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Sustainability of HSR as a mass transportation mode in terms of efficient use of natural resources

Watson, Inara

Amer, Ali

Bayyati, Ali

School of the Built Environment and Architecture, London South Bank University,[1]

Abstract

The global economic system depends on the sustainable use of natural resources some of which are renewable whilst the others are finite and non-renewable. There has been an increasing need to reduce the use of non-renewable resources particularly within the transportation sector, which is the major consumer of fossil fuels and thus responsible for most of the carbon dioxide emissions and pollution worldwide. High-Speed Rail (HSR) can provide a more sustainable and efficient use of energy and land whilst reducing emissions and pollution compared with road transport and other modes of transport.

The reported research takes the form of an investigation and critical evaluation of key existing factors that influence the sustainability of HSR in terms of the efficient use of natural resources. From the evidence that has been gathered from different resources and related critical evaluation, conclusions can be made to show that the development of HSR systems will improve the sustainability of transport in general and reduces the amount of non-renewable natural resources used by the transport industry. The secondary data methodology has been used in this research supported by empirical evidences. Most of the data was gathered from the internet including in depth research of HSR in selected countries, available railway statistics and relevant European and Institutional publications.

The main findings are that in many cases, HSR can bring a benefit for society by contributing to the reduction of carbon dioxide emissions produced by the transport industry, reduces the consumption of raw materials, and increases the use of sustainable energy. The expected outcomes of this research will contribute to the development and advances of more sustainable HSR systems that can meet the growing demand for travel due to the continuing growth of the world population and the increasing activities related to business, leisure, and social needs.

Keywords: High speed rail, sustainability, natural resources.

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[1] *Inara, Watson. Email: watsoni2@lsbu.ac.uk*
Amer, Ali. Email: alia76@lsbu.ac.uk
Bayyati, Ali. Email: bayyatia@lsbu.ac.uk

1. Introduction

Increased globalization has large impacts on the transport system. Traffic growth is largely the result of economic growth in a such a way that when a country's gross national product goes up, personal travel increases by a factor of 1.5 in relation to the GDP. It was estimated that the average growth rate of passenger kilometres increases by 4.6% every year (Whitelee & Haq, 2003a). The role of railway transport tends to increase and is becoming an important mode of transportation because it offers many advantages over other modes of transport. The transport system is considered sustainable if it satisfies three conditions, namely; its rates of use of renewable resources do not exceed their rates of regeneration, the use of non-renewable resources do not exceed the rate at which sustainable renewables are developed, and its rates of pollution do not exceed the assimilative capacity of the environment (Hoyle & Knowles, 1998).

Reducing the energy that is consumed by railways and reducing the amount of raw materials that is used by railways can sufficiently reduce the environmental impact of railway and improve its economical sustainability. The Carbon footprint that a train may accommodate over its lifecycle can be 55 to 85% due to energy consumption whilst the rest is related to the use of raw materials (Andries, 2016). HSR is comparatively the most sustainable transportation mode because it is powered by electricity that may come from renewable energy sources such as hydro, solar, wind and other environmentally friendly forms of energy, uses less non-renewable natural resources than any other transportation mode. HSR contributes to the growth of circular economy.

2. Resource Efficiency

The global economic system depends on how the natural resources are used. All-natural resources are divided into renewable resources and non-renewables such as raw materials, land and fossil fuels. At the present time, the transport sector is the major consumer of fossil fuels and is responsible for most of the emissions of CO_2. It is stated that the UK transport sector in 2014 consumed 54.2 million tons of oil (38% of the total consumption of oil) with an increase of 1.1% from that of 2013. Considering that transport is responsible for 74% of the total transport energy consumption, air transport is responsible for 23%, the rail transport is responsible for a percentage of 1.9% including high speed trains (Waters, 2015).

The growth of population may mean a growth in the consumption of raw materials whilst the world energy reserves and raw materials are finite. It was forecasted that oil reserves in the world would run out around the year 2040. This is only approximate, but it must be realised that oil reserves are limited. Modern transport depends 95% on fuel oil, and HSR can reduce dependency on this energy resource.

In the European Union railway transport carried 11% of goods and 8% of passengers and was responsible for only 0.6% of the emission of greenhouse gases and consumed only 2% of the total energy consumption in transport (Jehanno, et.al., 2011a). The railway network can accommodate more passengers and freight in the future. Resource efficiency for HSR means that there is a need to minimise emissions from the construction or upgrading of the railway infrastructures, increase recyclability of train components and parts of infrastructure, and sensitively use the land resources. Reducing the weight of rolling stock will reduce the amount of raw materials that are needed for their production.

Better use of insulating materials in the construction of rolling stock can reduce the energy output. Modernisation of existing high-speed trains instead of building new ones, can give sufficient savings in energy and raw materials. When the first generation of ICE was modernised, it gave savings of 16,000 tons of steel and 1,200 tons of copper (Jehanno, et.al.,2011b). Further weight reductions can be achieved by replacing conventional stock by articulated rolling stock and increasing the use of aluminium and light alloy construction.

Due to the high rate of scrapped cars around the world, transport is responsible for a large proportion of solid waste. Regarding the railway transport, there are abandoned lines, equipment and rolling stock. Improving recyclability by 10% in the European railway sector can produce an economic benefit of around 170 Million Euros per year (Garcia, 2010).

Regarding the car industry, in the UK in 2014 there were 2.47 million new cars sold, and it was estimated that more than one million of old cars and more than 40 million tyres were scrapped (www.bra.co.uk). Also, old batteries and other semi-hazard materials from motor vehicle production needed to be disposed. These millions of scrapped cars annually result in millions of tonnes of waste material. Such waste materials required recycling, reclamation and disposal. With an increasing amount of plastic in the production of cars there are not enough technologies that have been developed to recycle all the different types of plastic. Furthermore, the construction of one kilometre of three-lane motorway requires around 80,000 tons of aggregate and that gives a clear picture of the scale of the related damage to the natural habitat and landscape. For example, approximately 90 million tonnes of aggregates are used in the UK every year in the construction and repair of roads (Hoyle & Knowles, 1998).

Existing cars are not efficient and unsustainable when considering the overall cost and benefit as they incur very large expenditure of materials, energy, and effort to deliver a comparatively small benefit.

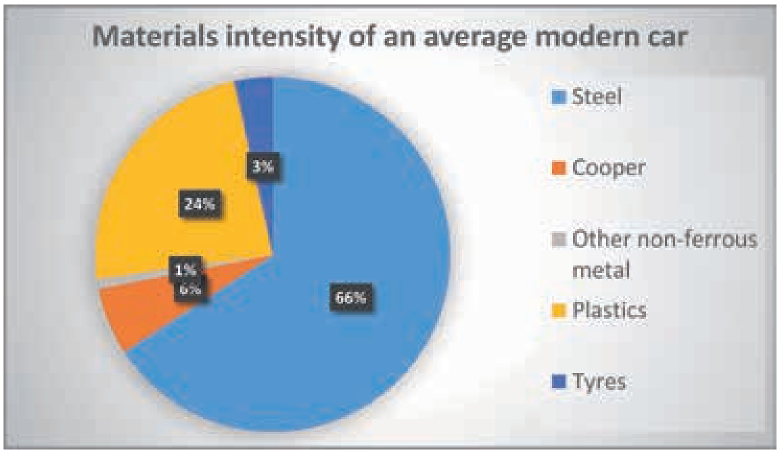

Figure 2.1 Materials intensity of an average modern car

Figure 2.1 shows the percentage of resources that are used to produce one car. An average modern car consists of 0.75 ton of steel, 0.07 ton of cooper, 0.01 tons of other non-ferrous materials, 0.27 tons of plastic and 0.04 tons of tyres. On average, the total weight of a car is 1.14 ton (Whitelee & Haq, 2003b). All these raw materials must be extracted and processed to manufacture the car and that requires energy and produces waste in the range of 25 tons which may pollute air, land and water.

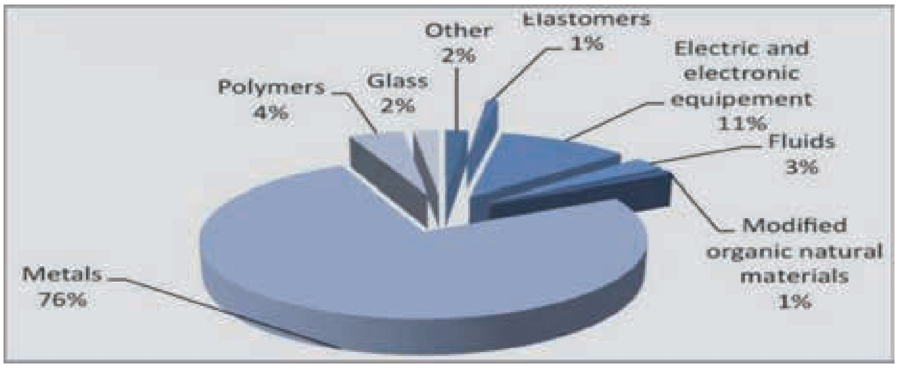

Figure 2.2 Typical train material content (Source: www.uic-environment.org, 2016)

The percentages of resources that are used to produce a typical train car are depicted in Figure

Figure 2.2. On average, the production of a single train vehicle requires more metal and less plastics than that used to produce a road car. In most countries, recently designed trains have around 40 years of service life and this long life supports the resource efficiency. In order to ensure that railway transport is fully competitive it is important to consider at all stages of the life cycle of the railway transport from the design and building stages to the operation and maintenance and eventually the disposal.

At the design stage of a new rolling stock, there is a need to minimise the amount of generated waste and to avoid potentially hazardous materials such as asbestos-containing materials or substances that may contribute to the damage of the Ozone layer and accelerate climate change. For example, at the production stage, there is a need to re-use parts and components of the rolling stock whilst at the disposal stage of the rolling stock there is a need to recycle the greatest possible amount of used materials. Bombardier's vision is to achieve 100% product recyclability and to use 100% recycled materials. At the current time, Bombardier has an average recovery rate for all manufactured rolling stock of 95%. The French high speed train AGV has 98% recyclability (Jehanno, et.al.,2011c). The proper disposal of the end-of-life rolling stock and components of railway infrastructure can reduce the negative impact on the environment.

When comparing the number of vehicles and carriages needed to be disposed, the amount of carriages is not sufficient compared to the number of vehicles, but waste generated by one carriage is greater than waste generated by one vehicle. It was found that disposal of one freight carriage generated is the same amount of waste as 16-20 passenger road cars. The waste of the disposal of one railway passenger carriage is equivalent to the waste of disposing 48-57 road passenger cars whilst the disposal of 3-part electric multiple unit will generate waste of 126-156 road passenger cars.

Some rail carriages are easier to recycle than others, for example, freight rail carriages are easy to recycle, as 60 to 80% of their mass is steel and cast iron and it is known that metals have the highest recyclability rate (www.unife.org, 2013a). Passenger rail carriages, particularly electric multiple units are more difficult and labour intensive to recycle. At the present time, there is a lack of technology for recycling polymer and plastics, but it is easy and cheap to produce them. Different types of plastics have different chemical components and this makes it difficult to dispose them.

The disposal of rolling stock is similar to the disposal of road cars, and this includes the following stages; send the vehicle to a recycling site, pre-treatment, dismantling, shredding and treatments of recovered materials and parts. Newport in the UK has the largest shredder in the world and can shred 450 cars per hour (www.weg.net.,2009). One of the most difficult issues of recycling of rolling stock is getting a rail carriage to the recycling site, as many of them in their current condition are not suitable for transportation on the main line. The scrap value of a carriages is around £11,500 but to get it to a recycling site will cost approximately £5,000 (www.unife.org., 2013b). There is little economic benefit for the railway industry to encourage it to recycle the rolling stock. For this particular reason, there is need for governments to support the railway industry in recycling the rolling stock and parts of railway infrastructure. Suitability for recycling or recovering is measured through Material Recovery Factor and Energy Recovery Factor. Material Recovery Factor represents the availability of recycling and inefficiency of the recycling processes. Energy Recovery Factor represents the suitability of the material concerned to be recovered as energy. Values of Energy Recovery Factor and Material Recovery Factor need always to consider the concept of valuating the efficiency of recycling. If materials do not have recyclability or energy recovery potential then these factors will be equal to zero (www.unife.org., 2013c).

Recycling needs to be considered in the design stage, in order to be able to make dismantling quick, cheap and easy. Internal panels should be easy to remove within only a few hours work. Recycling could be made easier if body shells were produced from as few materials as possible. This will reduce time for material sorting. Resources efficiency means using the Earth's limited resources in a sustainable manner whilst minimising possible impact on the environment. It allows creating more for less and to deliver greater value with less input (www.ec.europe.eu, 2017). The railway industry is working to reduce the waste and to re-use recycled materials in addition to reducing spending on raw materials and energy usage in order to be greener and more sustainable.

The strongest manufacturing industries producing rolling stock for HSR are; Germany, Spain, Japan and China. The rolling stock industries heavily depend on strong domestic market that has demand for this product. One example of influence on the domestic market on rolling stock industry can be the UK. In the middle of 1960s, large parts of the railway network in the UK was closed and that in turn affected the railway rolling stock industry in UK quite badly. With the creation of the EU and the single market, some changes in the rolling stock industry occurred. Railway stock manufacturers moved over the national boundaries and became international companies. As a result of the economic growth around the world, the railway networks started expanding. The International Union of Railways predicted that by 2025 HSR network will increase to 41,997km. Europe and Asia will have the biggest expansion and by 2025 will reach 17789km in Europe and 21460km in Asia (Jehanno, et.al., 2011d). High demand for new rolling stock is observed in China and South-East Asia. China is the largest producer of rolling stock in the world. Countries that have a developed railway network also manufacture and export rolling stock to other countries with less advanced railway technology. In 2012-13, the top 10 manufactures of rolling stock had 65% of the global market (Briginshaw, 2017). The two biggest manufactures of rolling stock in China are CNR and CSR.

Table 2.1 The Ten Biggest Manufactures of Rolling Stock

Rollin Stock Manufacture	Country	Place in the World in 2013
CNP	China	1
CSR	China	2
Bombardier	Canada	3
Alstom	France	4
Transmashholding	Russia	5
Stadler	Switzerland	6
Siemens	Germany	7
GE Transportation	UK	8
Uralvagonzavod	Russia	9
Trinity Industries Inc	USA	10

(Data taken from several sources)

Table 2.1 shows the ten biggest manufactures of rolling stock in the world. The biggest Japanese manufactures of rolling stock is not presented in the top ten. One of the explanations of this can be that the rolling stock produced by Hyundai-Rotem and Kawasaki has so high technology that it does not match the existing infrastructure outside Japan. Also, not presented in the top 10 is the Spanish manufacture CAF.

High speed trains that are presented in Table 2.2 have a large variety in terms of axle loading;

from 11.4t Hitachi Train to 23t Bombardier. Such large difference can be explained by the type of railway that uses this rolling stock. Shinkansen line that employs Shinkansen-Series 700 is HSR with fences and screens that secure the entire length of the track. In contrast, the Acela Express operated on upgraded infrastructure with level crossings equipped with anti-collision structure to meet USA crash standards.

Zefiro high speed train, which has 16.5t axle loading and manufactured by Bombardier, is one of the most economical and environmentally friendly trains in the world. With optimizing the energy use, minimising waste and lowering the carbon footprint from the total life-cycle, the efficiency of trains increased by around 50%. Resources efficiency with different constructors of rolling stock for HSR is different and it depends on raw material intensity that was used to produce the modern rolling stock. This may mean reducing the axle load and decreasing the amount of raw materials used to produce the rolling stock. Another important feature is the power system of HSR. With a centralized power system train that has a heavy locomotive engine, the subgrade and foundation must be stronger and a stronger rail must be used. This involves more raw-materials to build the high-speed railway lines. The distributed power system is more advanced in term of using fewer raw materials.

Table 2.2. Comparison of different types of high speed trains in terms of power systems, axle loading, and car body materials

Country	Main Constructor	Train	Power system	Axel Loads	Car Body
France	Alstom	AGV	Centralized	17t	Aluminium with carbon
Japan	Hitachi	Shinkansen-Series 0	Distributed	16t	Carbon steel
Japan	Hitachi	Shinkansen-Series 700	Distributed	11.4t	Aluminum alloy
Spain	Talgo	Talgo 350	Centralized	17t	Aluminium
Italy	Hitachi Rail Italy	Frecciarossa	Distributed	17t	Aluminum alloy
Germany	Siemens	ICE1	Centralized	19.5	Aluminium-silicon alloy
Germany	Siemens	ICE2	Centralized	19.5t	Aluminium-silicon alloy
Germany	Siemens	ICE3	Distributed	15t	Aluminium
Sweden	Bombardier	SJ X2	Centralized	17.5t	Stainless steel
USA	Bombardier	Acela Express	Centralized	23t	Stainless steel
China	Bombardier	CRH1	Distributed	15t	Stainless steel
China	Siemens	CRH3C	Distributed	17t	Aluminium
Canada	Bombardier	Zefiro	Distributed	16.5t	Aluminium

(Data taken from several sources)

Aluminium car bodies may give a raw-material saving and reduce energy consumption to operate trains in addition to reducing the wear of bodies and rail. However, aluminium car bodies have some disadvantages particularly the increase in maintenance costs. For example, in the event of an accident the steel car body is easier to repair. Another disadvantage will be the need to consider the insulation properties as they can be less effective compared with the situation when a steel car body is used. All new high-speed trains have an aluminium body but in the future, there is a big potential to use fibre-reinforced polymers for train car bodies. Replacing steel by aluminium can achieve weight reduction of the car body of a train between 20-30%. There is also a need to take into consideration the recycling rate which is high for aluminium car bodies. A typical high-speed train consist of 400,000 different parts (www.plmautomation.siemens.com, 2012).

3. Land Use

Land is one of the natural resources and as it is not infinite it must be taken seriously as an index of sustainable society. There is a reason to believe that in the future the land use would be a major barrier to the development of new transportation systems. There is a strong opposition for airport expansions and locating new airports in local communities such as the proposed expansion of Heathrow airport. Also, some motorway projects have been stopped in urban areas by concerned local communities. HSR is environmentally less polluting and consumes less land than motorways or airports whilst some of HSR routes for long distances run in tunnels. It was reported that approximately 90% of the route of the HSR in Taiwan (THSR) was paced in tunnels or on raised viaducts (Watson, et.al., 2017).

In the European Union, around 1.3% of the total land has been taken to build roads. In the UK, it was estimated that roads occupy around 1.5% of the land. The railways occupy substantially less, at around 0.2% (Hoyle & Knowles, 1998b). Allocating land for transport means that land is taking away from agriculture and causing biodiversity damage and fragmentation of the local community. It is inefficient use of land, as on average cars are used for 2.8% of the time and very often just with one person. The total amount of land that has been taken by road transport use in the UK is over 3,500km^2. The total length of roads in UK in 2016 was 396,719km compared with a total length of railways of 15,799km (www.gov.uk., 2013).

3.1 The railway is one of the most environmentally friendly modes of transport.

Railway infrastructure is less damaging in its use of space than road transport. A double track railway line takes only 25 metres in width but a dual 3-lane motorway occupies 75 metres in width (www.gov.uk, 2014a). One kilometre of road takes 13.729 hectares of land. Also, a road may transport only 225 passengers per metre width per hour based on the assumption of 1.5 people per car, but a railway can transport approximately 8700 passengers per metre width per one hour (Hoyle & Knowles, 1998c). Roads require much more land to transport the same volume of passengers and freight than railways. It was estimated that rail is potentially 60 times more efficient in terms of land use.

The transport infrastructures are the major land consumers. The amount of space occupied by railways is relatively small compared with road transport. For example, in Germany, the average overall land-take per kilometre of length of motorways is around 9ha compared with 3.5ha for the new build railway lines. The total amount of land in Germany given for roads is greater than that taken by general buildings and houses. In Germany, public highways occupy approximately 3 000^2 km or 1.23 % of the country's area (Transport policy and the environment, 1990). Furthermore, in Bangkok and Calcutta 7-11% of urban space is devoted to transport activities compared with 20-25% in European cities and over 30% in Manhattan (Banister, 2005).

In the UK, approximately 1.2-1.5% of the total amount of land is occupied by roads (Whitelee

& Haq, 2003c). It was estimated that each car takes 200m^2 of land. Similar data comes from Switzerland, where it is estimated that the average of land taken by each vehicle is 113m^2, but the land allocated for housing and gardening is only 20-25m^2 per person. Land covered by asphalt is lost to nature, it has affected the behaviour of groundwater and it breaks down ecological relationships with impact on fauna and flora.

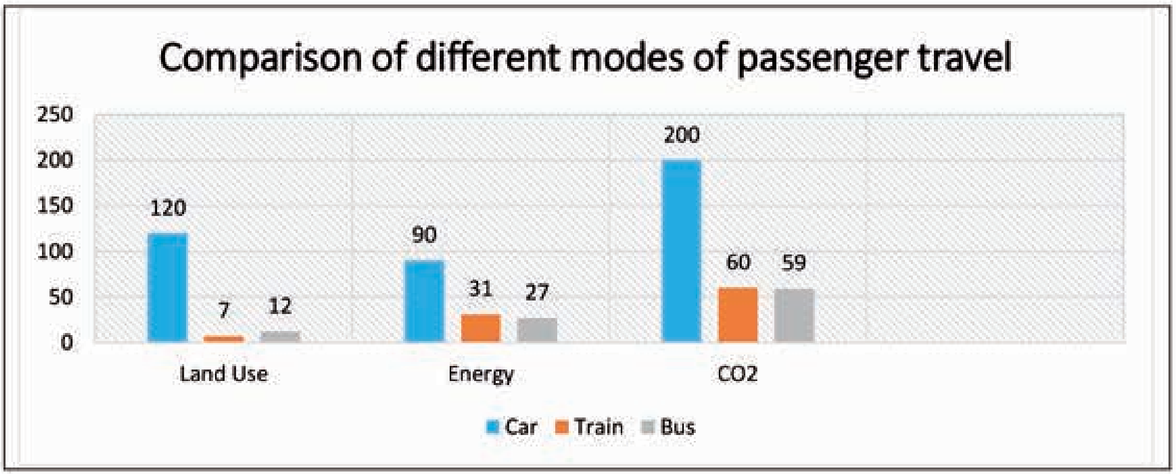

Figure 3.1. Comparison of different modes of passenger travel (Source: Adapted from (Whitelee & Haq, 2003d), where: Land use is measured in m^2/person, Energy- in grams of coal/pass.km, CO_2-grams/pass.km

It was calculated that lorries require around three time more space than trains to do the same work. Each passenger travelling by car uses 120m^2 land, by trains 7m^2 land, and by bus 12m^2 land. The amount of land that has been taken depends on which mode of transport is used. Also, there is a need to consider the secondary land taking. This means that in addition to the land allocated for railways there is a need to add areas that provide the raw materials needed to build railways and rail infrastructure, and manufacturing areas to produce steel and concrete.

In 2014, in the UK 35.6 million cars have been registered (www.gov.uk, 2015), and with the increasing number of cars on roads and the increasing number of trips, the total amount of land taken by cars will also increase. Between 1990 and 1996, around 10ha of land each day was taken to build new motorways in the EU. Roads are the biggest land consumer in EU (EEA, 2016a).

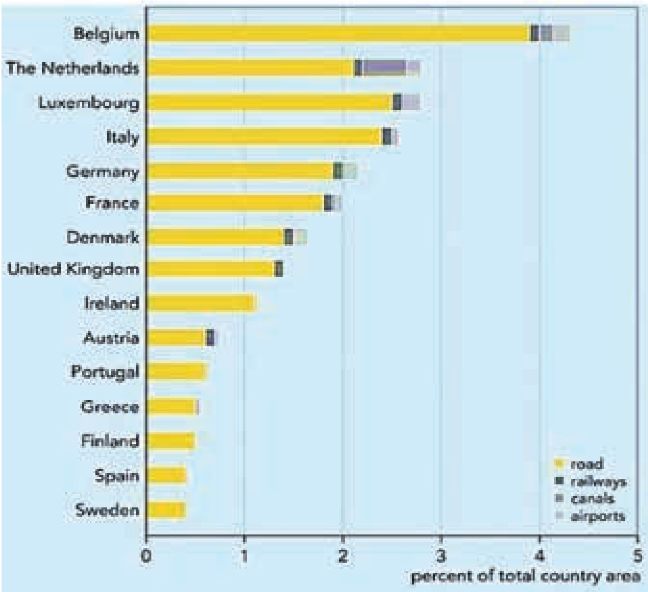

Figure 3.2 Total land-use by transport infrastructure in selected countries in 1996 (Source: EEA, 2016b)

Figure 3.2 shows that the road network takes most of the total land used by transport infrastructure, and it occupies 93% of the total land used by transport infrastructure when railways occupies around 4% and the rest is occupied by airports and inland water transport. With the increasing population and growth in global mobility, it was predicted that by 2050 there will be a need to build around 25 million lane-kilometres roads and 335 000 rail track kilometres. It will increase the built surface area between 250 000 km² and 350 00 km². It is approximately the size of Germany and UK combined that will be needed to build the new transport infrastructures (Dulac, 2013).

The shift of travel from roads to railways can reduce the amount of land that is needed to build new transport infrastructures. The network of HSR in the next 10 years will increase slightly, and most of it will be in countries that have developed HSR network already. There was a plan to build 14 000km of HSR in countries such as Iran, Morocco, Turkey, Argentina, and USA. However, with the present political and economic circumstances, it is questionable that these countries will build HSR.

HSR in France, LGV Bretagne Pays de la Loire are responsible for 2,300ha of taken land but Paris CDG airport had taken 3,200ha of land. When comparing the land that has been taken by HSR and airports, there is a need to bear in mind the indirect amount of land that has been taken by aviation and this number is very significant (Jehanno, et.al., 2011e). For example, Schiphol airport in Nederland has 26.8 km² land in direct use and 222.8 km² for indirect uses (Koetse, et.al., 2001). HSR can carry 12,000 passengers per hour per track, whereas a single line highway carries 2,250 passenger cars per hour and HSR is approximately 5-6 times more efficient than road transport in terms of land use (Agarwal, 2011). Building HSR will need more land take than that required to build conventional line as HSR needs to allow greater distances between the railway tracks. The reason for this is the pressure caused when two trains pass each other with a speed of 250-350 km/h. Also, HSR requires larger radius curves than conventional rail.

Table 3.1 Comparison of land-use for different types of transport infrastructure

Means of transport	Type	Average width	Surface occupied in ha
Railway	Conventional 2 tracks	26 m	2.6 ha
	Upgraded TGV line	32 m	3.2 ha
	New TGV line	35 m	3.5 ha
Road	Motorway 2x2 lanes	54 m	5.4 ha
	Motorway 2x3 lanes	60 m	6.0 ha
	Motorway 2x4 lanes	72 m	7.2 ha

Source: *(Publications.naturalengland.org.uk, 2011)*

Table 3.1 represents the difference in land occupied by different transport infrastructures. Land-use policies can be an effective tool to encourage shift to a more environmentally friendly mode of transport and can influence traffic volumes and behaviour. By building new residential areas close to railway stations or by building new stations close to residential areas, there can be an increase use of public transport. Urbanisation will make closer places to work, live and relax. Land-use policies can contribute to conservation of open spaces for further generations. “Reducing the land requirements for road transport is central to the achievement of sustainability and quality of life”, (Whitelegg 1994).

Table 3.2 Comparison of different corridors for HSR in terms of minimum radii of curve

Country	Corridor	Length km	Track	Type of Line	Radii of Curve m	Track Gauge m
Japan	Tokyo -Osaka	515.4	Double	Dedicated	Minimum 2500	1,435
France	Paris-Lyon	425.0	Double	Dedicated	Minimum 4000	1,435
Spain	Madrid-Barcelona	620.9	Double	Dedicated	Minimum 7000	1,435
Italy	Rome-Florence	254.0	Double	Dedicated	Minimum 3000	1,435
Germany	Cologne-Frankfurt	177.0	Double	Dedicated	Minimum 3,350	1,435
Sweden	Stockholm- Gutenberg	455.0	Double	Mixed Line	n/a	1,435
USA	Washington C.D. -Boston	729.5	Double	Mixed Line	Absolut minimum 76	1,435
China	Beijing-Shanghai	1,318.0	Double	Dedicated	Minimum 7000	1,435

Source: Data taken from several sources

Horizontal and vertical curves are important parts of the railway alignment. Minimum radii of curves depend on the maximum speed of the rolling stock, technical characteristics of the rolling stock, topography of corridor, safety standards, and constructional and operating costs. Large radii of curves are more comfortable for passengers to travel. New HSR lines built with a minimum curve radius of 7000 m will allow railway speed of up to 350-400 km/h. The amount of land needed to construct HSR depends on the geographic region and specific needs of the project. Also, there is a need to strike a good balance between the needs of the project and the local communities. The amount of land taken by a HSR depends on certain factors, such as; is it a new railway line or upgraded one, is it a single or double track line, what is the maximum speed, size of embankments, radii of curves, etc. The amount of cutting and embankments can influence the amount of land that is needed to build HSR. Embankments reduce the noise level, but the negative impact is that it reinforces the separation effect and it reduces the available living space.

For example, in the proposed project of HS2 in the UK, for deep cuttings and higher embankments of 16m, a safeguarding corridor of 70m from the central line was suggested. Therefore, the land needed to build a HSR would increase from 5 m to 67.5m from the centre of the outer tracks. The safeguarding boundaries can be wider for more deeper cuttings and higher embankments (www.gov.uk, 2014b).

Newly constructed high-speed lines are designed with a minimum of 7000m curve radius but in some cases the radius would need to be 10000m in order to accommodate higher future speeds and to improve the passenger comfort (Revolvy, 2017). Higher speed means more needed land and more distance between centres of the main tracks such as the case of 4.2 m used in Tokyo-Osaka lin. For a speed above 300 km/h, the UIC recommended a minimum value of 4.5 metres distance between track centres (www.uic.org). However, land-use and environmental impacts can be minimised by placing railways in tunnels and on viaducts.

4. Energy Consumption

It is widely accepted that oil production has now peaked and that in future it will become both costlier and more difficult to produce. Economic dependence on oil translates into political dependency on oil-exporting states. The oil reserves are concentrated in a very specific location.

Security of supply becomes a matter of political priority, which in turn leads to conflicts. World oil demand increased by 38% between 1983 and 2006, and with the increase in demand comes increases in global geopolitical instability (Cox, 2010). There are potential security threats to many higher motorised economies. Liquid fuels will be running out in about forty years, gaseous fuels in about sixty years and even coal has only around two hundred and fifty years of practical extraction (The Railways, Challenges to Science and Technology, 1995). The way forward is to develop and use advanced technology to cut fuel consumption and to produce less polluting vehicles coupled with effective measures to promote the shift of traffic from road to railways. However, transport is almost totally dependent on oil for energy as 95% of the total amount of transport around the world depends on fossil fuels (Watson, et.al., 2016) and it seems that there is little prospect for a major change even if oil prices rise substantially. HSR is a good alternative to road transport as it is powered by electricity and the proportion of renewable energy increases year by year. Some of HSR systems such as in Sweden is powered by 100% renewable energy.

Railways have the significant advantage over road and air transport, as electrified railways can use different types of energy; nuclear, wind, solar, water, oil. With the increasing use of renewable energy sources, railways are getting more environmentally friendly. It was estimated that using an airline will take 3 hours 50 minutes to get from Los Angeles city centre to San Francisco city centre but using a train will take 3 hours 2 minutes. The fuel consumption difference will be more dramatical. One passenger uses 10.56 gallons of aviation fuel flying but travelling by train requires only 0.74 gallon of fuel (www.1001-home-efficiency-tips.com.l). Fuel consumption difference is more than 14 times in favour of a train.

The energy consumption of a high-speed train depends on a number of factors including technical characteristics of train, layout of line and number of stops. The number of curves and their radii and length, the gradients of line and other factors can affect the train energy consumption. Reducing the number of curves can increase the speed of a train and in its turn a train uses less energy. Using regenerative brakes, high speed trains can recover some of the energy dissipated by braking and this energy can be used by other trains or can be returned to the power network. Improving the aerodynamics of trains can sufficiently reduce energy consumption. There is an energy loss during the transmission and transformation from the power station to the train, but there is a big difference in the losses for high speed lines electrified at 25kV and at 3kV as the loss for a line voltage of 25kV is lower than that 3kV. There is a need to provide 8.8% more electricity through a pantograph to operate a train at 25kV compared with 22.6% to operate a train at 3kV (Garcia, 2010).

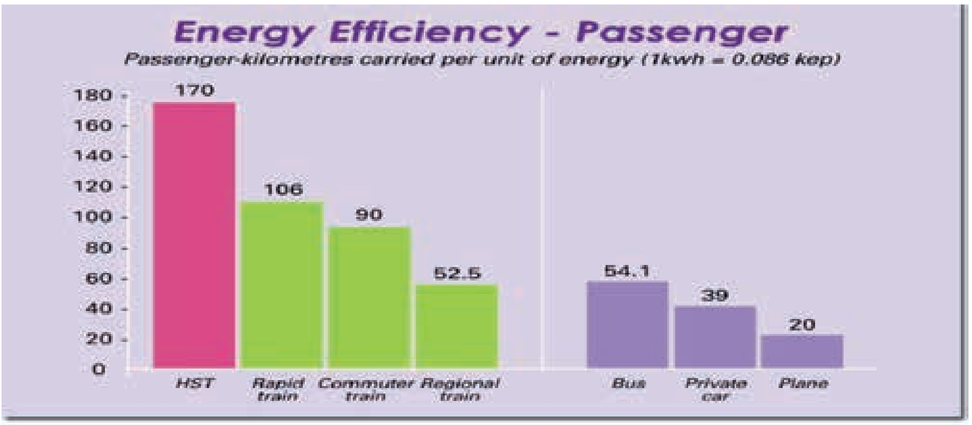

Figure 4.1 Passenger-kilometres carried per unit of energy by different transportation modes (Source: www.ushsr.com)

Consider Figure 4.1. there are clear differences in energy efficiency for different modes of transportation, but the HSR seems to be the most efficient mode of transportation. HSR loses its energy consumption benefit in comparison with air transport at speeds between 300 and 400 km/h, as the actual value depends on which route is considered and on the efficiency and aerodynamics of trains and airplanes. Two main factors determine a train energy consumption; namely, acceleration and overcoming rolling resistance. HSR is the more efficient transport mode, even when compared with conventional railway. New high-speed trains have improved design to reduce drag, increases capacity, and uses lighter materials that reduce the weight of the train. The new articulated high-speed train AGV from Alstom has a reduced weight and needs 15% less energy than that of TGV and has 98% recyclability (www.bombardier.com.). Power output for high speed trains depends also on a train formation. Trains can have different formations from 16 or eight cars as has Shinkansen Series 500 and Shinkansen Series 700 or the 8 cars that Frecciarossa has. Some trains are more flexible in formation as AGV can be formed from seven, eight, 10, 11 or 14 cars. Reducing the axle load is the most critical factor to increase the speed of trains and reduce the energy consumption. This can be achieved by introducing the articulated railcars, and using a new more lighter material. For TGV, Duplex car bodies, aluminium was used which is easy to recycle and it does not lose its quality after recycling. In order to increase the passenger-kilometres carried per unit of energy, there is a need to consider the train length, so that instead of having locomotive and passenger cars, these can be replaced by electric multi units.

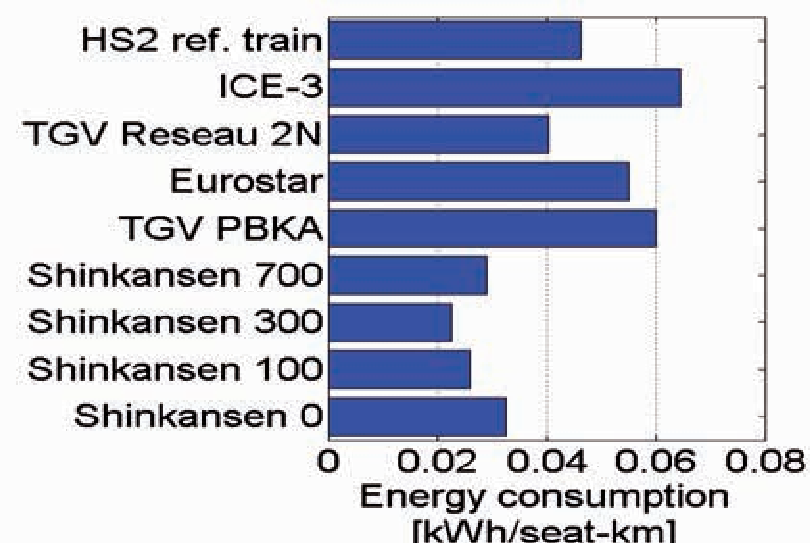

Figure 4.2 Comparison of the net energy drawn from the line by the HS2 reference trail output for the London-Birmingham baseline simulation with data for other high-speed trains (Watson R., 2012)

Figure 4.2 demonstrates that the lowest energy consumption belongs to Shinkansen rolling stock. One explanation for this is that in Japan rolling stock is renewed to a more efficient type every 15-20 year. Newer high-speed rolling stock has improved the design, reduced drag, increased capacity, reduced axel load, improved energy efficiency and upgraded passenger comfort to meet changing customer expectation considering the fact that trains in Europe are designed for 30-40 years' service life.

Table 4.1 Comparisons of different high-speed rolling stock in term of speed, power output and type of trains. Data taken from several sources.

Train	Maximum Speed Km/h	Power output	Type of train
AGV	360	5,760 kW	Electric multiple unit
Shinkansen-Series 500	300	18,240 kW	Electric multiple unit
Shinkansen-Series 700	270	13,200 kW	Electric multiple unit
Talgo 350	330	8,000 kW	Two Power Cars
Frecciarossa	300	9,800 kW	Electric multiple unit
ICE1	280	9,600 kW	Two Power Cars
ICE2	280	4,800 kW	One Power Car
ICE3	330	8,000 kW	Two Power Cars
SJ X2	200	3,260 kW	One Power Car
Acela Express	240	9,200 kW	Two Power Cars
CRH1	200	5,300 kW	Electric multiple unit
CRH3C	350	8,800 kW	Electric multiple unit
Zefiro 300	360	9,800 kW	Electric multiple unit

Table 4.1 shows selected high speed trains and what power output is required. With the introduction of the SJ X2 long distance trains in Sweden, the average speed increased by 44%, travel time was reduced by 30% from 4-hour 25 min to 3-hour 5 min and the energy consumption was reduced by 29% (Lukaszewicz & Andersson, 2008a). This shows that using more advanced rolling stock can increase speed and reduces energy consumption.

5. Conclusions

The demand for road transport continues to increase despite the fact that it mostly uses non-renewable natural resources. The railway transport is a strong alternative to road transport. Railway transport uses less energy, needs less land and uses less non-renewable natural resources. The railway industry increase to use environmentally friendly materials in its vehicles and rail installations. However, there is a considerable growth in the use of plastics that are not always recyclable which shows that there is an urgent need to develop new technologies for recycling different types of plastic.

There are many ways to achieve the targets for sustainable mobility. Such achievements can be made possible through a greater technological improvement. The HSR and railway industry are working to improve the efficiency, reduce the weight of vehicles, and develop new technologies to reduce the power needs for the industry. Despite the increasing speed of modern trains, energy consumption is reduced by 25-45% (Lukaszewicz & Andersson, 2008b). The assessment of transport efficiency in the future must be related to the total energy life-cycle, from the extraction of the minerals to their final return to earth as waste. For example, on average, the Alstom train is 93.3% recyclable and 98.5% recoverable and there is a future need to increase the recyclability closer to 100%.

In order to reduce the amount of raw materials used in the railway industry, manufactures are continuously working to minimise waste and to increase recycling and energy recovery. This can be achieved by improving the recyclability of the rolling stock and infrastructure and by increasing the use of the amount of materials that is being recycled. For instance, the recoverability of TGV Euroduplex is 97-98% (Andries, 2016).

There has been a growing understanding that the ever-increasing number motor vehicles will soon reach the environmental and social limit. Climate change, which is believed to be caused by the rising greenhouse gas emissions, threatens the world stability and life in general. The increasing global temperature could lead to a damage equivalent to 5-20% of GDP (Stern, 2006). These issues necessitate urgent and effective worldwide actions to improve the energy efficiency and to shift transportation from roads to a more sustainable mode of transport such as railways.

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