dependent and can be put under political pressure. In the EU the transport sector accounts for over 70% of oil consumption.

From Fig. 10 (A) and 11(A) it can be seen that rail transport is much more efficient than rubber tyres on asphalt and this has an effect on energy consumption and CO₂ emissions. From Fig. 11 (B) rail freight emits four and a half times less CO₂ than trucks.

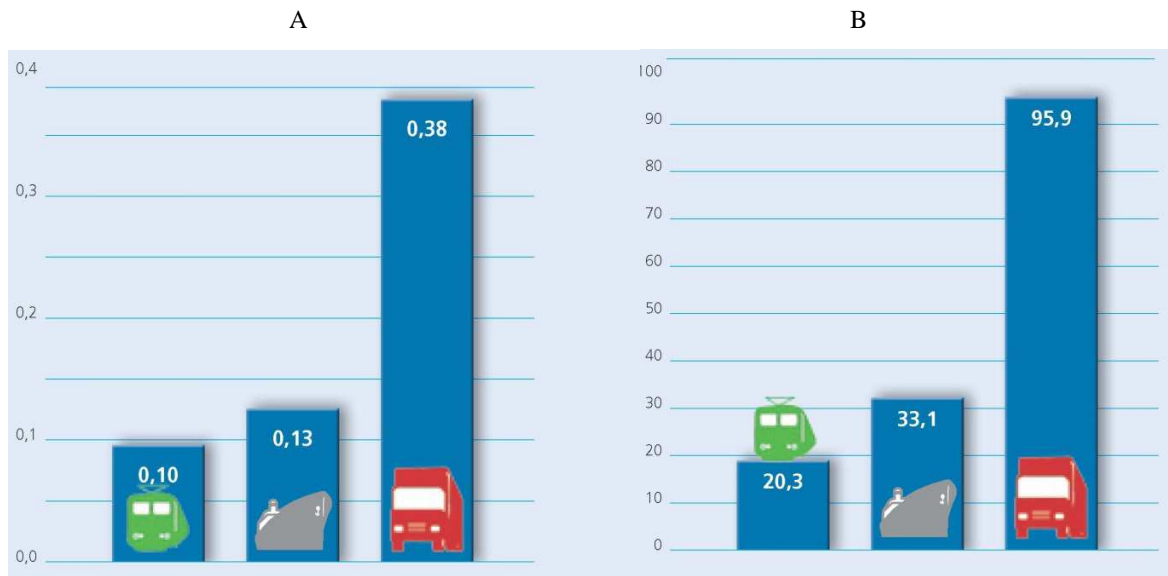


Figure: 11 showing the environmental credentials of rail freight compared to shipping and truck Fig. 11 (A) shows the energy consumption in kWh per tonne km and Fig. 10 (B) is the CO₂ emissions in grams per tonne km. Source: [6]

Fig. 11 shows that rail and shipping are very efficient as moving goods and freight and it can be seen that a freight and logistics systems based on these modes as the major component is the optimum scenario for sustainable freight. Germany as one of Europe's main transit countries profits from the country's high-performance rail transport system with 70% of long distance container transport to and from the Port of Hamburg being by rail. It is clear that if this freight went by road then the road network would be completely congested and overwhelmed.

Worldwide, metropolitan areas are expanding and towns and regions are merging. The railways are a perfect solution because they cover the increasing transport requirements of urban citizens and help to prevent transport chaos in metropolitan areas. This is why urban planners are focusing on rail transport in an increasing number of towns and cities. As can be seen in Fig. 12 the railways use less space.

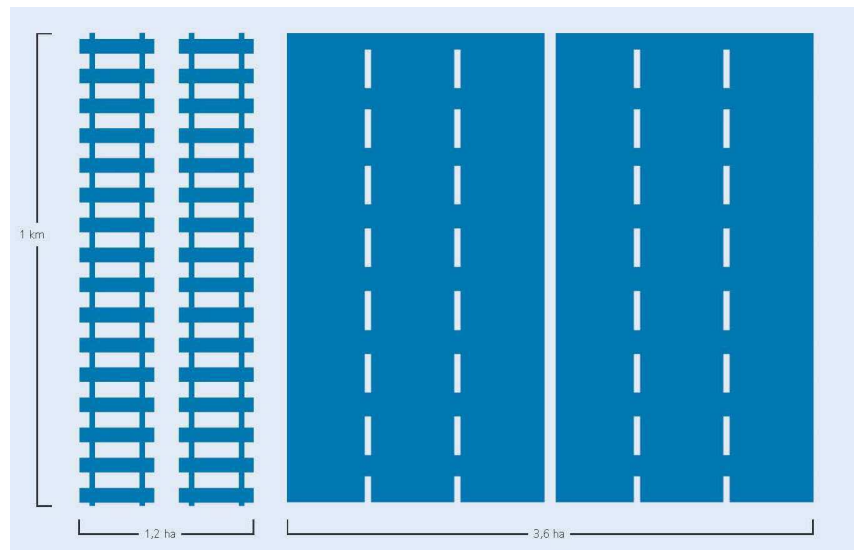


Figure 12: Land use showing that a double track railway line is less land intensive than two direction 3 lane highway Source [7]

In addition to being the most sustainable form of transport is also important to point out that travelling by train is safer than travelling by car. The risk of being killed in a car accident in Europe is 55 times higher than in a train accident [8], and the risk of being injured is 105 times higher. The safety record of railways is another major benefit for society. It is also important to note that freight transport by rail is also much safer than by road. Rail is one of the cleanest and safest transport modes but to achieve further sustainability levels, understanding of its performance levels is essential [21].

The railways also save society external transport costs [8], although the external (hidden) costs of transport are caused by those using the system, it is the tax payer, health insurers and the next generation that have to cover these costs. In Europe of the 80 billion euros in external transport costs, road transport accounts for 77 billion and railways for only 2.5 billion euros.

CONCLUSIONS

This paper has shown a small glimpse of the potential that rail has in order to be the sustainable backbone of an energy efficient transport chain for both passengers and freight. Moving towards sustainable mobility requires both integrated and efficient transport system as well as secure and clean energy. This paper demonstrates that modal shifts to rail can be a major driver for de-carbonization of the transport sector. It is important to continue to inform policy makers and railway operators to continue to move towards a sustainable energy and transport future.

ACKNOWLEDGEMENTS

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The authors acknowledge the work of the German organisation Allianz pro Schiene whose main aim is to increase the rail market share of both passenger and freight. It achieves this in a number of ways including the dissemination of the role of rail in a sustainable transport vision. The pro-Rail Alliance produces brochures and data to initiate mode comparisons that can inform decision makers.

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