NTNU – Trondheim
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'Less is more' : Pathways for Lower Steel Stocks in Developing Countries

An assessment of leapfrogging potentials in transportation

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Preface

This research was completed in the spring of 2012 to fulfil the Industrial Ecology Master's Thesis requirement at the Norwegian University of Science and Technology (NTNU).

Firstly, I would like to express utmost gratitude to my supervisors Daniel Müller and Stefan Pauliuk for their valuable guidance and support. I thank Daniel Müller for inspiring me and devoting so much time to discuss the challenges I was facing during the course of my work. The constant motivation, help and constructive feedback I received from Stefan Pauliuk kept me going. I hope this work has done justice to the guidance that it received and that it is useful for further research on the subject.

I would also like to thank the officers from Statistical Offices of the Netherlands, Switzerland and New Zealand who very promptly provided me with the data I needed and also helped in translating some of the information into English.

Finally, I thank my friends and family who have been pillars of strength to me throughout.

Mita Broca

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Abstract

Effective climate change mitigation requires global carbon emissions to be reduced at least by 50% over the 2000-2050 period, as recommended by the IPCC. Producing steel accounts for approximately 9% of all energy-related green house gas emissions. With the rapid urbanization and industrialization of the developing countries, demand for steel is anticipated to at least double by 2050. The daunting challenge is how emerging economies like India and China will be able to develop into modern economies without generating significant repercussions for the global climate. Today's best available steel making processes have optimised energy use to a large extent. For further emission reduction, climate change mitigation policies primarily aim at a response based on carbon sequestration of process and electricity related emissions. However, these approaches are far from proven and carry both technical and financial risks. This research shifts the focus from supply-side to demand-side measures to address this issue. The need to include management of in-use stocks in environmental policy is underlined, as stocks are important drivers for resource and energy consumption as well as waste and emission generation.

The central idea behind this work is to highlight that *the goal for developing countries should not be to acquire the same level of in-use stock as seen in the developed counties, but to attain the same services enjoyed by them with lower material stocks*.

This study first attempts to quantify the differences in steel stocks in vehicles, along with the total embodied energy and emissions among a set of developed countries. Using a novel approach, service provided by the vehicle stock is defined using suitable parameters. Further, using passenger car steel stock as an example, scenarios are developed for India, which reflect ways in which India could possibly attain the same level of service as seen in industrialized countries, but with lower steel stock. The approach presented here is based on a static model, which is used to provide an indication of the embedded energy and emissions associated with the instantaneous build-up of the steel stock, to provide a certain level of service. Factors that influence dependence on personal transport are studied and possible ways of making people less reliant on cars are suggested. The results from the scenario analysis indicate that for passenger cars, the emissions embedded in steel stock can be reduced by 75% if India chooses not to replicate the US pattern of development, but instead, with proactive planning and decision making, adopt measures that can make the population less dependent on individual transport. This project therefore, is a step towards drawing attention to the importance of including the role of anthropogenic stocks in environmental policy.

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1. INTRODUCTION

1.1 Climate change and materials

Global climate change has emerged as one of today's most challenging and complex issues and is continuing to present pressing concerns. There is broad scientific consensus that our climate is changing - both regionally and globally - largely due to the combustion of fossil fuels and other human activities that increase atmospheric concentrations of green house gases. A series of international negotiations on this issue have helped focus global attention on the urgent need to reduce these green house gas emissions. The IPCC recommends a minimum cut in total annual global emissions of 50%-85% from 2000 levels by 2050 to stabilize the global mean temperature rise between 2.0 and 2.4 °C above preindustrial levels (IPCC 2007). Mounting evidence pointing to disruptive effects even with a 1°C temperature increase is compelling governments to adopt more stringent approaches. The recent COP17 at Durban, December 2011, for example, was marked by the establishment of the 'Durban Platform for Enhanced Action'. According to it, all the signatories to Kyoto (and the U.S.) agreed to forge a treaty by 2015 that would bring all countries, developed and developing, under the aegis of a legally binding agreement by 2020.

Urbanization and industrialization are key drivers for material use and associated energy use and consequent greenhouse gas emissions. A sector wise breakdown of emissions is provided by IEA and illustrated in figure 1(Allwood, Cullen et al. 2010). The largest contributing sector is industry at 36% of total emissions in 2006; 56% of which are driven by production of five key material groups-steel, cement, plastic, paper, and aluminium. 25% of the total industrial carbon emissions are due to steel alone.

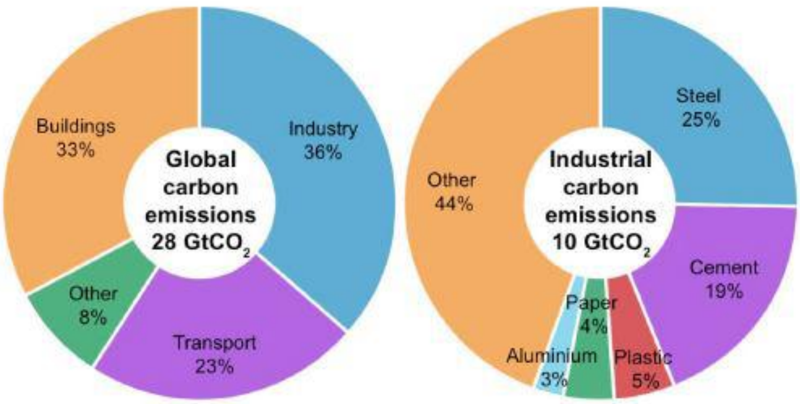


Figure 1: Global energy and process related emissions of carbon dioxide by major sector, and broken down within industry (Allwood, Cullen et al. 2010)

Demand for these materials is anticipated to double at least by 2050 (Allwood, Cullen et al. 2010), by which time global carbon emissions must be reduced. This is a daunting challenge as the material demand is very high, driven by industrialization of the developing world. This entails that with demand for materials doubling, there is a need to reduce CO_2 per ton by a factor of four, in order to

be able to achieve an emission cut of 50%, provided that each sector contributes with an even share. For emerging economies like India and China, it is very crucial that they urbanize without causing severe impact on the global climate. This project focuses on Steel, a material that finds application across all sectors and plays a vital role in building a modern society. The essential role of steel in the economy and environment is very comprehensively documented by Worldsteel as ''the rails, roads and vehicles that make up our modern transport systems use steel. Steel provides a strong framework and connections in the buildings where we work, learn and live, and shields people and property from the elements. Steel protects and delivers our water and food supply. Steel is a basic component in technologies that generate and transmit energy''(Williams 2009). Consequently, as developing nations around the world seek to improve their standards of living and lift populations out of poverty, it is inevitable that the demand for steel will increase. It remains an open question what pathways developing countries can take towards economic development, while simultaneously achieving the substantial global emissions reductions.
This work strives to provide an answer to this question in a way that has not been addressed so far in literature.

1.2 Stocks and embedded emissions and energy

Climate change mitigation strategies have till now, focused on reducing the energy use and emissions per kg steel produced by making the steel production process more efficient. Since the 1950s, the world steel industry has reduced its SEC by 85% (Yellishetty, Ranjith et al. 2010). This reduction can be attributed to changes in technology mix, improvements in Blast Furnace/Basic Oxygen Furnace and Electric Arc Furnace, improvement in manufacturing the semi-products, improved scrap collection and sorting. Also, the rise of scrap flows has made large scale recycling possible. The best steel mills are now limited by the laws of thermodynamics in how much they can still improve their energy efficiency. With most major energy savings already achieved, further large reductions in CO_2 emissions are not possible using present technologies (Worldsteel 2009). Further significant reductions in carbon emissions may be possible only through implementation of radical new production technologies. Efforts are being made to develop carbon-free reducing agents, for example the feasibility of the use of hydrogen as a clean reducing agent is a proposed area of research. The use of electrolysis for the steel industry is being understood, which might be attractive in terms of CO_2 emissions, if the carbon content of electricity is sufficiently low. The use of biomass as a reducing agent, either from charcoal for example or syngas is also being looked into. Another potentially attractive solution for carbon-intensive activities is CO_2 sequestration. Modifications in the blast furnace to accommodate Carbon Capture and Storage (CCS) as in the 'top gas recycling blast furnace' are being tested under the Ultra low carbon steel making (ULCOS) initiative of the EU. Such sophisticated technologies could be carried out, in principle, in a variety of ways, although all remain speculative, as no large scale practical experience has been acquired yet. Due to the high risks and technical and financial uncertainties associated with such measures, the steps to scale them up from the laboratory to commercial reality may take many years. With the ever increasing demand for steel, especially in the developing countries, and a need for a 50% reduction in overall emissions by 2050, it is absolutely crucial to look beyond supply-side measures for climate change mitigation.

This research project in the form of a master's thesis attempts to draw attention to demand-side measures. The anthropogenic stock in-use is taken to be the driver of the system and its responsible management is highlighted. Stocks in the built environment are the materials piled up by mankind to serve its needs: materials in buildings, infrastructure, transportation, machineries, appliances, landfills etc. Steel remains in-use stock for many decades and provides services and therefore, can be considered as a measure of industrialization. In-use stock management is so far, not mentioned in policy debates even though it may have large impacts on future emissions. Also, stocks form reservoirs of materials that can eventually be recovered for re-use or recycling, thereby potentially lowering the energy demand and emissions for materials production. This is possible in developed countries which have high degree of urbanisation and significantly larger per capita stocks. Developing countries, in contrary, have the opportunity of leapfrogging, e.g., by building up their built environment systems in a more efficient way, by using less material in the first place, to provide same level of service. In this work, such potential measures are identified for a developing country like India, where the necessary emissions associated with building up stocks that provides a decent level of service are estimated, rather than that associated with raising production to a decent level. This opens up a pertinent topic of what defines a decent service level, which is discussed in the next section.

1.3 Stocks as a measure of service level

A review of the current literature brings out several ways in which service level has been interpreted and defined. The interactions between the environment and the economy, and welfare gains to humans is well represented by figure2, taken from a study conducted by the Wuppertal Institute (Bartelmus).

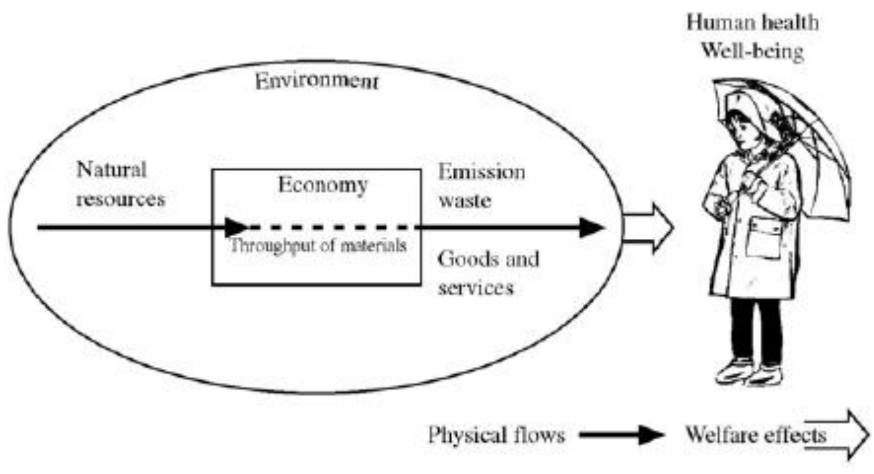


Figure 2 Environment-economy interaction and effects (Wuppertal Institute)

Conventional economics have suggested that increasing levels of economic consumption lead to increasing levels of well-being and that GDP per capita is a good indicator of welfare. This view however, has been criticised on both environmental and social grounds. Economic consumption has essentially been synonymous with material consumption. Material intensive lifestyles, such as those seen in western economies have been instrumental in escalating emission levels and have also led to the depletion of natural resources. The non-economic view therefore points to a broader definition of welfare. For example, some scientists link human well-being to satisfaction of human needs by including social and psychological components of human welfare(Jackson and Marks 1999). ‘Need’ is a very relative term and has been defined in different ways. One of the most well known works on human needs is that of Maslow whose early characterisation (Maslow 1954) postulated a hierarchical pyramid of human needs stretching from basic physical needs at the bottom to social and moral needs at the top.

Durning,A., in his book, ‘How much is enough?’ brings to attention and discusses the very fundamental questions related to human needs, such as, is there a level of living above poverty and subsistence but below the consumer lifestyle? What level of consumption can the earth support?(Durning 1992). It emphasises that consumerism beyond minimum requirements leads to ecological decline. In the same vein, another notion that explores benchmarks for leading a comfortable life with bare minimum consumption is the concept of ‘environmental space’. Figure 2 taken from Spangenberg’s work (Spangenberg 2002) illustrates the concept, showing that the ‘ceiling’ represents the upper limit to resource consumption based on carrying capacity and equity arguments, while the ‘floor’ defines the minimum resource accessibility that permits to lead a dignified and comfortable life.

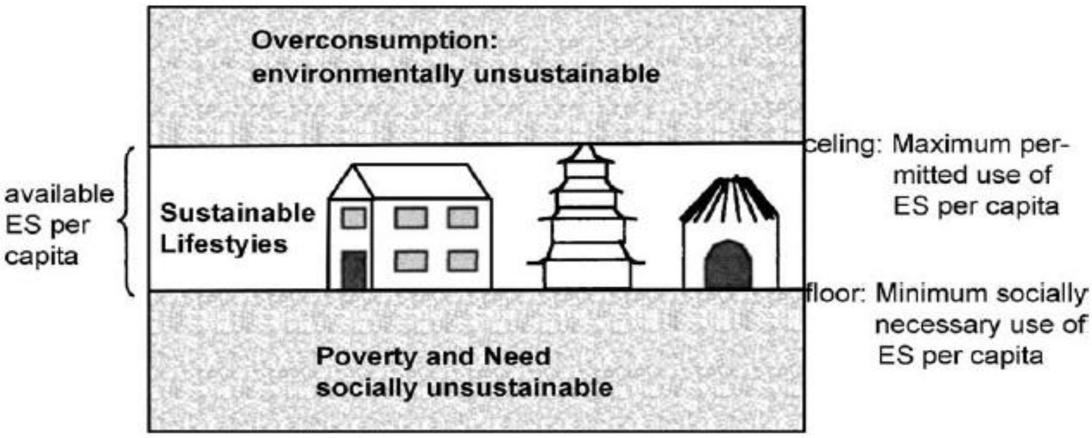


Figure 3: Environmental space concept (Spangenberg 2002)

As is evident from the works cited so far, definitions of welfare, needs, satisfaction are varied and vague. As a result, many different indicators of service levels have proliferated. They include income levels, material throughput through economies, carrying capacity or ecological footprints, all of which are all related to flows. These concepts are no doubt interesting, but remain abstract since they cannot be quantified. The issue of green house gas emissions leading to climate change represents a physical problem and therefore, requires thinking in physical dimensions. Concepts like welfare, need, satisfaction, well-being, sufficiency, etc need to be connected to physical quantities. What has widely been neglected in defining service levels is the inclusion of built environment stocks as a measure of industrialization. Stocks have a physical meaning as they provide services to people and define their lifestyles and due to their robustness are better suited for long-term analysis. One of the first mentions of the concept of ‘stock’ as fundamental in defining human well being was made by Kenneth Boulding, though his classic essay, ‘The economics of the coming spaceship Earth’. It brought to light the central role of stocks in shifting from high waste to low waste economy and in estimating future environmental impacts (Boulding 1966). In more recent works, the importance of in-use stocks is highlighted as not just providing service to people but also as sources for future secondary resources (Müller, Wang et al. 2006). This project attempts to link stocks to service level by the use of suitable parameters, which will be explained in section 2.3.1.The following section provides an overview of stock estimations carried out for iron.

1.4 Stock estimates

Quantification of in-use stocks has recently started gaining interest and attention. Majority of the in-use metal stocks lie in the developed countries (Gerst and Graedel 2008).This fact points towards the dependence of modern lifestyles on a substantial stock of metals. According to the data available, per capita in-use stocks in more developed countries typically exceed those in less developed countries by factors of five to ten. Of the total metal stock, five metals- iron, aluminium, copper, zinc and manganese, make up more than 98% (Gerst and Graedel 2008). The per capita stock of iron is largest amongst all metals as is intuitively deducible from the high rates of flows of iron into use and the long lifetime of iron-bearing products. The following paragraphs explain the two approaches used for stock estimation and present a review of in-use stocks of iron.

A common method of anthropogenic stock estimation is the 'top-down' estimation which takes information regarding flows, and infers metal stocks in society by computing the cumulative difference between inflow and outflow. Mathematically, if St is stock at time t, then in discrete time steps,

$$S_t = \sum_{T_o}^{T} (\text{Inflowt} - \text{Outflowt}) + S_o$$

where T_o is the time of the initial time step, T is the current time step, and So is the extant stock at the initial time step. S_o may be unnecessary to include in the calculations as it is negligible compared to the contribution of S_t in increasing the material stock in society (Gerst and Graedel 2008). Time steps are typically one year. An extensive review of top-down estimates of iron stocks was carried out as part of the specialisation project and a summary is attached as table 1 in Appendix A (Broca 2011). To provide an estimate of the iron stocks in developed countries, it is worth mentioning a study involving a dynamic material flow model to analyse the patterns of iron stocks in-use for six industrialized countries. Iron stocks reached a plateau of 8-12 tons per capita in the US, France and UK (Müller, Wang et al. 2011). The decomposition of the total iron stock indicates further similarities: all of the investigated countries employ most of the iron in construction, followed by machinery and appliances, transportation, and others. Furthermore, the per capita iron stocks are fairly similar for machinery and appliances (from 2 tons in France to 3 tons in Canada), transportation (from 1 ton in U.K. to 2 tons in U.S.), and others (from 0.3 to 0.6). However, there are large differences in the amount of iron employed in construction (from 2.5 tons in France to 9-10 tons in Japan). Another recent top-down study estimates the per capita iron stocks in China to be 2.8 tons and that in India to be 0.6 tons (Wang, Muller et al.). In both countries, same stock ranking is seen-machinery and appliances, then construction, followed by transportation.

The second major method of stock estimation is called 'bottom-up' estimation which involves gathering information on stock variables to estimate in-use stock, and (if desired) inferring behaviour of flows. It is represented by

$$S_t = \sum_{I}^{A} N_{it}m_{it}$$

where N_{it} is the quantity of final commodity i in use at time t, m_{it} is the metal content of in-use final commodity I, and A is the number of different types of final commodities (Gerst and Graedel 2008). Fewer bottom-up studies have been done as compared to top-down studies. One of the most extensive bottom-up estimates has been conducted for iron stocks in China, which suggests a per capita in-use stock of 1.5 tons (Wang 2009). A project at the Yale University estimated the per capita in-use stocks of iron in the State of Connecticut, USA to be 9.3 tons (Eckelman, Rauch et al. 2007). Another detailed bottom up study was conducted for the city of New Haven which revealed that the per capita iron stock is 9.2 tons in the city infrastructure, buildings, transportation systems, and equipment(Drakonakis, Rostkowski et al. 2007). Of the iron stock 28% is in items such as rail cars and ships in ocean trade not permanently within the city, and 22% is devoted to receiving and delivering oil fuel to the city and its surrounding communities.

From these estimates, it is observed that there exists a glaring gap in the per capita in-use stocks of iron between developed and developing countries. Developing countries are in the process of building up their supporting infrastructural base in order to strive for better living standards and this means additional strain on resources along with significant repercussions for the global climate. No previous studies have been found that look into the emissions and energy associated with building up the stocks in-use. This project first quantifies the differences in steel stocks in developed countries using a bottom-up approach and provides estimations of the embodied emissions and energy. Further, it highlights the fact that the development trajectory followed by the western developed world would have to be discarded by the developing countries and a conservation-based model with less strain on energy and materials would need to be followed. It looks at how a developing country like India can have a lower carbon footprint of building up material stocks to reach a service level seen in western countries. Since developing countries have an advantage of choosing the most efficient way of building up their stocks, lessons can be learnt from what has already been experienced in the industrialised world. For doing this, an attempt is made to define service level using different parameters as described further in the methodology section.

1.5 Project aim and scope

This research attempts to use a novel approach to address the following objective:

> How can developing countries build up material stocks to attain the same level of service as seen in industrialized countries in a way that they have a lower carbon footprint in comparison?

Scope

Since in the given time frame, it was not possible to look into all sectors of the built environment stock, it was decided to narrow the scope down to transportation only. According to top-down stock estimates mentioned in section 1.4, for all developed countries investigated, most of the steel is employed in construction, followed by machinery and appliances, and then transportation and other applications. Inspite of this, transportation sector (rolling stock) was selected as the focus of research due to a number of reasons. Data on rolling stock is made available by national statistical offices in most countries and is therefore reliable and relatively easily obtainable. For bottom-up estimation of steel stock in vehicles, it was possible to obtain metal content from manufacturers, if not already available. For commodities such as buildings, this is more difficult as they are not mass-produced and are not standardised across countries. First, a set of developed countries is analysed to provide insights into the following questions:

1. How large are the steel stocks in road and rail vehicles in a set of developed countries?

2. What are the suitable measures of service provided by the vehicle stock?

3. What are the differences observed among the developed countries in terms of service levels and steel stocks and what countries are better suited as role models with respect to green house gas emissions for developing countries to reach the same level of service?

4. How large are the embodied energy and emissions in the ferrous components of the vehicle stocks in the set of developed countries?

After estimating the steel stocks in vehicles as well as the associated emissions and energy for developed counties, passenger cars as a mode of transportation was then made the focus of further research. Reason being, that it was best suited for the way modelling was carried out in this work, as it included user behaviour, technology and product design. The most interesting motive for selecting transportation sector and particularly transportation by cars was that it is dependent on the manner in which the rest of the built environment is set up. This enabled inclusion of the impacts of infrastructure, land use and city structure on automobile dependence. An attempt was made to provide answers to the following questions and thus impart deeper meaning to the work:

5. How do patterns of automobile dependence vary from region to region (country level and city level)?

6. Are there factors that influence demand for passenger cars beyond GDP? What are they?

7. What kinds of relationships exist between urban transportation, land use and economics and how do they enhance our understanding of the broad patterns of automobile dependence?

8. What insights can be inferred from such data for policy makers, consumers, producers and urban planners?

From the results obtained from the analysis of vehicle stock and embedded emissions of developed countries and with the understanding of the factors affecting automobile dependence, finally, scenarios were built for India that looked into the following:

9. How can India attain the same level of service as seen in developed countries with lower steel stock in passenger cars?

10. What potential leapfrogging opportunities can be identified to achieve this?

1.6 Outline of the study

This project is composed of many elements which are all vital in contributing towards the main goal. It is necessary to visualise at an early stage how each element connects with each other. Figure 4 represents a schematic of how the complete study is carried out. Work is divided into three stages, with each stage attempting to answer the corresponding research questions listed in section 1.5. Here, each stage is briefly described, while the detailed methods adopted to carry out each of it, are provided in section 2.3.

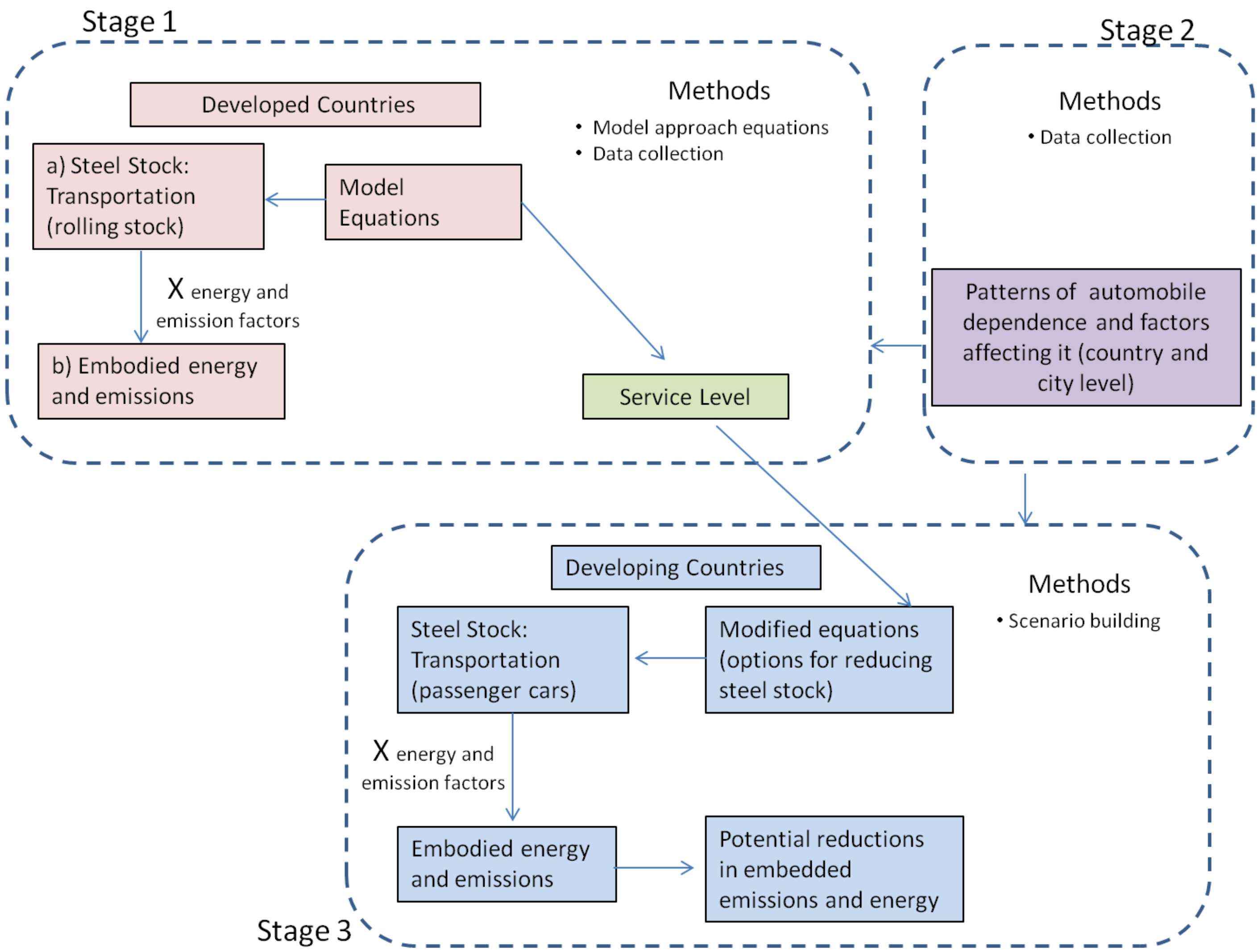


Figure 4: Schematic of project execution

Stage 1: Estimation of steel stock in vehicles for a set of developed countries and defining service level

This stage relates only to the developed countries, aiming at providing answers to questions 1 to 4 mentioned in section 1.5. The key steps involved are development of model equations to calculate steel stocks in vehicles and related energy and emission estimation and relevant data collection. Through the equations, it is also attempted to define 'service level' using different parameters. This stage brings out the differences amongst developed countries in terms of steel stocks in vehicles and the varying levels of service provided by them.

Stage 2: Patterns of automobile dependence and factors affecting it

As mentioned in section 1.5, the scope of the work is narrowed down to studying the demand for passenger cars. This component of the study is important to understand patterns of automobile dependence and to discover whether relationships exist between urban transportation, land use and economics. Often, the wealth levels in cities are thought to be critical in determining the vehicle ownership in urban environments. However, this section investigates whether there are other external factors that affect the need to use automobiles. It brings into focus how different city structures and land use patterns affect accessibility to more oft-visited places and how that changes the need to travel. The inferences drawn from this investigation, therefore, add new dimensions to the definition of service level, and help in providing answers to the questions 5 to 8 outlined in section 1.5. They would play a vital role in suggesting suitable policies and realistic recommendations for developing countries in order to achieve the central objective of attaining the same level of service by using lesser material. The approach adopted for this stage as described in section 2.3, is step-wise data collection and analysis, first at country level and then zooming into city level information.

Stage 3: Scenario building for developing countries

This is the last component which attempts to finally provide answers to the central objective of the study by specifically providing insights on questions 9 and 10 mentioned in section 1.5. The goal is to find ways in which the developing countries would reach the same level of service as seen in the developed countries, using lesser material and therefore have a lower carbon footprint than the developed countries. India is taken as an example of a developing country and instantaneous build up of stocks to reach a level of service comparable to the developed countries is assumed for each scenario that is developed. The scenarios therefore do not refer to historic stocks. Estimations are presented as a snapshot of year 2009. India's iron and steel industry depends to a large extent on iron ore mining. The in-use stock of iron is growing rapidly with an output of iron exiting use that is about eight times smaller than the input of iron entering use (Müller, Wang et al. 2007). Due to this high accumulation ratio of in-use iron stock, domestic post-consumer scrap availability is very limited and therefore, the Indian Steel Industry cannot rely on secondary production. Therefore the embedded energy and emission embedded in stocks are estimated for the primary production route only, using the factors mentioned in section 2.2. The detailed description of how each scenario is built is provided in section 2.3.

2. METHODOLOGY

2.1 System definition

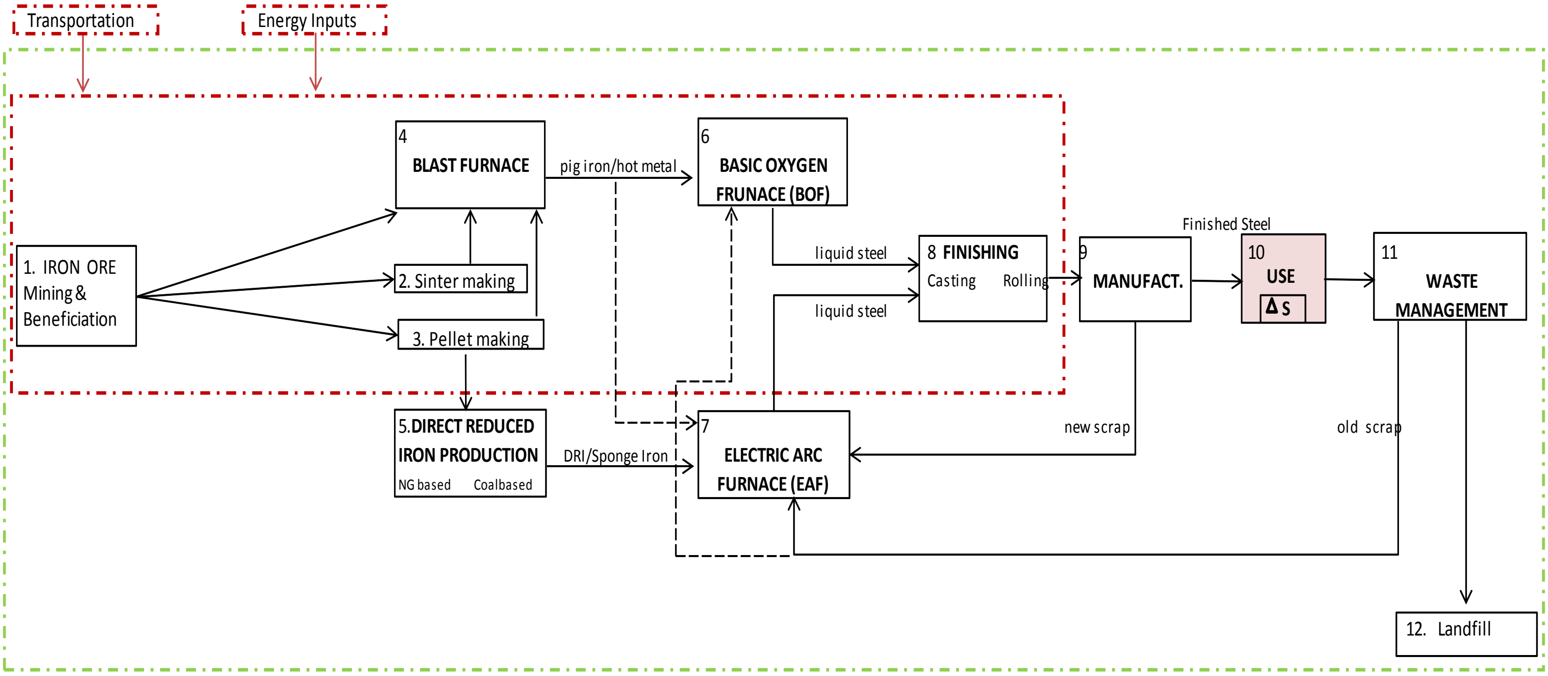


Figure 5: System definition for steel

In this project, the steel stock of vehicles in the Use phase (process 10 in figure 5) is considered. The steel cycle consists of closely interconnected processes, as represented in figure 5. The main processing stages included in steel production are iron making (processes 1, 2 and 3 in the figure), primary and secondary steelmaking, casting and hot rolling. These are followed by some of the following fabrication processes depending on the type of finished product required. The two main process routes are:

- the integrated route, often referred to as the Blast Furnace/Basic Oxygen Furnace route, using mainly raw materials (iron ore, coal and limestone) and some steel scrap as input.
- Electric Arc Furnace route using predominantly steel scrap as well as some pig iron or direct reduced iron

Strictly speaking, these are not two distinct process routes and neither route is solely a 'primary' steelmaking or 'secondary' steelmaking route. As is illustrated from the figure, the EAF can often contain primary material (pig iron or DRI) and the BOF contains scrap. But many a times, for broader convenience, the integrated route and the EAF route are often referred to as the primary and secondary production routes respectively. The integrated route accounts for two-thirds of steel production(OECD/IEA 2007), producing a wide variety of steel compositions each tailored according to the requirements of the final use of the steel.

The green dotted line in figure 5 represents the boundary within which the material flows are discussed in this work. Quantifications of each material flow are not done for the purpose of this project. As already mentioned, the focus here is only the estimation of steel stock in the use phase and providing an indication of the associated energy demand and carbon emissions. It is important to mention here, that stocks build up over a long time, and so, quantifying emissions embodied in stocks is inherently dynamic. However, in this work, the time dimension is neglected and a static model is employed, giving a snapshot (in this case, for the year 2009 owing to data availability) of emissions and energy associated with a given level of service. The energy and emission factors used in this work are from the Life Cycle Inventory (LCI) study done by Worldsteel. The system boundary used in their calculation corresponds to the red dotted line in figure 5. It includes the primary production route of steel making and all major upstream processes, including the production and transportation of raw materials and energy sources. The following paragraph describes in brief, the methodology used by Worldsteel and the processes included to calculate accurately, the energy and emission factors.

2.2 Emission and energy factors

Published literature on estimation of energy and emission factors from the steel industry was reviewed. It was observed that the calculations of these factors are influenced by the methodological choices made by the various organizations/institutions/authors. The factors used for this project were taken from the recent Life Cycle Inventory (LCI) study undertaken by Worldsteel in accordance with the standards ISO 14040: life cycle assessment-principles and framework (ISO 2006)and ISO 14044: life cycle assessment-requirements and guidelines (ISO 2006). The methodology used to develop the factors is transparently documented in a detailed report (Worldsteel 2011), from which the key points explaining the system considered are detailed in the following paragraph.

The impact assessment is based on the methods and data compiled by the Centre of Environmental Science at Leiden University, CML 2001 – Dec.07. It is a cradle-to-gate LCI study, covering all of the production steps from raw materials 'in the earth' (i.e. the cradle) to finished products ready to be shipped from the steelworks (i.e. the gate). Finished products for which emission (kg CO_2-equiv./kg finished product) and energy (MJ/kg finished product) factors were made available for NTNU by Worldsteel on request, are electro-galvanized sheet, finished cold rolled coil and hot dip galvanized sheet, all of which are relevant to a range of downstream applications in the automotive sector (Broadbent 2012). For the purpose of this study, average values of the three are used and displayed in the table 1.

Table 1: Emission and energy factors per kg finished products (LCI study, Worldsteel 2011)

Emission and energy factors per kg finished products	Electro-galvanized sheet	Finished cold rolled coil	Hot dip galvanized sheet	Average
CML2001 - Dec. 07, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	2.57	2.31	2.47	2.45
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	28.72	24.91	27.59	27.07

These factors are calculated for the primary production route (BF/BOF) and do not consider the scrap input (secondary production) or end-of-life recycling into the process of steelmaking. The Worldsteel LCI study is the most recent and representative LCI study for steel as it covers data from 49 sites, located in 17 countries from Europe (Austria, Belgium, Finland, France, Germany, Italy, Luxembourg, the Netherlands, Norway, Spain, Sweden and the UK) and Asia (China, India and Japan). North America is included in the global average data sets. The data on process operations are collected from the individual sites from 2005 to 2008. The steel product manufacturing system encompasses the activities of the steel sites and all major upstream processes, including the production and transportation of raw materials, energy sources and consumables used on the steelworks. The system boundary is shown (as the in the following figure 6, taken from the methodology report (Worldsteel 2011).

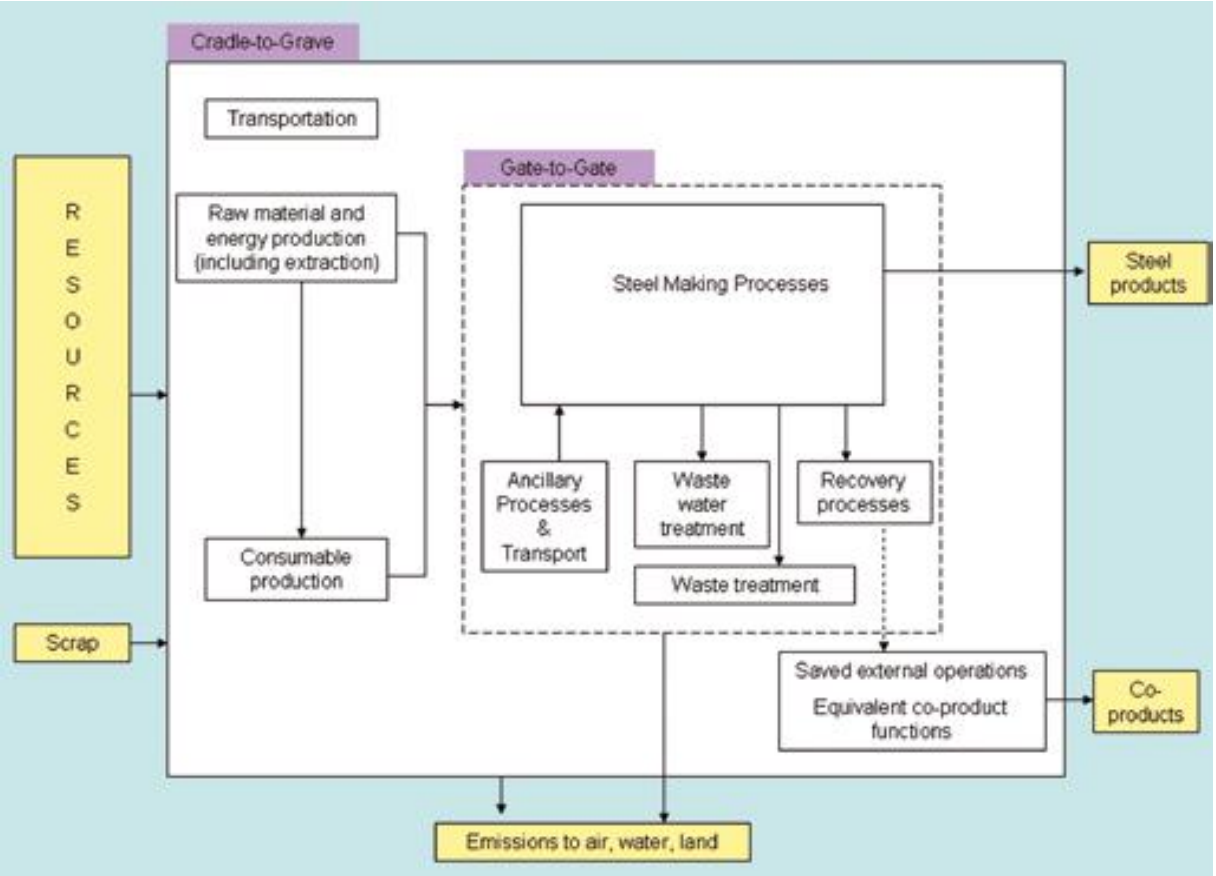


Figure 6: System boundary for LCI for steel products (Worldsteel 2011)

The LCI model was created in the software GaBi 4. The data are collected by a site-by-site and process-by-process basis through GaBi Web Questionnaires. Transport was included for iron ore, pellet, coal, scrap, limestone, lime and dolomite as well as steel intermediate products. The models for transport options come from the GaBi 4 database and consist of an average fuel supply based on European data. For all energy inputs (e.g. electricity, heating fuels, diesel for internal transport), the country/region-specific upstream inventories have been taken into account. For example, for each site contributing data, the country specific electricity grid mix is used, as defined in the GaBi 4 database.

2.3 Methods adopted

The methods adopted are described in 3 parts, each corresponding to the stages described in section 1.6. This is done as an attempt to establish connection with the previous and subsequent sections and to maintain a consistent form.

2.3.1 Model approach equations

This corresponds to stage 1 described in section 1.6. A methodology is developed to estimate steel stock in vehicles, both road and rail in a set of developed countries. This is done by developing generic equations which are applied across different modes of transportation for the countries selected. Using the emission factors presented in section 2.2, the associated energy demand and emissions are estimated. It must be kept in mind that these estimations are meant only to give an approximate indication of how large the energy and emissions embedded in the vehicle stock of developed countries are, assuming instantaneous deployment of steel stocks. In reality, stock development takes place over time and the replacement of obsolete stock would result in higher environmental impacts. The objective is also to define, through these equations, 'service level' using suitable parameters. The following paragraphs describe in detail how this was done.

Estimation of steel stock in vehicles for a set of developed countries and defining service level

Two model approach equations are developed, each attempting to define service level in different ways. They are described as under:

1. The first approach is a straightforward one, which calculates steel stocks by multiplying the vehicle stocks by the amount of steel contained in a reference vehicle for each class of vehicle. This is essentially the bottom-up method of stock estimation. The equation (i) is

$$population\ (p) \times \frac{vehicles}{capita} \times \frac{kg\ steel}{reference\ vehicle} = kg\ steel \qquad eq\ (i)$$

   Service level definition 1: Here, service level is defined by the **physical ownership** of the vehicle, given by the parameter 'vehicles per capita'.

   Although this is a useful indicator, it is not enough to understand the patterns and efficiency of usage of vehicles. In order to capture these, the above equation is broken down into several parameters, explained further in point 2.

2. The second approach is a more detailed one, in which use parameters are introduced. The equation (ii) is derived as follows for each vehicle type:

$$p \times \underbrace{\frac{km\ travelled}{person \times yr}}_{\text{personal kilometrage}} \times \underbrace{\frac{1}{\frac{km\ driven}{vehicle \times yr}}}_{\text{vehicle kilometrage}} \times \underbrace{\frac{1}{\frac{persons\ travelling}{vehicle}}}_{\text{occupancy rate}} \times \underbrace{\frac{kg\ steel}{reference\ vehicle}}_{\text{material intensity}} = kg\ steel\ \ eq\ (ii)$$

Where the following relations hold:

$$intensity\ of\ use\ of\ vehicles = vehicle\ kilometerage \times occupancy\ rate \ldots (a)$$, and

$$personal\ kilometrage = \frac{vehicles}{person} \times \frac{persons\ travelling}{vehicle} \times \frac{km\ driven}{vehicle \times yr} \quad \ldots (b)$$

Service level definition 2: The definition of service level is extended to represent **intensity of use** by the introduction of new parameters, travel budget (kilometres travelled per person per year and kilometres driven per vehicle) and occupancy rate.

Kilometres driven per vehicle and the occupancy rate together represent the intensity of use of the vehicle. Kilometres driven per vehicle is a measure widely used internationally and domestically to assess the magnitude of the pressure transport puts on the environment and how it is changing over time (NZGovernment 2012). Vehicle occupancy rates are an important indicator in explaining changes in the levels of vehicle ownership and in illustrating changes in the efficiency of mass passenger transport. The occupancy rate is calculated as a ratio between passenger kilometres and the supplied vehicle kilometres. The total number of vehicle kilometres can be reduced if the efficiency of passenger transport, in terms of vehicle occupancy rates, increases. Consequently, fewer vehicles would be needed to transport the same number of persons (EEA 2012). Kilometres travelled per person also depend on three parameters according to the above relation. Further in the analysis section, scenarios are developed where the interdependencies of the parameters are discussed as well.

Estimation of the embodied energy and emissions in the steel stock in vehicles

The steel stocks calculated for each country, using the equations described above, are multiplied by the energy and emission factors mentioned in section 2.2.

$$Steel\ stock\ (kg) \times\ Energy\ or\ emission\ factor\ (MJ\ per\ kg\ or\ CO_2\ equiv.per\ kg) = Total\ energy\ or\ emissions\ (MJ\ or\ kg\ CO_2 equiv.) \quad eq(iii)$$

2.3.2 Data requirement and data treatment

Data requirement is described in detail for both stage 1 and 2 separately. All sources are documented and key assumptions and uncertainties are stated.

Stage 1: Estimation of steel stock in vehicles for a set of developed countries

No previous studies have been found that look directly at the material stocks embedded in national vehicle stocks or their corresponding embedded emission and energy. A few top-down estimates have been made through modelling of material flows into and out of the transport sector, as mentioned in section 1.4. In contrast, this study adopts a bottom-up approach, which is currently not addressed in literature.

Six developed countries, namely; United States of America (USA), Japan (JP), United Kingdom (UK), The Netherlands (NL), Switzerland (CH) and New Zealand (NZ) are considered for this study. The choice of countries was made such that they could represent a range of population densities. Also, data availability was an important factor that led to the selection. Sources and treatment of data for both the equations described above in section 2.3.1 are explained for each country individually and all the data is presented as tables in Appendix B. Furthermore, road vehicles and rail vehicles (rolling stock) are treated separately. In general, publically available national statistics for 2009 road and rail rolling stock have been used for each country. These provide total numbers of vehicles registered on a yearly basis, by vehicle category, rather than a direct measurement of the number of vehicles present in a particular country. It was observed that each country has different vehicle classification systems, and for some, the exact definition for each class is not always available. The classifications were carefully studied for each vehicle so that they could be assigned to a suitable reference vehicle whose material composition was known. The following paragraphs describe the main features of each country's vehicle stock statistics, first for road vehicles and then for rail vehicles. This is followed by a section on material composition that explains reference vehicles and their selection process.

United States of America (USA)

Road: Vehicle stock and use parameters

The primary source used was the website of the Federal Highway Administration (FHWA 2011), which provides on a yearly basis, tables for the total number of automobiles, buses, trucks and motorcycles registered with State authorities. In the American classification system, all light duty vehicles include passenger cars, light trucks, vans and sport utility vehicles. Light trucks are two axled four wheeled trucks up till 4536 kg, while those weighing more are classified as heavy trucks. (see Appendix B, table 1)

Data on passenger kilometres travelled and vehicle kilometres were obtained from the same source. The procedures used to derive data elements contained in the tables are detailed in a technical report also available online (FHWA 2011). Rest of the parameters were derived. For example occupancy rate was calculated as passenger kilometres divided by the vehicle kilometres. (see Appendix B, table 2)

Rail: Rolling stock and use parameters

Data on railways was taken from the internet edition of the National transportation Statistics. The Bureau of Transportation Statistics administers transportation data collection, analysis and reporting (BTS 2012). The rail profile gives the number of Class 1 rail vehicles (locomotives and freight cars) and Amtrak vehicles (train-cars and locomotives). The transit profile documents the number of heavy, light and commuter rails. The same sources were referred to for data on vehicle and passenger kilometres travelled. (see Appendix B, tables 3 and 4)

Japan (JP)

Road: Vehicle stock and use parameters

The statistics provided by Japan's Ministry of Land, Infrastructure, Transport and Tourism were used (MILT 2012). Vehicles are recorded as ordinary trucks, small/light goods trucks, passenger cars, light two-wheeled vehicles, special use vehicles and light motor vehicles and buses. Light motor vehicles are defined here as passenger cars with an engine capacity of 660cc or less (TIA 2007). Buses include passenger and chartered buses. (see Appendix B, table 5)

The figures on passenger and vehicle kilometres travelled were also taken from other tables compiled by the Ministry (MILT 2012) and other official statistics obtained from the web (Statistics 2005). (see Appendix B, table 6)

Rail: Rolling stock and use parameters

For data on the railway sector, the Railisa Database was used (UIC 2012). It is published by the International Union of Railways, which includes 197 members across the continents. It provides data on the number of passenger cars and freight trains and also on the distance travelled by vehicles and passengers. (see Appendix B, tables 7 and 8)

United Kingdom (UK)

Road: Vehicle stock and use parameters

The data was taken from the statistics compiled by the Department for Transport. Total number of cars, motorcycles, light goods vehicles, heavy goods vehicles, buses and other vehicles are registered on a monthly basis (DfT 2012). (see Appendix B, table 9)

Passenger and vehicle kilometres travelled were obtained from an archived website of the Department for Transportation (DfT 2012). (see Appendix B, table 10)

Rail: Rolling stock and use parameters

Data on railways was taken from the Railisa database (UIC 2012). It provides a breakdown of the number of passenger cars owned by different companies like ATOC, Eurostar and NIR and also the number of freight wagons. Vehicle and passenger kilometre travelled is also recorded for each type of rail vehicle. (see Appendix B, tables 11 and 12)

The Netherlands (NL)

Roads: Vehicle stock and use parameters

Statistics Netherlands has an online database portal called Statline which was accessed for most of the data required (CBS 2012). Total number of passenger cars, motorcycles, commercial vehicles, trailers and semi trailers are recorded on a yearly basis. Commercial vehicles include buses and coaches, vans, rigid vehicles, articulated vehicles and special vehicles. The definitions of each of these vehicle types are provided in detail in the source mentioned. Some of the information was available only in Dutch. The Bureau was contacted through emails for translations and clarifications. (see Appendix B, table 13)

Passenger kilometres travelled were obtained also from Statline (CBS 2012). The occupancy rate of passenger cars was found from a study conducted by the European Environment Agency (EEA 2012). Data on vehicle kilometres for buses is taken from the traffic performance data set provided by Statline (CBS 2012). For the rest of the vehicle types, data was provided by the data manager of the portal on request (CBS 2012). Distance travelled per person per year is also recorded in Statline (CBS 2012), which actually corresponded to the calculated figures. (see Appendix B, table 14)

Rail: Rolling stock and use parameters

Data was taken from the Railisa Database which provides data on the number of passenger cars and freight trains and also on the distance travelled by vehicles and passengers (UIC 2012). (see Appendix B, tables 15 and 16)

Switzerland (CH)

Road: Vehicle stock and use parameters

Road vehicles registered in Switzerland are recorded by the Swiss Federal Statistical Office (SFSO 2012) as passenger cars, passenger vehicles, goods vehicles, agricultural vehicles, industrial vehicles, motorcycles and trailers. Passenger vehicles were taken to be as buses, based on clarification with scientific officers from SFSO. (see Appendix B, table 17)

Data on distance travelled per person per year by vehicle type were taken from a report prepared by the Federal Department of Home Affairs, FSO (FDHA 2011). Another report published by the FSO was referred to for the occupancy rate of passenger cars in Switzerland and also for the travel budget of all vehicle types, i.e. vehicle kilometres travelled (FDHA 2011). (see Appendix B, table 18)

Rail: Rolling stock and use parameters

The rail rolling stock data was taken from a report published by the Swiss Federal Railways, Switzerland's biggest transport company. There are several other cantonal and private railway companies operational in Switzerland, however, they were assumed to be fairly insignificant compared to the national one, which owns by far the largest market share (SBB 2011). The report also documents the total operating performance in terms of train kilometres, passenger kilometres and volume of freight carried. (see Appendix B, tables 19 and 20)

New Zealand (NZ)

Road: Vehicle stock and use parameters

Analysis produced by Research and Statistics, Ministry of Transport of New Zealand was used to get data on the number of vehicles, which is also presented in a report published by the ministry (MoT 2011). Vehicles are categorised as light passenger, light commercial, motorcycles, trucks and buses. Light commercial are goods vans if under 3500 kg and trucks if over 3500 kg. Buses are also defined as light commercial if under 3500 kg and buses if heavier. More details are provided in the aforementioned report. (see Appendix B, table 21)

Data on vehicle kilometres travelled was also taken from the spreadsheet complied by the Ministry of Transportation on New Zealand vehicle fleet statistics (MoT 2011). For passenger kilometres travelled, data was obtained from a factsheet examining the results from a Household Travel Survey conducted for the Ministry of Transport. It is prepared by the financial, economic and statistical analysis team of the Ministry of Transport (MoT 2011), using data from 34,311 people in 13,674 households. Based on the results of three separate surveys carried out, another publication looks at the travel patterns of New Zealanders. Data from this work is used for getting the values of distance travelled per person per year (MoT 2011). (see Appendix B, table 22)

Rail: Rolling stock and use parameters

Rolling stock data was taken from the Railisa Database (UIC 2012) which records number of passenger trains and freight wagons. Data on vehicle kilometres was obtained by contacting officials from the National railway company in New Zealand, KiwiRail (KiwiRail 2012) and on passenger kilometres was taken from International Historical Statistics (Mitchell 2007). (see Appendix B, tables 23 and 24).

The total vehicle stocks, including all types, are summarised in table 25, Appendix B for each country. As added research, passenger kilometres travelled by cars, buses and rail was collected for all European countries from a report published by the Road Federation of the European Union (ERF 2011). The data is compiled as table 28 and also represented as graphs 1 and 2 in Appendix B.

<u>Material Composition</u>

As explained by equation i) in section 2.3.1, the vehicle stocks have to be multiplied by the amount of steel contained in a reference vehicle for each type of vehicle in order to calculate the steel stocks. For this, a suitable representative reference vehicle, whose material composition is known, was needed to be chosen. This section is heavily based on the work done as part of the advanced course in Industrial Ecology at NTNU by Loveland,S (Loveland, Lia et al. 2011).

Road vehicles

The reference road vehicles and the steel content in each are displayed in table 26 in Appendix B. Majority of the sources used and assumptions made are borrowed from Loveland's work. A life cycle analysis modelling of generic compact passenger cars in Europe was made in a study, which was used to get the material composition for European cars (Nemry, Leduc et al. 2008). For the US, the category light vehicle includes passenger cars and light trucks and the material composition of an average light vehicle was found. The Transport Energy Data Book (Davis, Diegel et al. 2011), which represents an assembly and display of statistics characterising US transport activity, quotes Ward's Motor Vehicle Facts and Figures 2010, which provides data on material composition of light vehicles. For minicars, which are relevant in the Japanese case, information was not available in English. The weights of a typical European car and two Japanese minicars, Daihatsu Move and Mitsubishi i (Wikipedia 2012) were compared and it was assumed that the steel content in minicars would be 75 percent of that in the European car. For buses and trucks, the material composition was taken from the Ecoinvent database for lorry and bus production (Spielmann, Bauer et al. 2007). For the bus, Ecoinvent has based its analysis on a Volvo bus, information for which was taken from a product declaration. The lorry chosen was the medium size (28 tonne) in the Ecoinvent database. For motorcycles, trade flow data (UN 2008) was used for each country, calculating the steel content in the standard model produced in each country as 45% of the total weight (Müller, Wang et al. 2011). There are reference motorcycle models therefore, for each country and their steel content can be seen in the individual tables for each country in Appendix B.

Rail vehicles

Ecoinvent LCI tables were used for the material composition of locomotive and goods wagons (Spielmann, Bauer et al. 2007). The reference locomotive used is the 'Re 460' which is used for both rail and passenger transportation in Switzerland. Ecoinvent mentions in its analysis that the types of rail wagons are extremely inhomogeneous. Data on three types of goods wagons are documented and then an average value is calculated. For material composition data of electric rolling stock, a report published by Network Rail was used (NetworkRail 2009). Network Rail runs, operates and invests in Britain's rail network. (see Appendix B, table 26)

Once the steel stock in vehicles is estimated for the selected developed countries, it is then multiplied by the emission factors described in section 2.2 to get an indication of the associated emissions and energy. The results for all countries are compared in section 3, with an attempt to provide answers to the research questions posed for stage 1) in section 1.5. Further, the aim is to focus on passenger cars and to understand factors that influence its demand in the different countries and cities. The next step in data collection is therefore, towards this direction, and is explained in details below.

Stage 2: Patterns of automobile dependence and factors affecting it

Since the aim is to study patterns of dependency on passenger cars and discover what factors have an impact on it, data collection for this section was not restricted to the six developed countries mentioned above. The following paragraphs detail the methods and the data requirements.

- Country level data

As a first step, data on country level was gathered in order to check if any patterns could be revealed by looking at the relationship between car ownership and income level, and also to discover other factors that might explain differences in transportation patterns between countries. For this part of the analysis, data was taken from the book on world development indicators, prepared by the development data group of the World Bank (Worldbank 2011). It is a comprehensive database that provides internationally comparable statistics on countries across the globe. Data for the year 2009 is collated for about 213 countries across the globe. The World Bank classifies countries based on gross national income (GNI) per capita in US dollars for 2009. GNI measures total domestic and foreign value added claimed by residents. When calculating GNI, the World Bank follows the World Bank Atlas conversion method, which is explained in the statistical methods section of the book. Every economy is classified as low income ($995 or less), middle income; subdivided into lower middle ($996-$3945) and upper middle ($3946-$12195), or high income ($12196 or more). Low and middle income economies are regarded as developing economies. Population density is calculated as the midyear population divided by total land area in square kilometres.

Data on passenger cars and road network are compiled for World Bank by the International Road Federation (IRF) and by contacting several agencies and statistical offices. It is evident that the data quality is uneven as the coverage of each indicator differs across countries because of different definitions. Broadly, passenger cars in the World Bank database are defined as road motor vehicles, other than two-wheelers, intended for the carriage of passengers and designed to seat no more than nine people including the driver. Total road network includes all roads in the country-motorways, highways, main or national roads, secondary or regional roads, other urban and rural roads. These specific parameters are presented in table 1 in Appendix C and corresponding figures 21 to 23 obtained are contained in section 3. The excel file presented along with this report contains more data from the same source that could be needed for further analysis on the subject.

- City level data

In all metropolitan regions in the world today, the growing levels of motorisation and its impact on urban societies is a major issue. It is not precisely known how cities really differ from each other in their basic transportation patterns and what factors really have an effect on automobile dependence. Unlike for nations, there are no systematic urban databases from which data on transportation systems in cities can be extracted. Therefore, it is very difficult to find easy and reliable explanations for differences in patterns of automobile use in cities. Attempts were made to collect data; however, the datasets obtained were either not complete or not robust enough to carry forward the analysis. Number of passenger cars in cities and GDP per capita was relatively easily available, but the challenging part was to find data on urban form and land use. During the course of the data analysis process, one of the important learning outcomes was that in order to calculate urban density, it is crucial how urban area is defined. Using the total land area gave misleading results as it is not the most accurate parameter to use, as explained below.

Through extensive survey of published literature, it was found that such issues have been discussed by Kenworthy J.R. and Laube F.B., who carried out similar work and have partly addressed the lack of comparative urban transportation data in their works (Kenworthy and Laube 2001). Their database has been compiled into the 'Millennium Cities Database for Sustainable Transport' for the International Union (Association) of Public Transport (UTIP) in Brussels. The database provides data on 100 cities on all continents. Unfortunately, the entire database is not publically available. The choice of cities is well described in another article (Kenworthy and Laube 1999) where it is mentioned that an attempt was made to select a set of the major cities in each region which would cover a range of population sizes, not excluding smaller cities, but generally weighted towards medium to large cities. Several cities were added due to their unique urban form and transportation patterns, like some developing countries, which added a comparative context to their analysis. The data was collected over a period of seven years through collection of a large set of primary data items (e.g. population, urbanised land area, vehicle kilometres of travel in cars, transit vehicle kilometres of service and passenger boardings for each city etc.). It involved direct contact with authorities in each city through on-site visits to offices, and through subsequent telephone calls, faxes and e-mail communications to authenticate the data gathered.

The data used for this analysis is extracted from a summarized article (Kenworthy 2008) in which cities have been grouped into higher income (cities in United States, Australia and New Zealand, Canada, Western Europe, high income Asian cities) and lower income (cities from Eastern Europe, Middle East, Latin America, Africa, low income Asian cities and Chinese cities) regions. The five higher income areas have average GDPs between US$20 000 and US$32 000, while the six lower income areas range from US$2400 to US$6000.The data are primarily based on averages of the various data items from the sample of cities in each distinct geographic region. The specific cities comprising the regional averages are found in Appendix C, presented in table 2. The data are for the year 1995 and the key variables selected for this analysis are urban density, GDP per capita, passenger cars per 1000 people and passenger kilometres travelled per person. The urban densities are based on actual urbanised land area which excludes all regional scale open space, undeveloped land, forests, agricultural land and water bodies. Total land area is not used. Urbanised land includes all road and streets, all developed land and all local open spaces. Data are obtained for each metropolitan region from detailed land use data. The summarised data can be found as table 3 in Appendix C. The corresponding figures 24, 25 and 27 are part of section 3, which is followed by discussion on them in section 4.

The relation between passenger cars and urban density is also analysed on an individual city level. For this, a set of data has been extracted from the paper (Kenworthy and Laube 1999). Although the data being from 1990, is not very recent, it does help in bringing out the relationship between car ownership and urban density. The original dataset has been extended in this work, to include some more cities in an attempt to have a larger compilation for further analysis. Attempts were made to choose cities with high urban densities. The data on passenger cars for most of the cites has been taken from the Eurostat database (Eurostat 2012) and the urban densities from an annually published inventory of population and population densities for world urban areas (Demographia 2012). The reason for selecting this source is that the definition of urban areas corresponds to how Kenworthy and Laube defined it in their work. Therefore, the extension of datasets maintains consistency and makes the values comparable. Data on Las Angeles, Oslo and Madrid have been taken from individual reports. For LA, data has been taken from the transportation profile report compiled by the Department of transportation(LADOT 2009). In the case of Oslo, a report published by Statistics Norway was used (StatisticsNorway 2009). And finally, for data on Madrid, a publically available factsheet from the database developed by the International Association of Public Transport was referred to. All data is compiled into table 4 in Appendix C, which is used to develop corresponding figure 26 presented and discussed in the section 3.

In order to include transport infrastructure into the discussion, data on the length of motorways in cities was gathered. The main source used for this was the Eurostat database available online (Eurostat 2012). For Madrid and Las Angeles, the sources used were the same as those mentioned previously. The data is compiled as table 5 in Appendix B and the corresponding figure 28 presented in section 3.

Data assumptions and uncertainties

Some key assumptions were made in stage 1 of the data collection and treatment. They are listed below:

- It was assumed that vehicle registration data is representative of the vehicle stock numbers. This may exclude vehicles which are not recorded by the statistical authorities like some agricultural, military and unused vehicles. Also, each country may have different procedures of vehicle registration with varied levels of coverage and effectiveness.
- Definitions of each vehicle type in each country were not always available. Therefore, the assignment of each vehicle type to a reference vehicle was done, in many cases, based on value judgement and critical evaluation of the limited information available.
- It was assumed that a reference vehicle would be a representing all the vehicles in a particular category. In reality, material composition of vehicles varies enormously, even within a specific class. For passenger cars, it may be a fair assumption as the differences within the class are not very stark. However, the uncertainty may be high in the cases of rail locomotives, lorries/trucks owing to their extremely heterogeneous categories.

2.3.3 Scenario building

Equipped with the understandings and inferences drawn from stage 2, scenarios are created for developing countries using the model equations described in stage 1 (see section 2.3.1). Scenarios are developed for passenger cars only and are made using actual data collected for the developed countries so that best practices (in realistic terms) can be implemented by developing countries. Since road vehicle steel stocks in India are currently negligible (38 kg per capita), as concluded in earlier work (Loveland, Lia et al. 2011), it is assumed here that India would build the stock from scratch and this build up needs to be fed from primary production. As mentioned earlier, it is a static model, assuming an instantaneous build-up of stock and therefore, overlooks the temporal aspects of restructuring and replacement of obsolete stock. Using the data from developed countries, different possibilities in which India can build-up its steel stock (in passenger cars) in order to achieve the same service level as seen in developed countries are explored. For each case, the embodied emissions and energy are estimated (see figure 7)

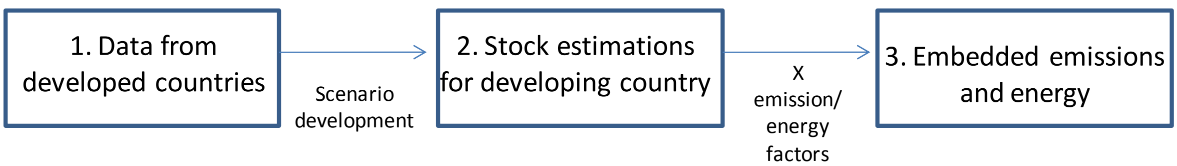


Figure 7: Final treatment of each scenario

The first two steps which describe how different stock levels are obtained for India using data from developed countries are represented in figure 8, and explained in detail below. For each scenario, the reference vehicle used for steel content is a typical European Car (containing 742 kg steel/car).

1. DATA FROM DEVELOPED COUNTRIES		
Service level	Parameter	Cases
Car ownership	1. vehicles/cap	a. High (US)
		b. Medium (CH)
		c. Low (NL)
Intensity of use (Travel Budget)	2. km/cap/yr and km/car/yr	a. High (US)
		b. Medium (UK)
		c. Low (JP)
Combination	3. High Persons/car (UK)	a. High travel budget (US)
		b. Medium travel budget (NZ)
		c. Low travel budget (NL)

Approach 1: Extrapolating the identified individual country cases for India (without changing/combining parameter values)

Approach 2: Combining parameters from identified countries and calculating required cars/cap for India

2. STOCK ESTIMATIONS FOR INDIA if:	
Parameter	Cases
1. vehicles/cap	a. High
	b. Medium
	c. Low
2. km/cap/yr and km/car/yr	a. High
	b. Medium
	c. Low
3. High Persons/car	a. High travel budget
	b. Medium travel budget
	c. Low travel budget

Figure 8: Scenarios for developing different stock levels in India

As mentioned in section 2.3.1, different parameters are used to define service level in different ways in this work. These are used in the following way to provide an indication of the steel stock in vehicles and the embedded emissions and energy in India.

Scenario 1a-1c: If car ownership in India is the same as that in selected developed countries

Three cases are identified from the set of developed counties, with high, medium and low levels of vehicles per capita. Here the service level is described in physical in terms using car ownership as the service parameter. If India were to have the same level of service as seen in the identified developed countries, it would have to have the same number of cars per capita. The high, medium and low levels of cars per capita are applied to India and the corresponding steel stock and embedded emissions are calculated, using equations (i) and (iii) respectively.

Scenario 2a-2c: If intensity of use of vehicles is same as that in selected developed countries.

As defined in section 2.3.1, the intensity of use is represented by kilometres travelled per person per year, kilometres driven per vehicle per year and occupancy rate (persons travelling per vehicle). Kilometres travelled per person per year, kilometres driven per vehicle per year are found to be directly related (also see figure 30 in section 3), and are therefore treated as a single parameter called travel budget. Again, three cases are identified from the set of developed countries; ones with high medium and low travel budgets, with their given vehicle ownerships. The steel stocks for India are calculated for the high, medium and low travel budgets as seen in the identified developed countries using equation (ii).

For both scenarios 1 and 2, the approach followed was that the identified developed country cases were applied to India without changing or combining parameter values. For the next scenario, instead of replicating developed country cases, parameters from different developed countries are combined in a way that lower stock benchmarks for India are proposed.

Scenario 3a-3c: Combination of service parameters

Intensity of use of a vehicle also depends on occupancy rate. For this set of scenarios, the highest level of occupancy rate observed amongst all developed countries is applied to India. This occupancy rate is combined with high, medium and low levels of travel budget. For the three combinations, the numbers of vehicles required are estimated using equation (b) and then the steel stock and embedded emissions are calculated. By having different levels of travel budgets, the aspect of accessibility is implicitly addressed. When accessibility to places visited is high, the need to travel is reduced, leading to low a low travel budget.

Further potential in lowering steel stock also lies in reducing the steel content in the vehicle itself. This would then include the 'material intensity' parameter of the eq (ii). As a last step in scenario building, lightweighting is introduced as an option to reduce the steel content in vehicles. Lightweighting of steel products has the potential to reduce liquid metal demand and therefore energy usage and CO_2 emissions. Previous work establishes that all steel products could be lightweighted by 30% on average and therefore, this would reduce the demand for metal in final products by 30% (Milford 2011). This 30% reduction of steel content in cars is applied to all previously described scenarios and the resulting stocks, energy demand and emissions are subsequently calculated.

The results from each scenario are presented in section 3.4.2 and using the results, options for reducing steel stock in vehicles for developing countries are identified and discussed in section 4.

3. RESULTS

The presentation of results is done in parts, each corresponding to the stages described above in section 1.6 to maintain easy link between the description and the results.

3.1 Estimation of steel stock in vehicles for a set of developed countries (Stage 1a)

3.1.1 Vehicle Stocks

Road Vehicles

Figure 9 shows the absolute and per capita vehicle stocks respectively, corresponding to table 25 in Appendix B. For each country, the vehicle stock represents the sum of all types of vehicles mentioned in the individual country tables in Appendix B (including passenger cars, buses, trucks, motorcycles). The US has a strikingly higher vehicle stock compared to the other developed countries. On a per capita basis, US still is in the lead with a little over 0.8 vehicles, while UK has the lowest of about 0.5 (figure 9).

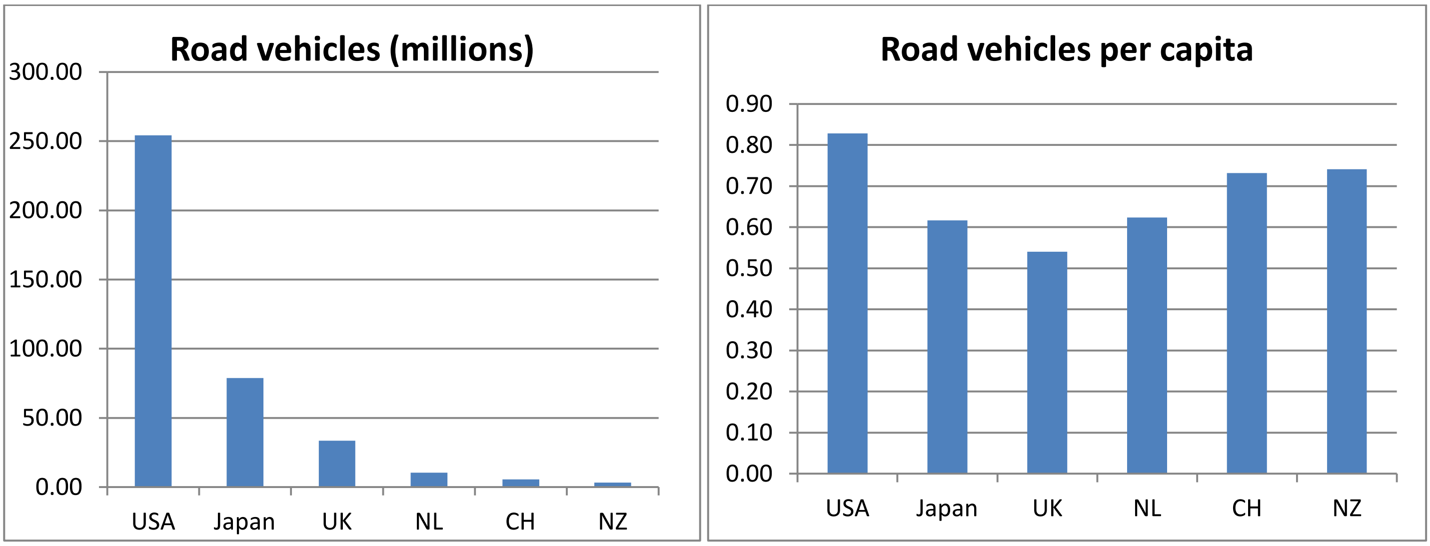


Figure 9: Total number of road vehicles and road vehicles per capita for selected developed countries

Rail rolling stock

Figure 10 shows absolute and per capita rail rolling stock respectively, corresponding to table 25 in Appendix B. For each country, the rolling stock includes all types of vehicles (passenger cars, freight trains, wagons, locomotives). The size of the rail rolling stock of all other developed countries is negligible as compared to the US (figure 10). This is because of the far higher number of goods wagons in the US (approximately 1.36 million).

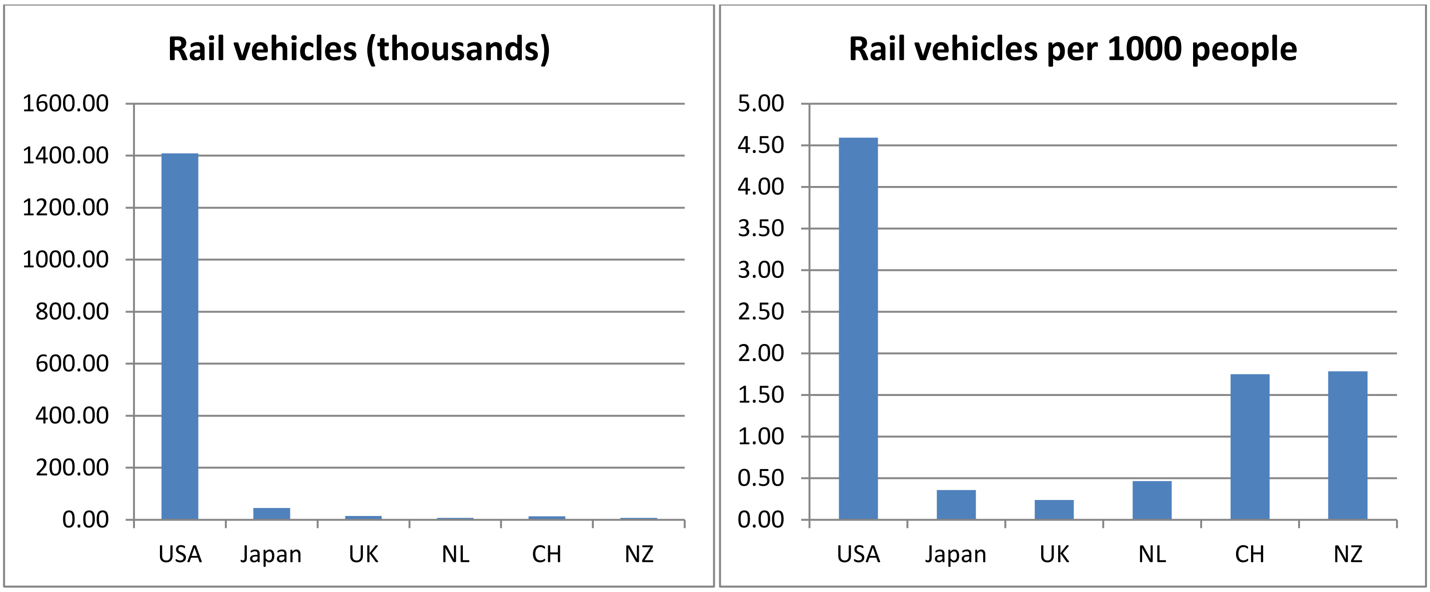


Figure 10: Total number of rail vehicles and rail vehicles per capita for selected developed countries

3.1.2 Steel stocks

Road vehicle steel stock

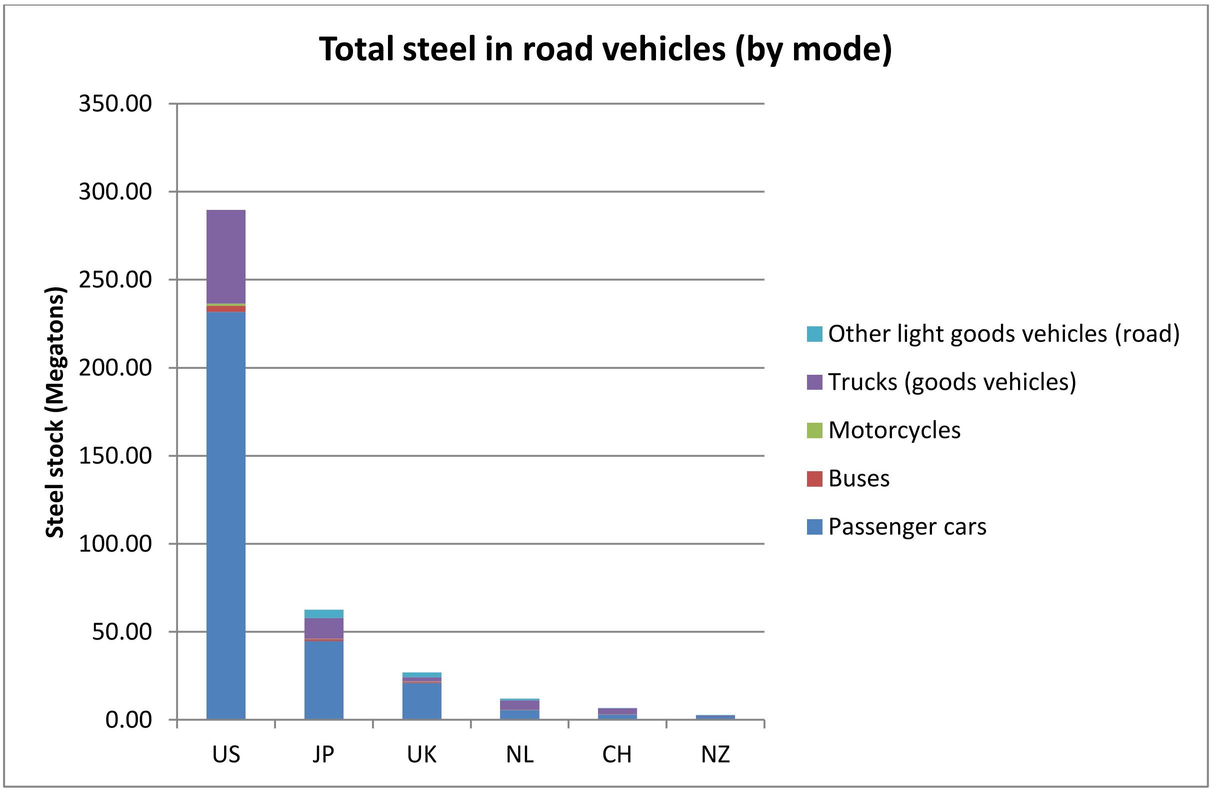


Figure 11: Total steel stock in road vehicles for selected developed countries (by mode)

Figures 11 and 12 represent the absolute and per capita steel stock in road vehicles for the developed countries. Steel stocks in road vehicles are is proportionate to the sizes of the vehicle fleet. It is apparent from figure 11 that passenger cars have the largest absolute steel stocks in the cases of US, Japan, UK and New Zealand. In the Netherlands and Switzerland, the steel stock in passenger cars is comparable to that in goods vehicles (trucks). Per capita values of steel stocks in figure 12 suggest that across all countries, passenger cars are the largest stock of steel, followed by trucks. Although the total road vehicles per capita are almost the same in the cases of Switzerland and New Zealand, the steel stock of the Swiss vehicle fleet is significantly larger than that of New Zealand. This may be due to the larger proportion of heavy trucks in Switzerland. Also, the per capita steel stocks in the US are significantly higher than the other countries, particularly Japan and the UK.

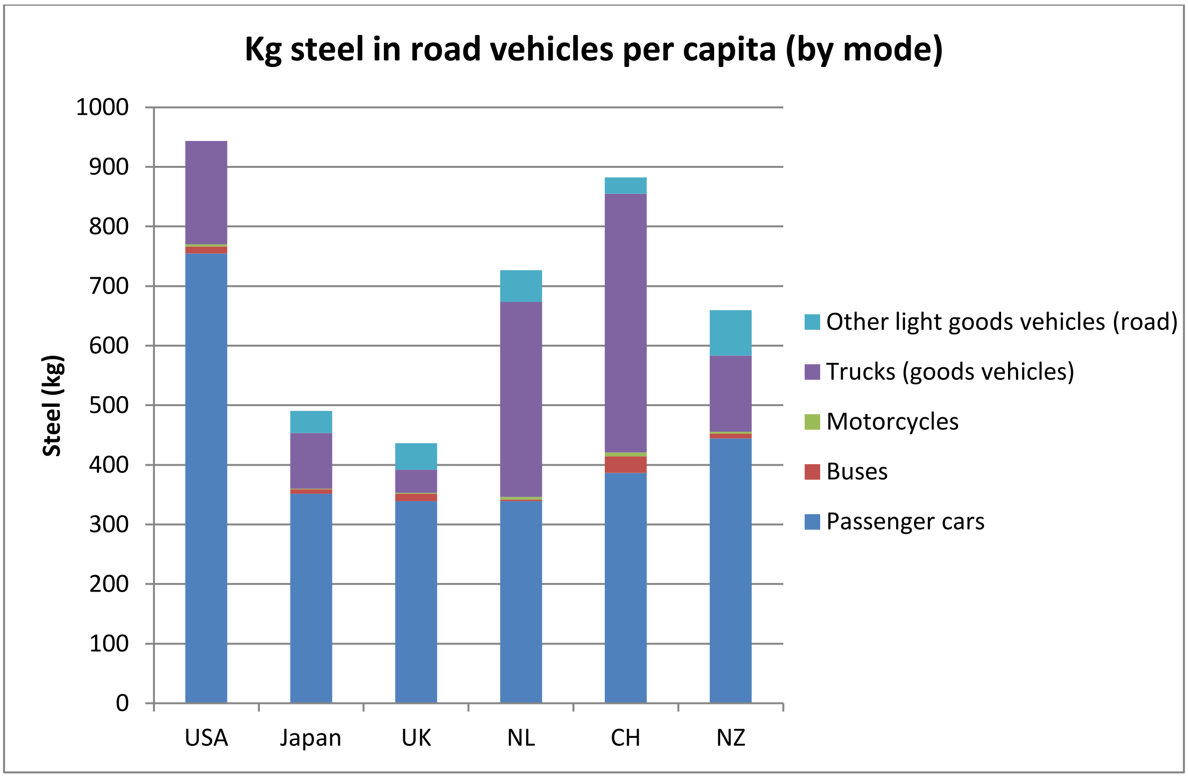


Figure 12: Steel stock per capita in road vehicles for selected developed countries (by mode)

Rail vehicle steel stocks

The sizes of the steel stocks in rail vehicles in absolute and per capita terms are represented by figures 13 and 14 respectively. These closely follow the sizes of the vehicle stocks in each country. In most countries, the largest stock of steel in rail vehicles is the freight wagons, except in Japan and UK, where there are more passenger trains than freight wagons.

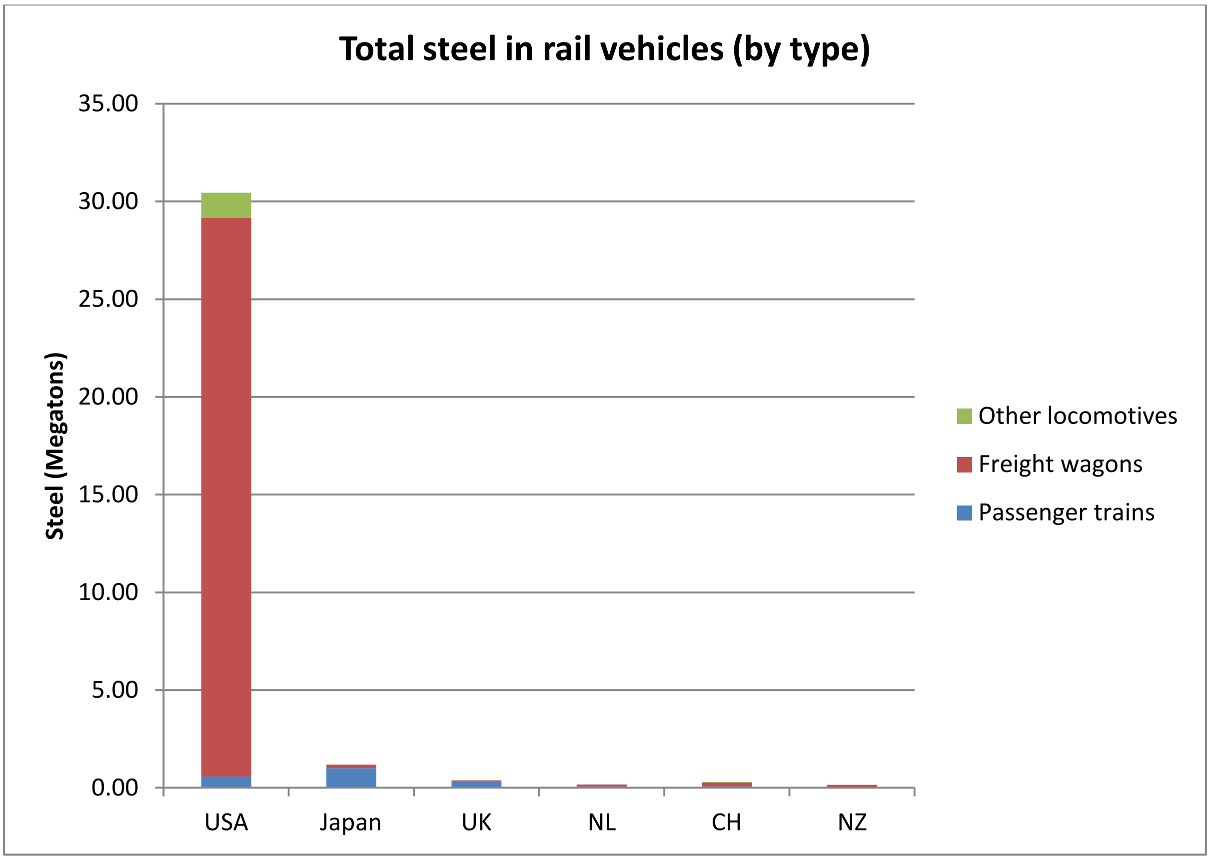


Figure 13: Total steel stock in rail vehicles for selected developed countries (by mode)

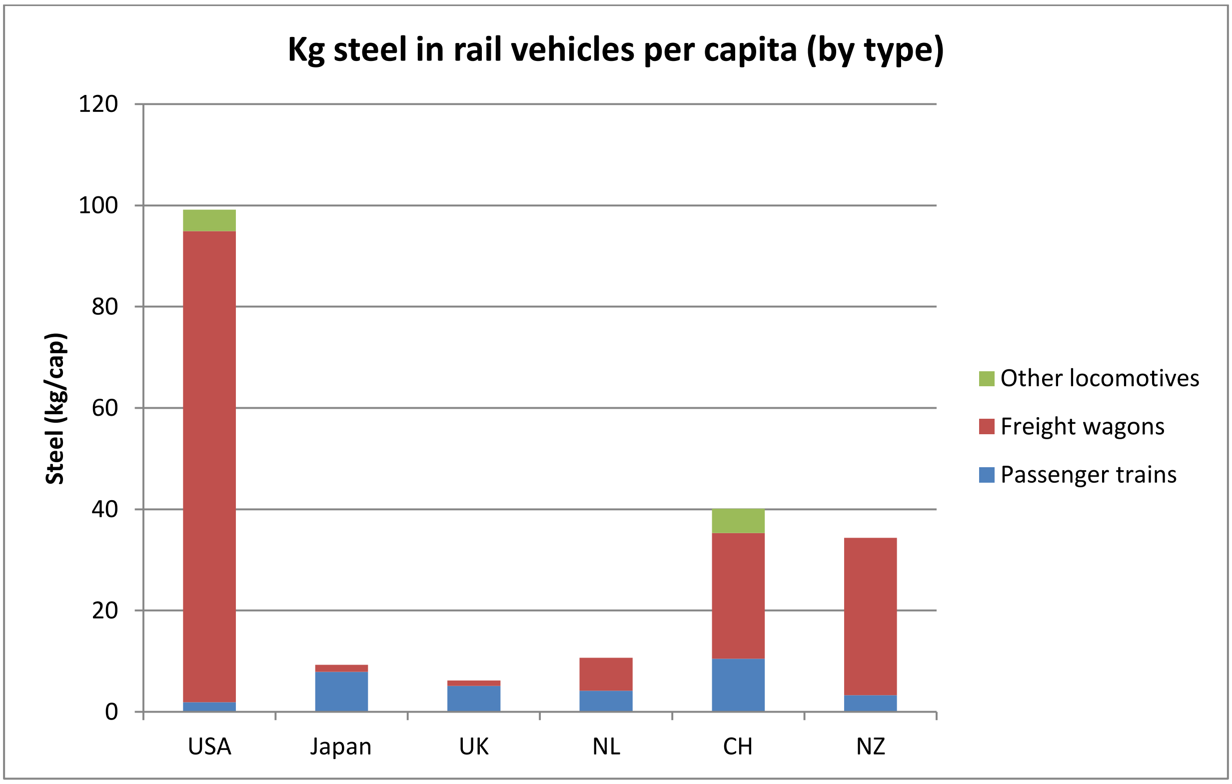


Figure 14: Steel stock per capita in rail vehicles for selected developed countries (by mode)

Figure 15 represents that the road vehicles represent the larger share of steel stock across all countries.

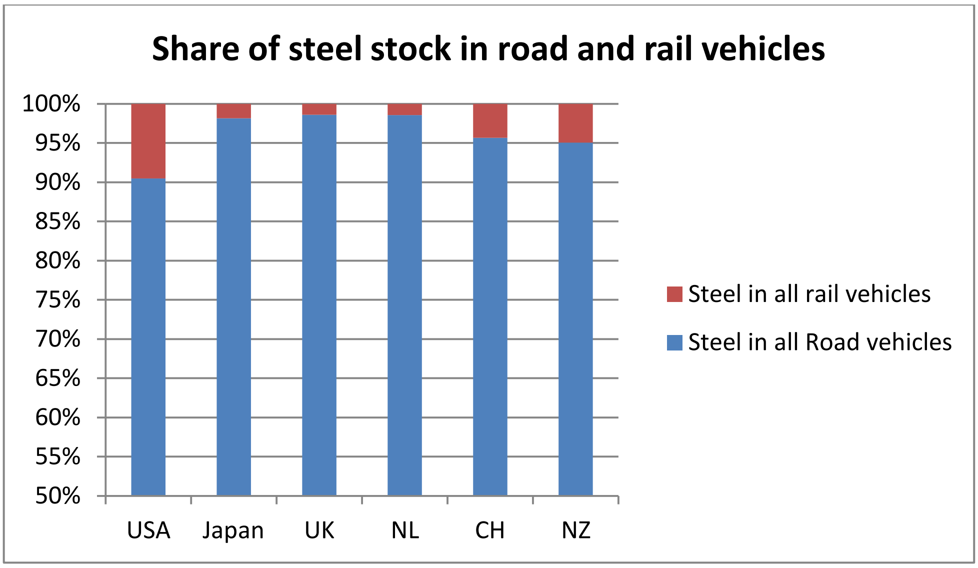
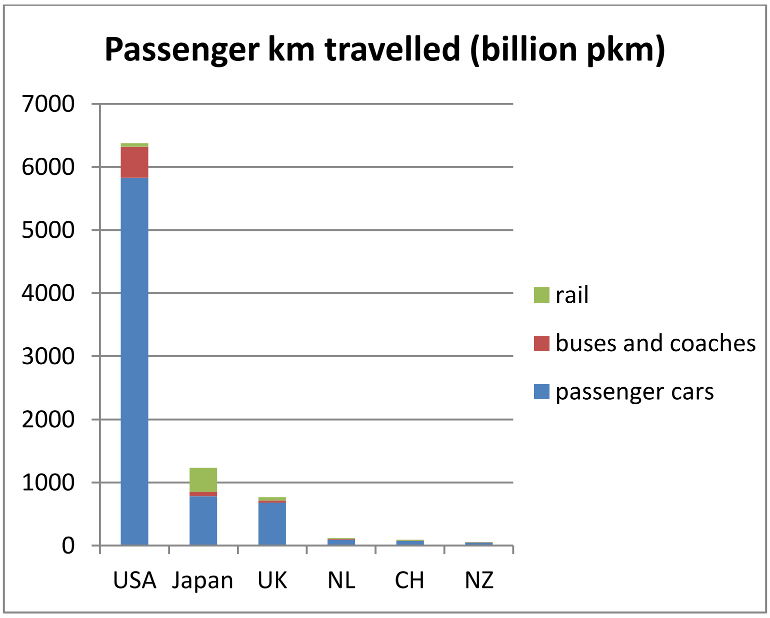


Figure 15: Share of steel stock in road and rail vehicles in selected developed countries

3.1.3 Passenger transport

Figure 16 shows the actual passenger kilometres travelled by cars, buses and rail in each country and also, a normalised representation of the passenger kilometre share by each mode. It is clear that cars have the largest share of passenger transport. Of all countries, Japan has the largest rail transport share, followed by Switzerland and the Netherlands. (see table 27, Appendix B; table 28 in Appendix B is a compilation of passenger kilometres travelled by each mode in all European countries as added information)



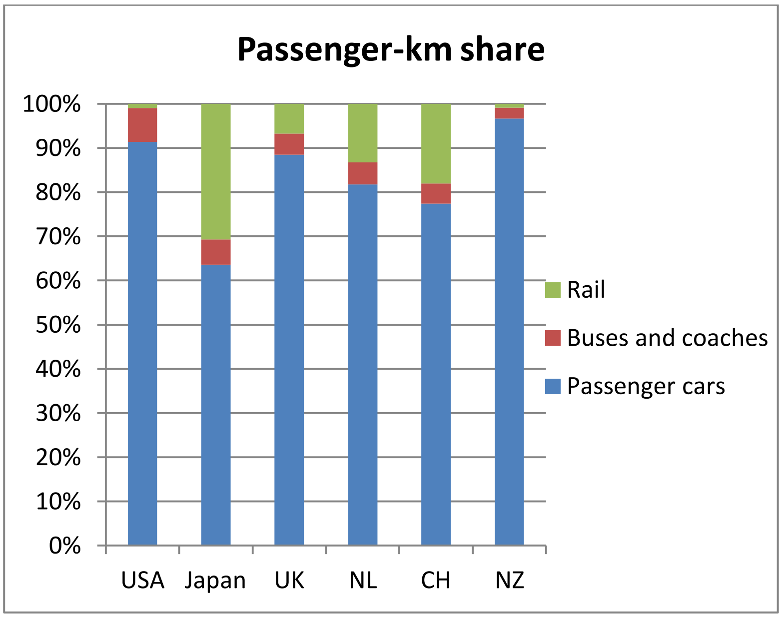


Figure 16: Passenger transport by mode; absolute and share

Figure 17 is a representation of steel stock per passenger distance travelled in a year. In countries like Japan, Netherlands, and Switzerland, lesser steel stock in rail is lesser per passenger kilometre. This is expected as seen from the figures above, these countries have the highest percentage of rail passenger kilometres compared to the other countries. Although the number of passenger cars per capita are comparable in UK and The Netherlands (457 cars per 1000 people), their usage is very different. In UK, passenger km is higher (680 bill pkm) than what is observed in the Netherlands (95 bill pkm). Consequently, the steel stock required per passenger km is much lower in the UK. More on the use patterns is discussed in the results from stage 2.

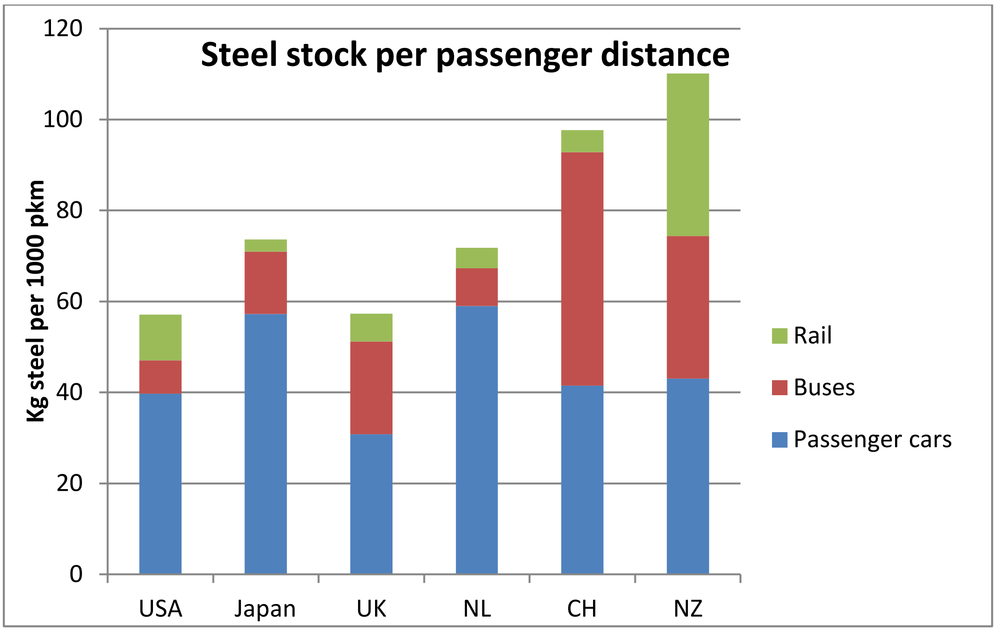


Figure 17: Steel stock per passenger kilometre

3.2 Estimation of embedded emissions and energy in vehicle steel stock for a set of developed countries (Stage 1b)

Embedded emissions and energy in road and rail vehicles have been represented in the same figure 18 and it is observed that they are proportionate to the size of the steel stocks. As also steel from the stock sizes (see figures 11 and 13), US far exceeds the other countries in the associated emissions and energy as well. 90% of the emissions and energy are embedded in the road vehicle steel stocks and the remaining 10% in rail vehicles. For values, refer to table 29 in Appendix B. The per capita emissions and energy represented in figure 19 also follow closely the sizes of per capita steel stocks for both road and rail vehicles (see figures 12 and 14).

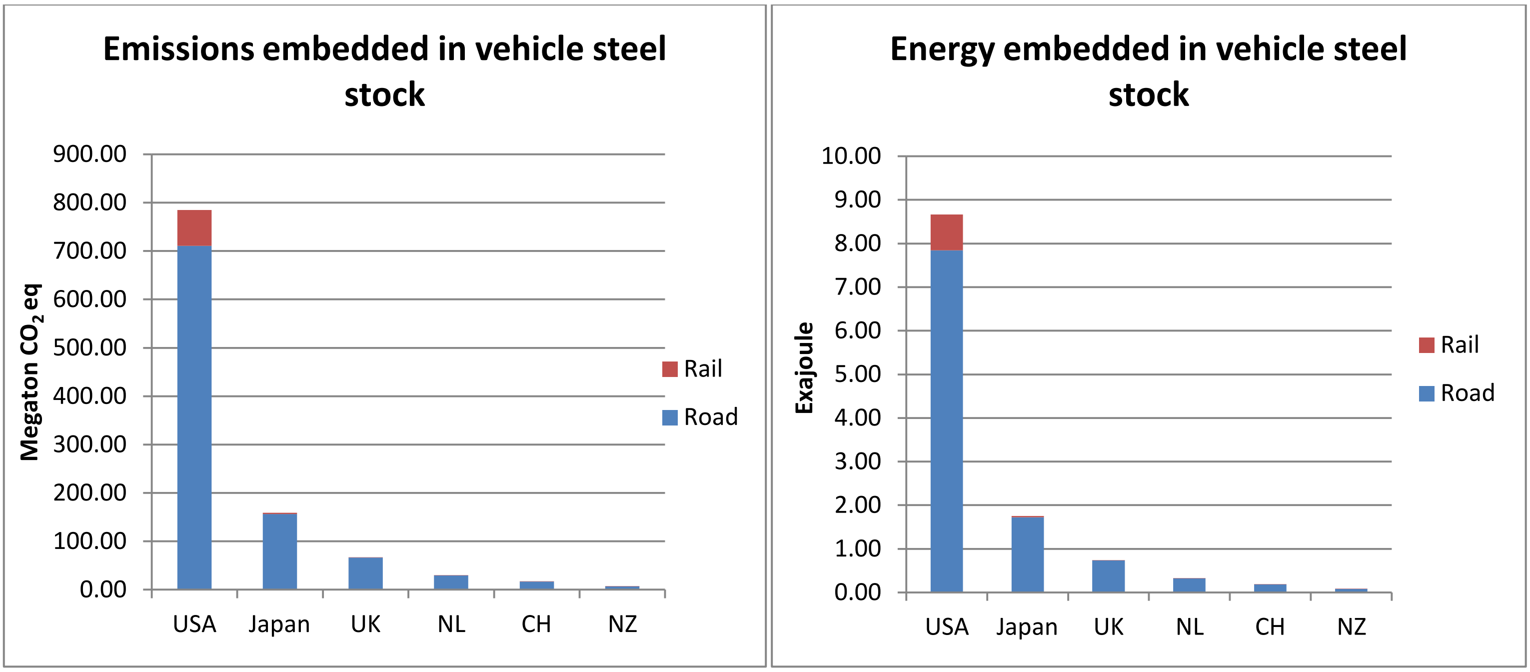


Figure 18: Emissions and energy embedded in vehicle steel stock (road and rail) for selected developed countries

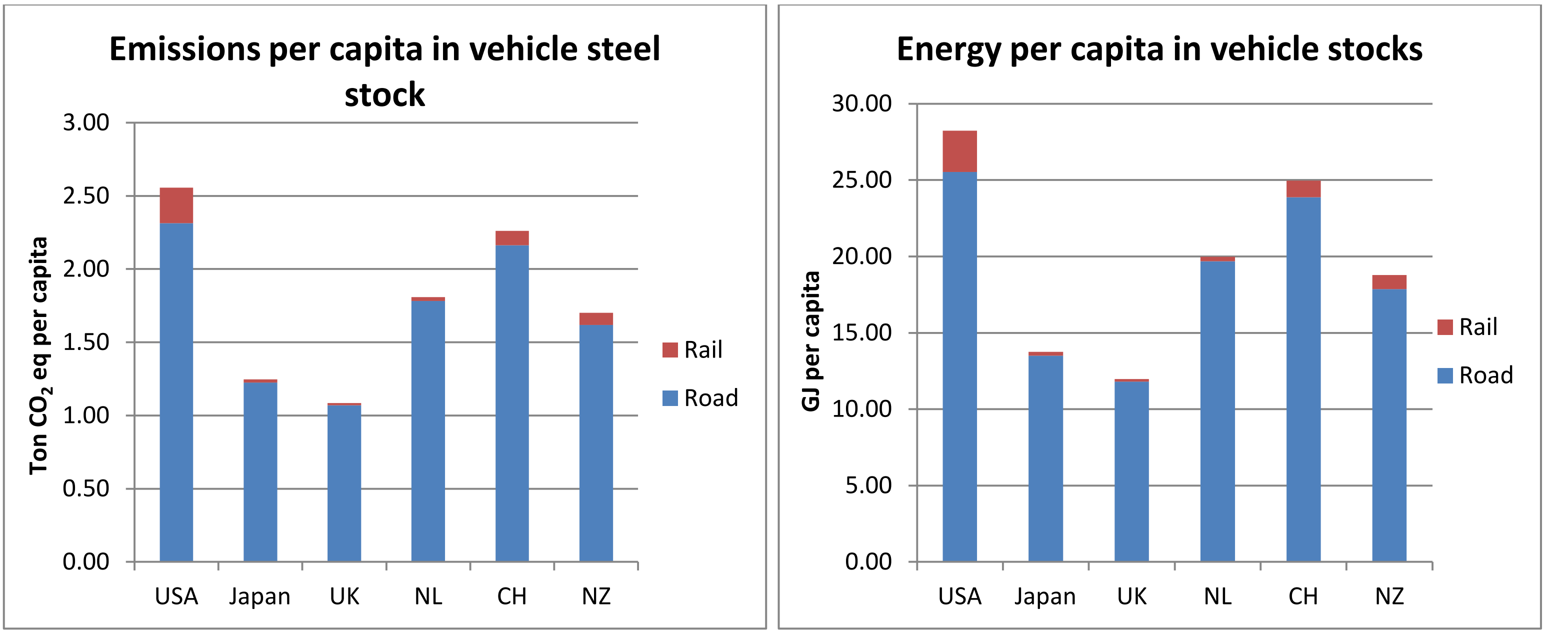


Figure 19: Emission and energy embedded per capita in vehicle steel stock (road and rail) for selected developed countries

It is interesting to note the results when the emissions and energy are normalised against passenger distances in figure 20. It is observed that in the US and New Zealand, railways are used less to transport people. The embedded emissions and energy in the US and New Zealand (1.29 and 0.92 Kg CO_2 equiv per pkm, for example) far exceed the equivalent figures for the other countries (which range between 0.01 and 0.05 Kg CO_2 equiv per pkm). In Japan, Switzerland and The Netherlands, there is less dependence on passenger cars for movement compared to what is observed in the US and UK. It must be mentioned that the kilometres travelled are for one year while the stocks remain in use for many years.

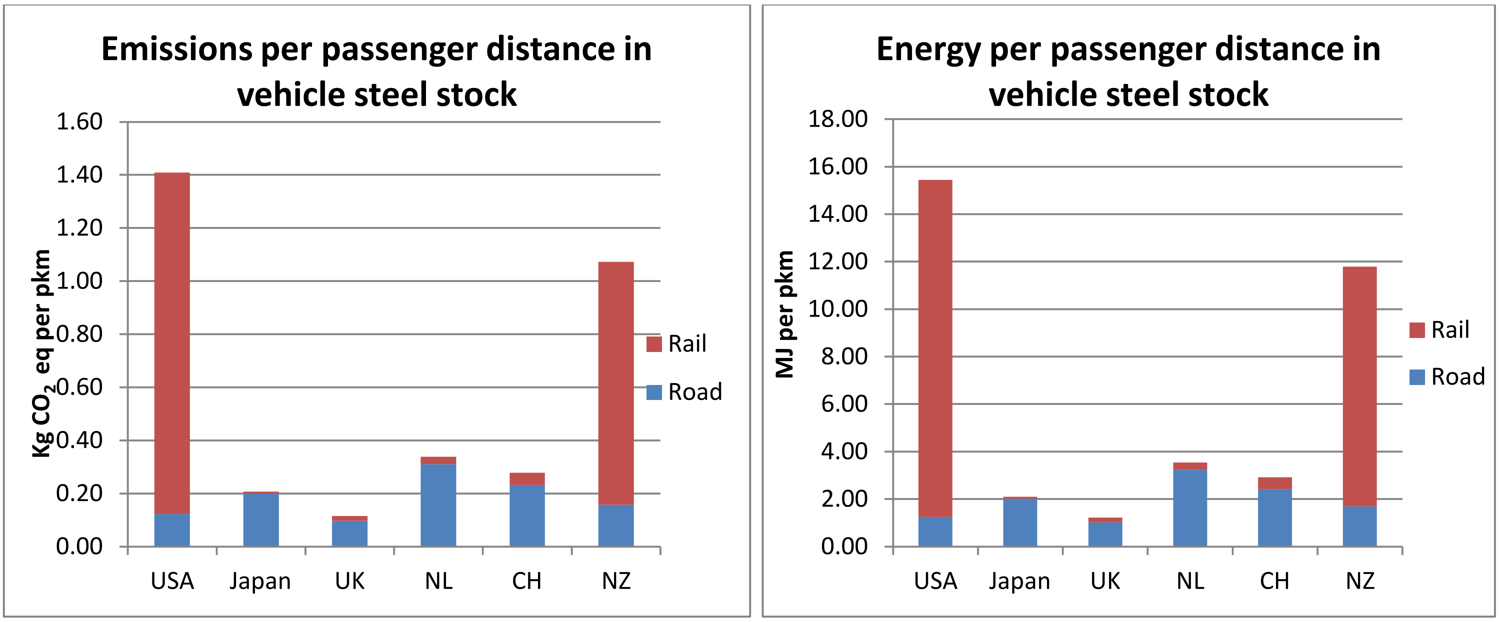


Figure 20: Emissions and energy per passenger distance in vehicle steel stock (road and rail) for selected developing countries

3.3 Patterns of automobile dependence and factors affecting it (Stage 2)

3.3.1 Country level results

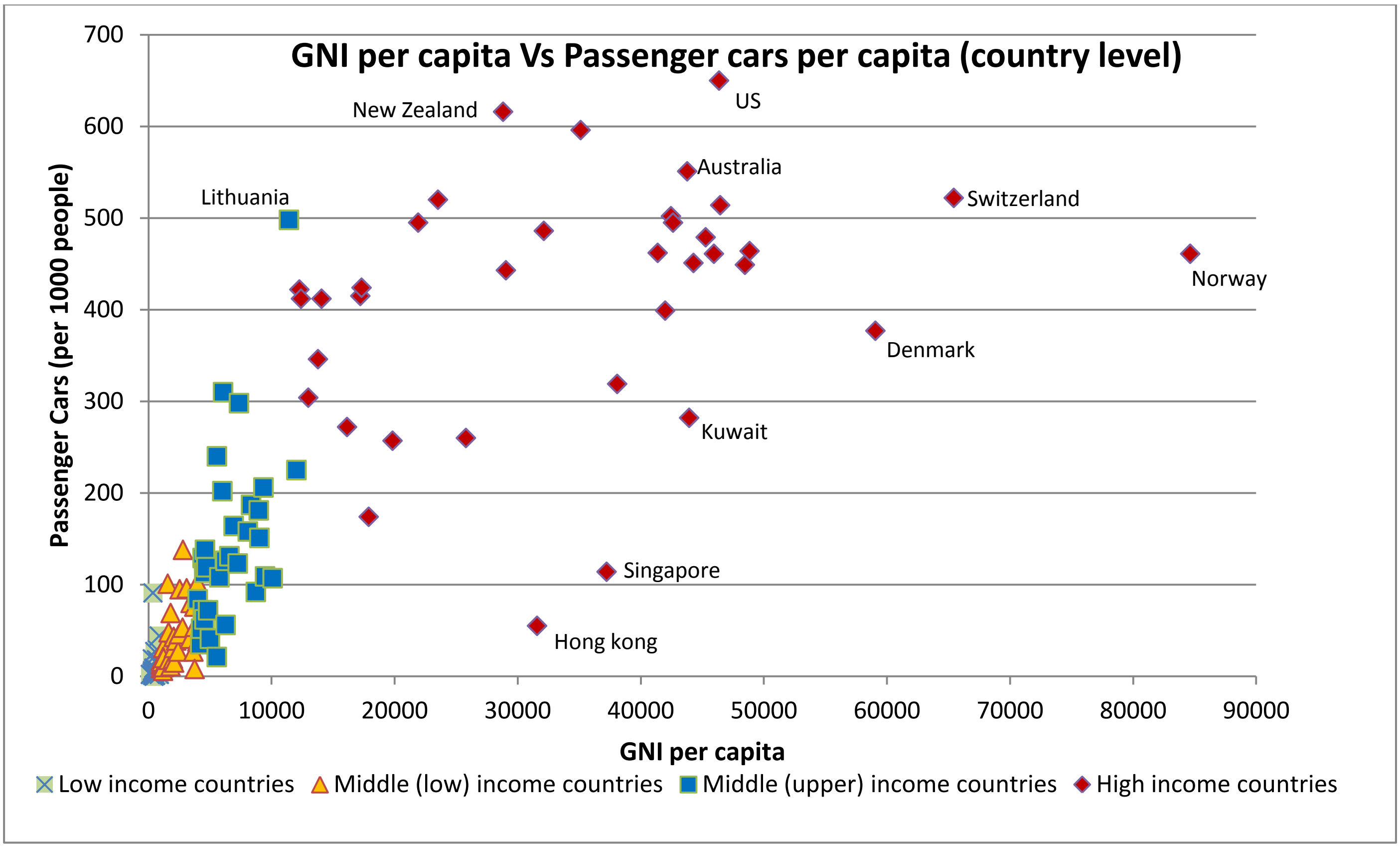


Figure 21: GNI per capita vs. Passenger cars per capita (country level)

From figure 21, it is not unexpected to see that there is a general linear rise in per capita car ownership with increasing personal wealth. Low and middle income countries have significantly lower cars per capita. However, it is observed that within the developed countries, there is a great variation seen in car ownership. What comes out as a very striking observation is that Hong Kong and Singapore, inspite of being very wealthy have low automobile dependence. Also, most rich European countries are notably behind other less wealthy countries like the US and Australia. Some middle income countries show high ownership as well. This graph highlights the fact that there must be other factors apart from GNI that influence automobile dependence.

In figure 22, passenger cars per capita are plotted against population density. Both Singapore and Hong Kong have high population densities and this can be one of the possible reasons for them having low cars per capita. However, by looking at the all the other countries in the figure, no clear trend between population density and cars per capita is revealed. This may be because country data is on a macro level and may not be very accurate. It does not make sense to try to learn something about urban density by looking at country-level data as each country varies tremendously in its size and land use patterns. The impact of urban density on transport is brought out clearly when city level data is analyzed through figures 25 and 26.

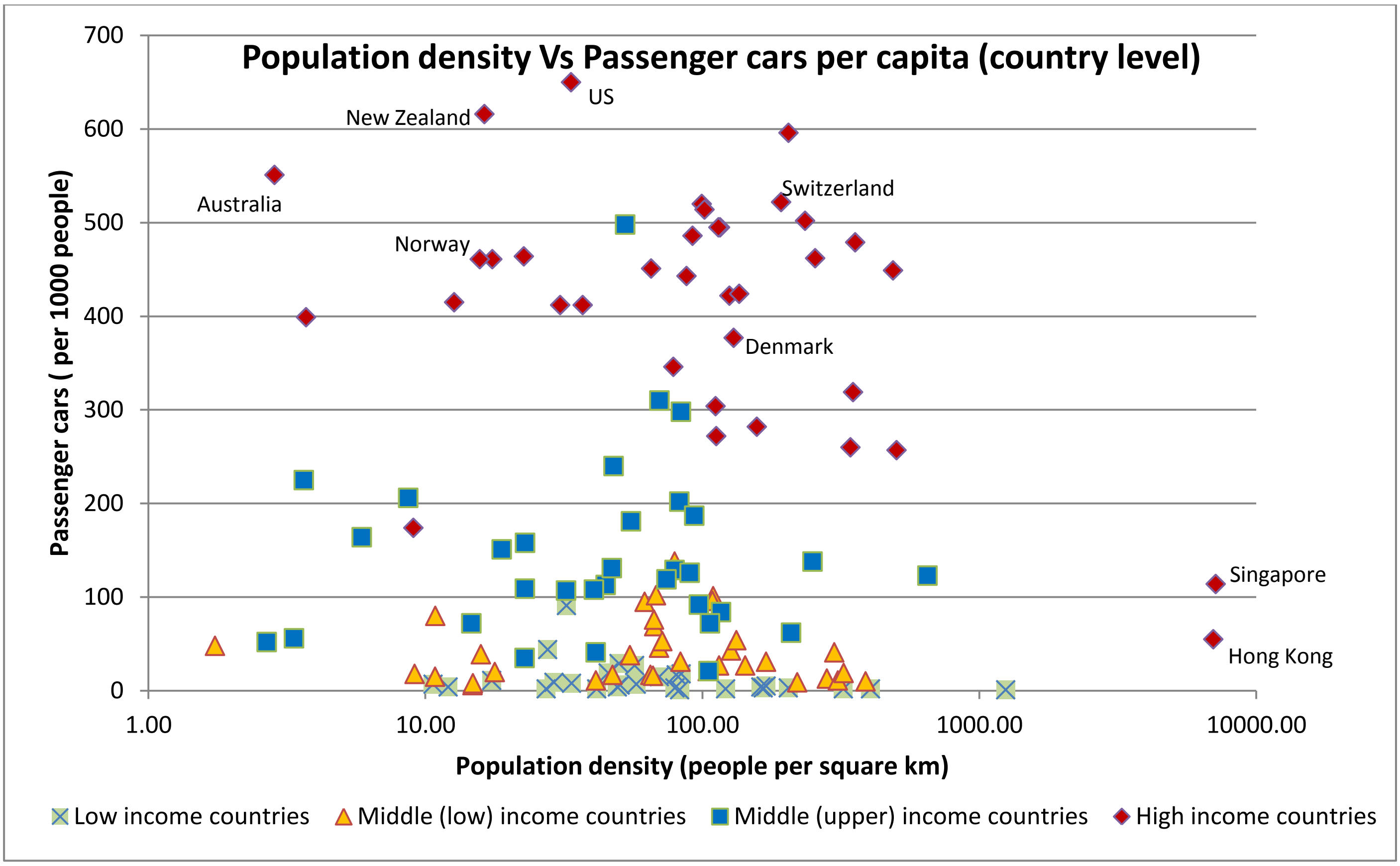


Figure 22: Population density vs. Passenger cars per capita (country level)

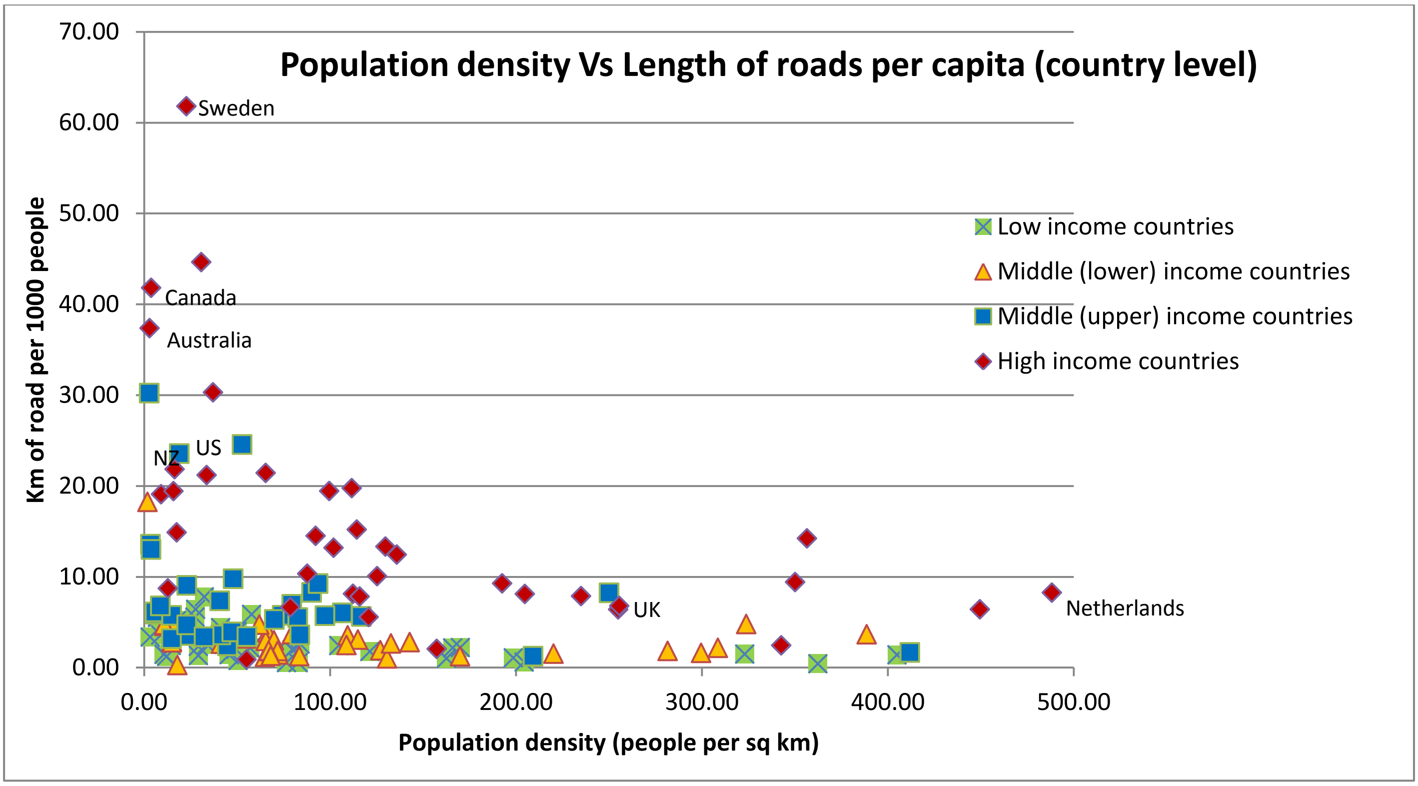


Figure 23: Population density vs. Length of roads per capita (country level)

In figure 23, population density of countries is plotted against the length of road network per capita. Countries with population density higher than 500 people per square kilometre are not shown in the graph as their road network is negligible compared to the rest of the countries, especially those with low population density. A more extensive road network is needed to connect sparsely populated and sprawling areas, for instance in Canada and Australia, compared to UK or the Netherlands which have higher population densities, as is reflected in figure 23. This pattern is also observed with the city level data.

3.3.2 City level results

Figure 24 expresses car ownership relative to wealth in cities. Each data point represents an average of a number of cities in that country. For exact values, refer to table 3 in Appendix C. As explained in section 2.3.2, cities have been grouped into higher income cities: from United States (USA), Australia and New Zealand (ANZ), Canada(CAN), Western Europe(WEU), high income Asian cities(HIA) and lower income cities: from Eastern Europe (EEU), Middle East(MEA), Latin America(LAM), Africa(AFR), low income Asian cities(LIA)and Chinese cities(CHN) regions (Kenworthy 2008). The broad inference drawn from this graph corresponds to what was observed in the country level data figure 21. For the cities belonging to the low income countries, the general trend, is that the number of cars per capita increases with increasing wealth. However, there is no such correlation observed within the cities belonging to the high income countries. Clearly, the North American and Australian/New Zealand cities lead the world in car ownership; however, Western European and prosperous Asian cities have a much lower fraction of cars in relation to their GDP. This suggests that while cities may have the financial capacity for higher levels of car ownership, some other inherent factors dominate in determining this level.

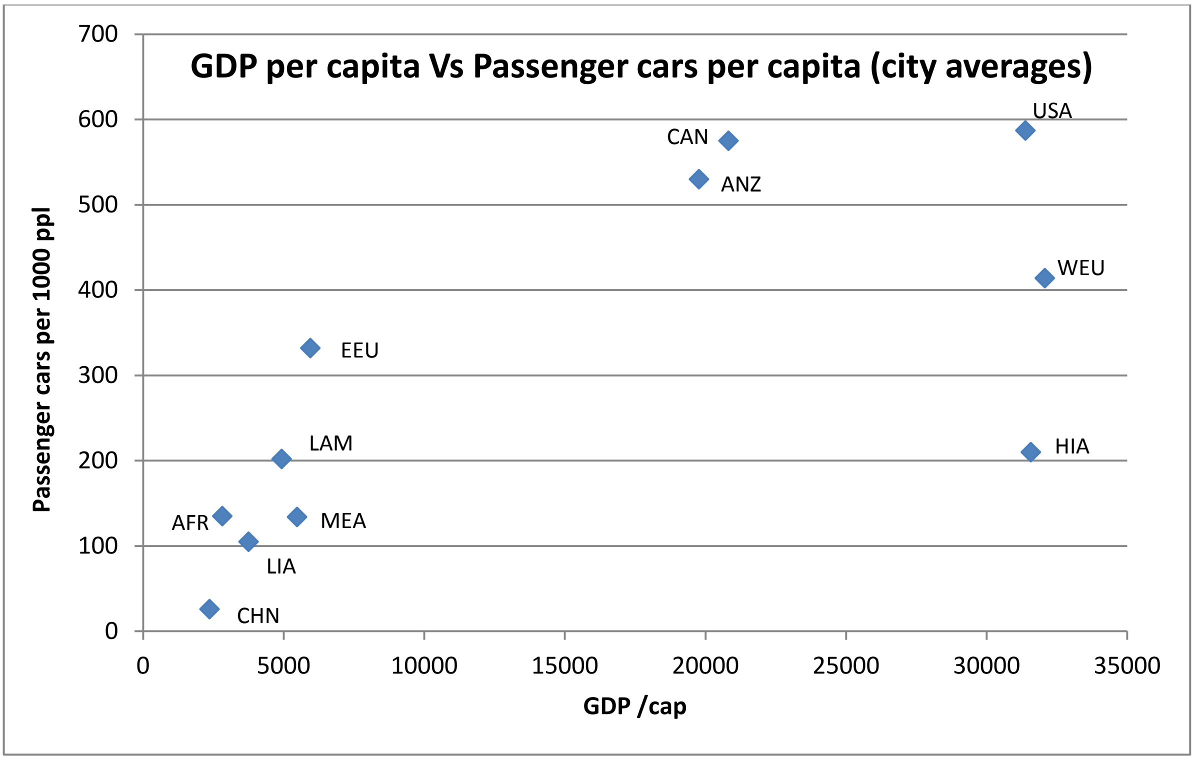


Figure 24: GDP per capita vs. Passenger cars per capita (city averages)

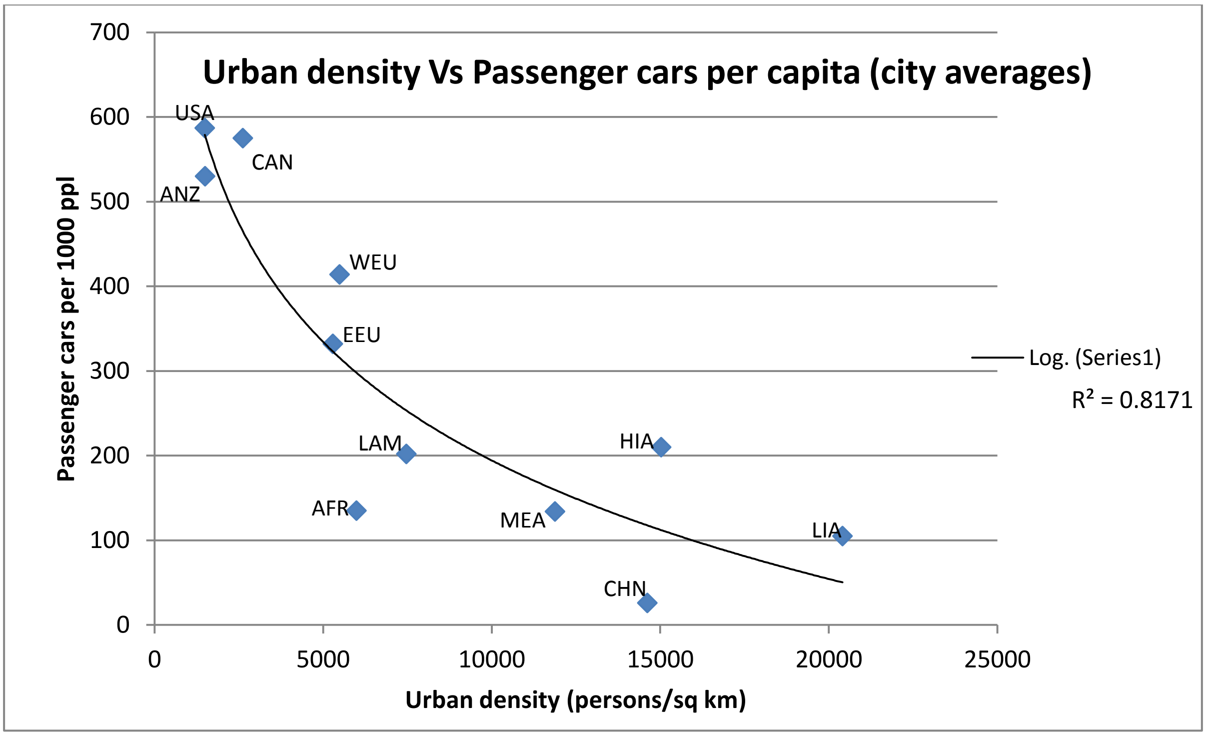


Figure 25: Urban density vs. Passenger cars per capita (city averages)

The correlation between urban density and passenger cars per capita could not be revealed through country level data (see figure 22), but is clearly evident from the city level data in figure 25. As mentioned earlier in section 2.3.2, the density data used here is the actual urbanised land excluding all regional scale open space, undeveloped land, forests, agricultural land and water bodies. The data reveal that the regions with highest passenger car ownership are North America and Australia, where the overall metropolitan densities has been low. Land use in such cities is heavily zoned and segregated, which makes the population extremely dependent on individual motorised transport especially cars. The need for passenger cars reduces in dense, compact urban environments, as is seen in many western European and high income Asian cities.

The relation between urban density and passenger cars per capita is also analysed on an individual city level and is represented in figure 26, which further reiterates the fact that less dense cities rely more on passenger cars for movement. A wealthy city like Hong Kong has low car ownership of 43 cars per 1000 people, while a less wealthy developing Asian city like Bangkok has a whopping statistic of 199 cars per 1000 people. This glaring difference can possibly be explained by the much higher density of Hong Kong as compared to Bangkok as shown in the figure. A specific observation here is that even within cities, automobile dependence varies and this is again related to the city structure and urban densities. For example, the urban density of inner London is two and a half times that of outer London and this has a positive correlation with the number of passenger cars in each region. The number of passenger cars in outer London is found to be 65% more than those in inner London. Figure 26 therefore illustrates the fact that living in the central area of the city reduces the need to depend on cars.

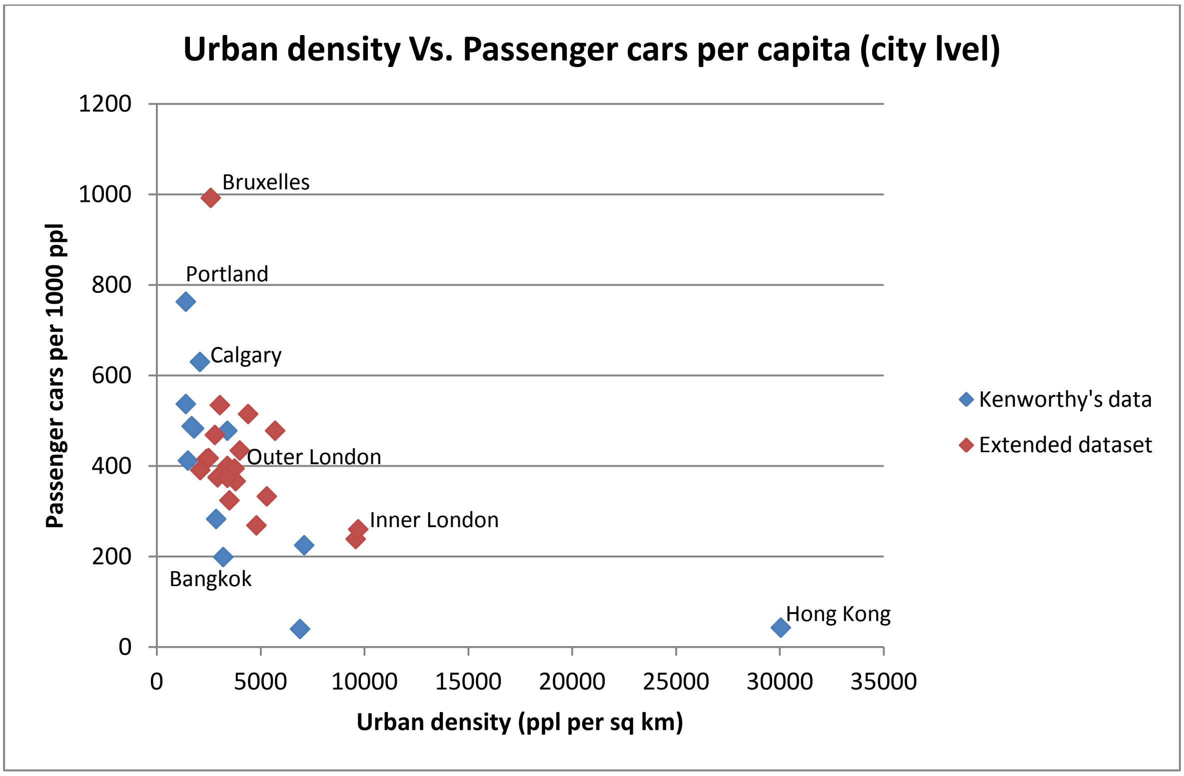


Figure 26: Urban density vs. Passenger cars per capita (city level)

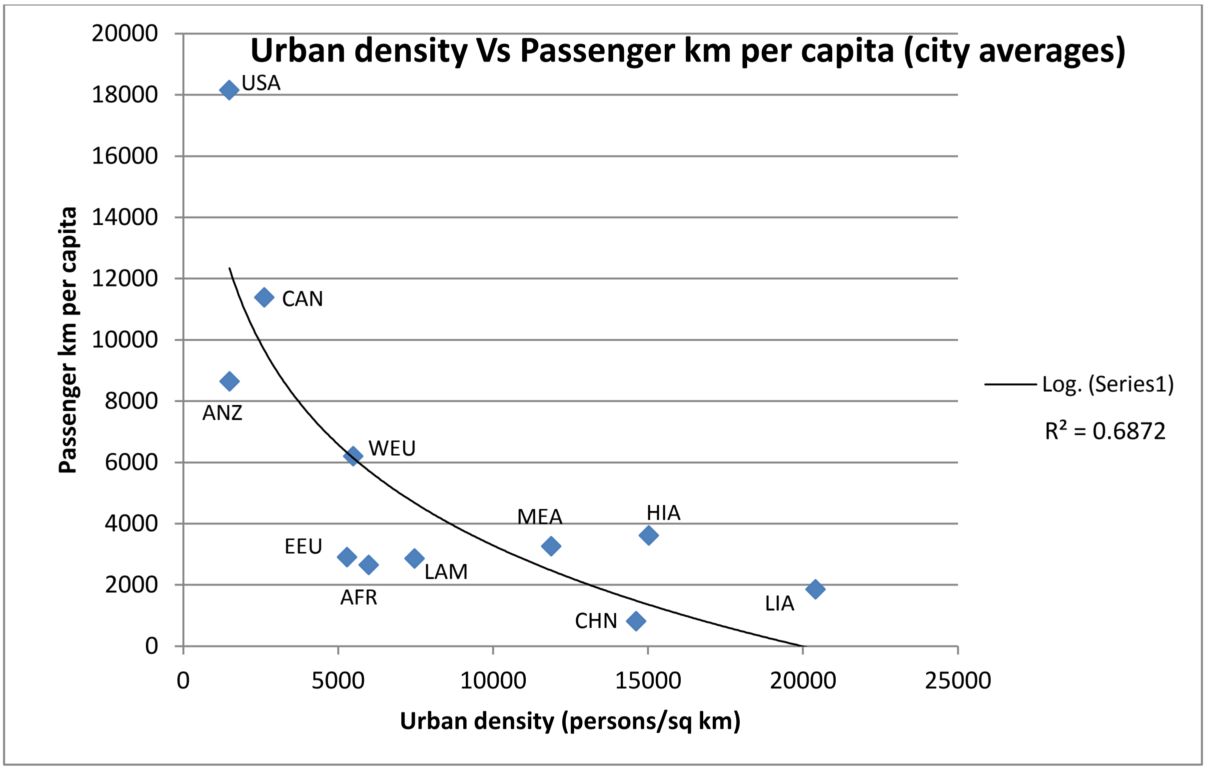


Figure 27: Urban density vs. Passenger car passenger kilometres per capita (city averages)

Figure 27 shows the correlation between urban density and passenger car passenger kilometres travelled per capita. Kilometres travelled per capita can be considered as an indication of the actual use of the car. Tracing back to figure 25, it was observed that North American and Australian cities were observed to have comparable number of passenger cars per capita. However, it is interesting to note from figure 27, that the use patterns amongst these cities are very different. US cities are approximately 80% higher in car use than average Australian and Canadian cities, 3 times higher than wealthier European cities and 5 times higher than the wealthy Asian cities. This gap between US cities and other cities in their automobile dependence is not as strongly expressed in the actual ownership of vehicles as it is in their use. For example, US cities have 1.5 times more cars per capita than western European cities and nearly 3 times more than wealthy Asian cities-margins that are lesser than those seen in the car use patterns. The graph demonstrates that a factor that might be responsible for this is the urban density. Less dense cities have a greater need to travel larger distances than more dense cities.

Figure 28 shows the relationship between urban density and length of motorways in different cities. As expected, more dense cities have lesser road networks. It increases viability to walk, cycle or use transit instead of depending on cars. This also established a link with figure 25, which showed that more the urban density, lesser are the cars per capita.

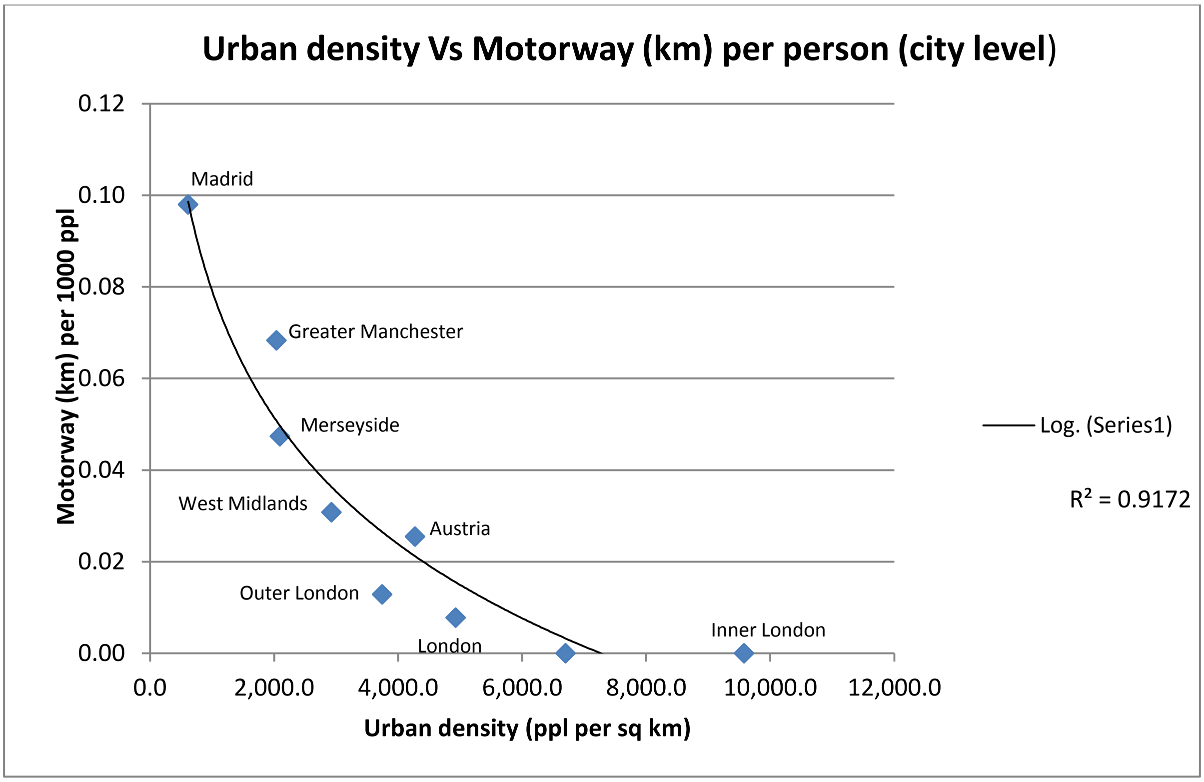


Figure 28: Urban density vs. Length of motorway (km) per person (city level)

3.4 Scenario building (Stage 3)

The objective of building scenarios is to identify and develop ways in which developing countries can achieve the same level of service as seen in developed countries, with lesser material and consequently reduced carbon footprint than the developed countries. As mentioned in section 1.5, we focus on passenger cars in India as the case study. Before presenting the scenario results, another set of results are discussed, which aid in the process of developing scenarios. Different parameters (from eq i and ii described in section 2.3.1) are studied for the six selected developed countries, to first discover whether any relationships exist between different parameters and then to use the information gathered in scenario building. In the figures 29 to 33, for each data point, the value of the steel stock per capita in passenger cars is displayed. For data, refer to table 1, Appendix D.

3.4.1 Parameter relationships

In figure 29, population density of each country is plotted against the number of passenger cars per capita. According to the outcome from the previous section the general trend is that lower the density, higher is the car ownership, which is represented by figure 29 to some extent. A slight anomaly is observed in the cases of Japan and The Netherlands, which, inspite of their high population densities compared to the other countries, seem to have higher number of cars per capita. Also, the more the number of cars, the larger is the steel stock per capita for each country. US, Switzerland and The Netherlands are selected to represent developed countries with high, medium and low cars per capita respectively.

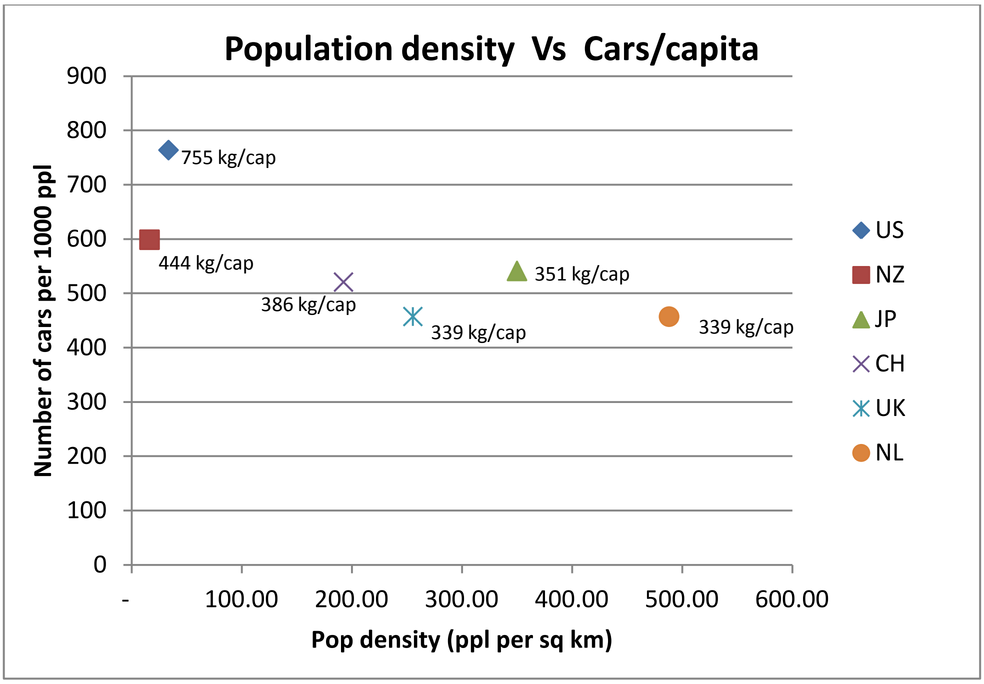


Figure 29: Population density vs. Cars/capita for selected developed countries

In figure 30, a broad linear relationship was observed between kilometres travelled per person per year and kilometres driven per passenger car. However, even though for Japan and The Netherlands, the distance travelled per person per year is almost comparable, however, the kilometres driven per car is much higher in The Netherlands. A reason for this may be that the occupancy rate of cars in The Netherlands is lower than that of Japan. Another fact that is striking from the graph is that the smaller stock (339 kg/cap) in UK, compared to Switzerland, Japan and New Zealand, is being more intensely used. And even though UK and The Netherlands have the same vehicle stock, they vary greatly in their use patterns, as is also seen in figure 31.

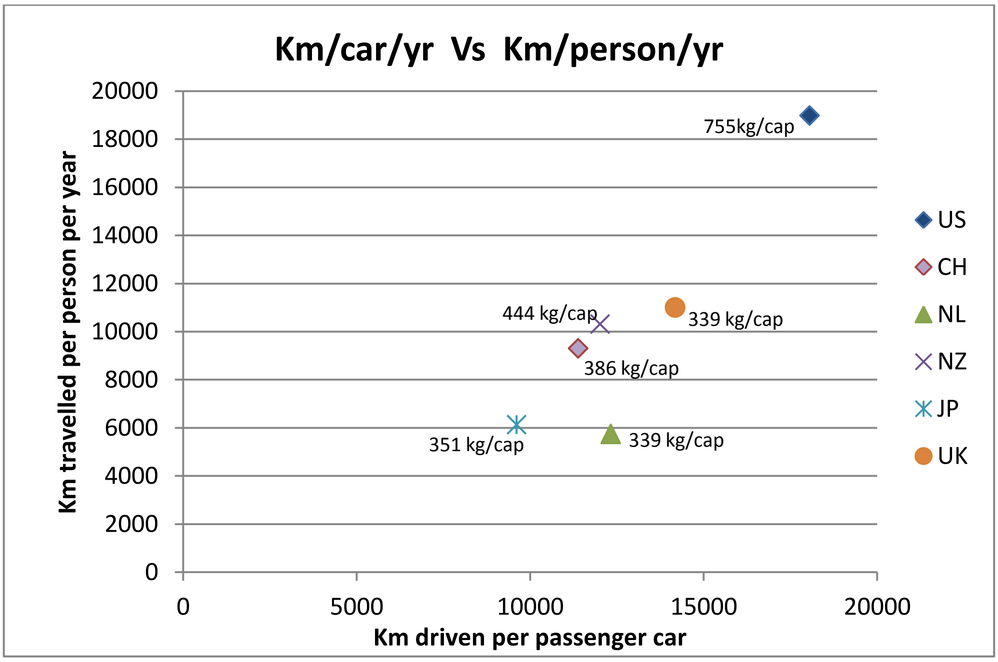


Figure 30: Kilometres driven per car per year vs. Kilometres travelled per person per year by car for selected developed countries

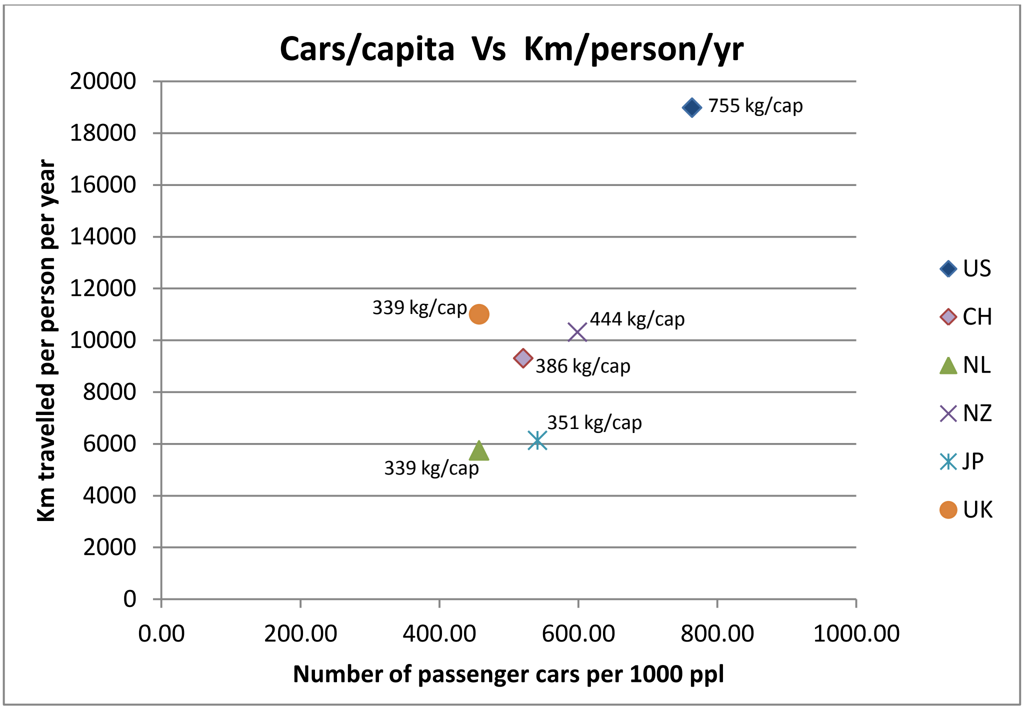


Figure 31: Cars per capita vs. kilometres travelled per person per year by car for selected developed countries

Figure 31 shows broadly, that the kilometres travelled per person per year increases with increasing car ownership. However, a clear exception is seen when comparing UK and the Netherlands. Both countries have almost the same level of car ownership (approximately 457 cars per 100 people) and so, the same steel stock as well. But inspite of this, personal travel depends heavily on cars in the UK as compared to what is observed in the Netherlands. This may be due to the high urban density of the Netherlands which reduces the need for extensive travelling by car.

The next two figures 31 and 32 show that no particular pattern exists between occupancy rate and cars per capita and occupancy rate and kilometres travelled per car per year respectively. It is observed that for passenger cars, UK has the highest occupancy rate.

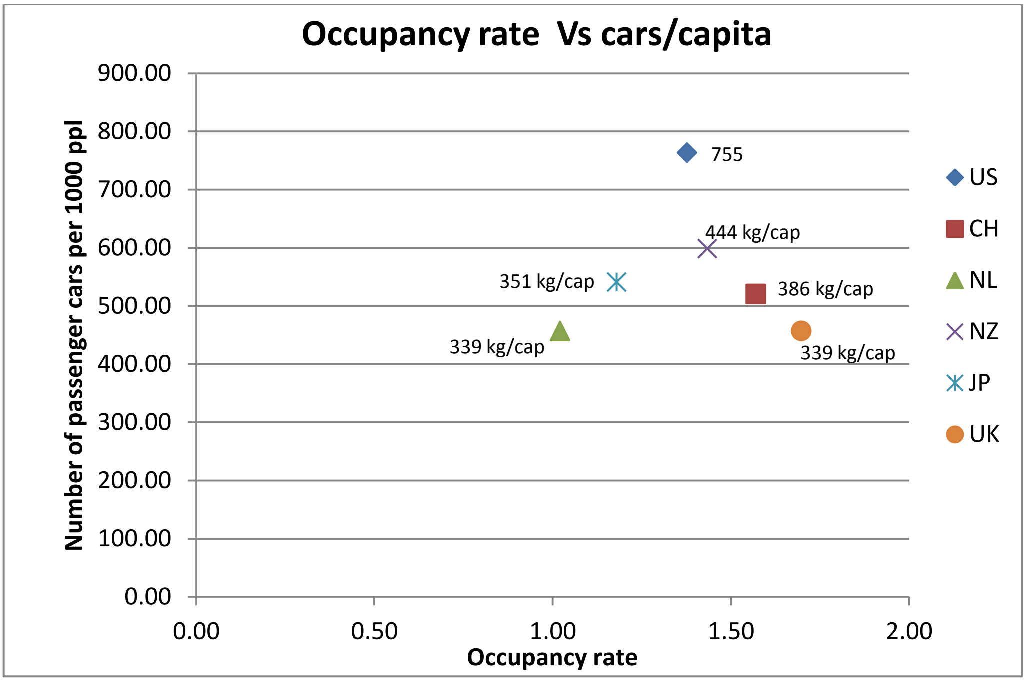


Figure 32: Occupancy rate vs. Cars per capita in selected developed countries

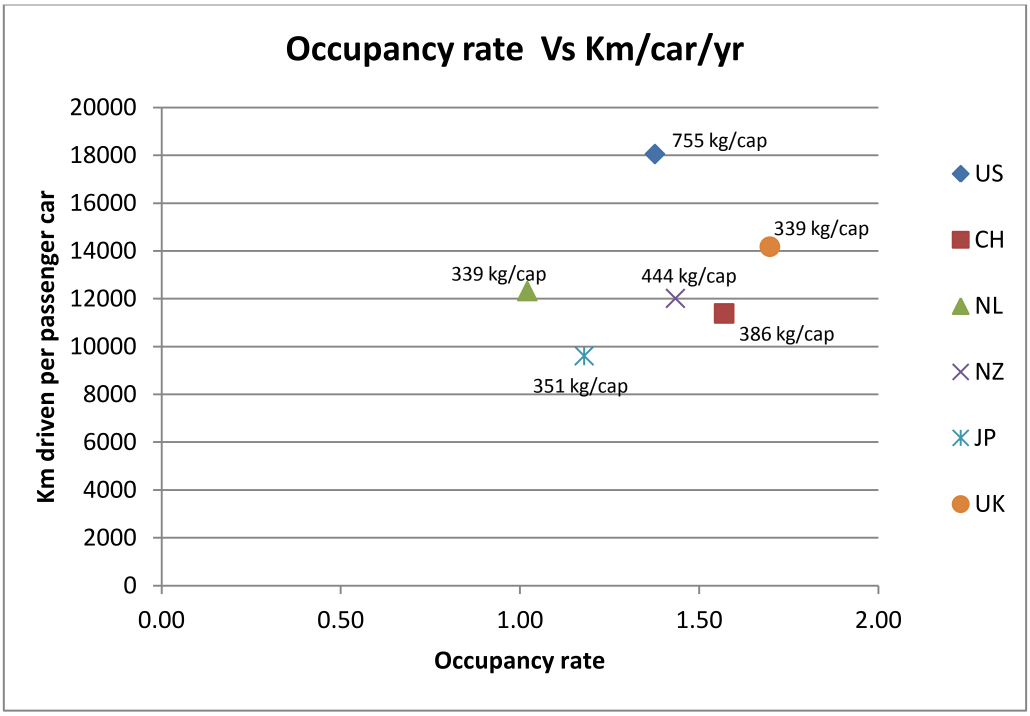


Figure 33: Occupancy rate vs. kilometres driven per car per year in selected developed countries

3.4.2 Scenario results

This section summarizes the embedded emissions and energy associated with the different scenarios described above to build up steel stocks (in passenger cars) in India, to reach a service level seen in western countries. It is restated to make the reader aware that these scenarios refer to instantaneous build up of stocks in India and this is achieved through primary production alone. It is a static model, providing estimates for the year 2009. First, the steel stocks are demonstrated for each scenario, and then the emissions and energy associated to build the stock. With each graph, refer to the corresponding tables in Appendix E for exact values.

Steel stocks build up in India

Figures 34 and 35 present scenario results for absolute and per capita steel stock levels in passenger cars, if India were to have similar levels of service as seen in selected developed countries (also see table 1, Appendix E). As described in section 2.3.3, scenarios 1a-1c represent stock levels India would need, if it had the same vehicle ownership as seen in US (high), Switzerland (medium) and the Netherlands (low). It is obvious that the steel stocks vary proportionately with the number of cars. For instance, if India were to have similar car ownership level as seen in the Netherlands (low), which is around 40% lower than that of the US, the steel stock (absolute and per capita) also reduces by a proportionate 40%.

Scenarios 2a-2c show the steel stock India would need, if it were to have the same intensity of use of passenger cars, using travel budget (km travelled per person per year and/or km driven per vehicle per year) as the indicator. High, medium and low cases for India are modelled after US, UK and Japan respectively. An observation worth noting here is that even if the distance travelled per person is low; it does not necessarily indicate a low stock. For instance, Scenario 2c is the case which represents the steel stock in passenger cars if India is modelled after what is observed in Japan. The steel stock if found to be approximately 20% higher than that when the travel budget is modelled after UK, even though in Japan, the kilometres travelled per person per year by car is about 40% lower than in UK. This is because Japan has higher vehicle ownership.

Scenarios 3a-3c show the steel stock for passenger cars in India when a high vehicle occupancy rate like that observed in the UK is combined with different levels of usage patterns of vehicles (travel budgets). A low travel budget suggests that there is a reduced need to travel, which is possible in a well planned city with high urban density. This scenario therefore, implicitly includes the factors discussed in section 3.3 that influence automobile dependence. The last case (3c), which combines a high occupancy rate with a low travel budget is the one that requires the lowest steel stock (204 kg per capita). This level of stock is about 60% lower than the case with the largest steel stock (567 kg per capita). A further 30% reduction in the steel stock is possible through lightweighting of passenger cars and this is calculated for each case. Including lightweighting, there is a final reduction of steel stock by 75% from scenario 1a to scenario 3c.

Acronyms used in following graphs:

OR= Occupancy Rate
TB= Travel Budget

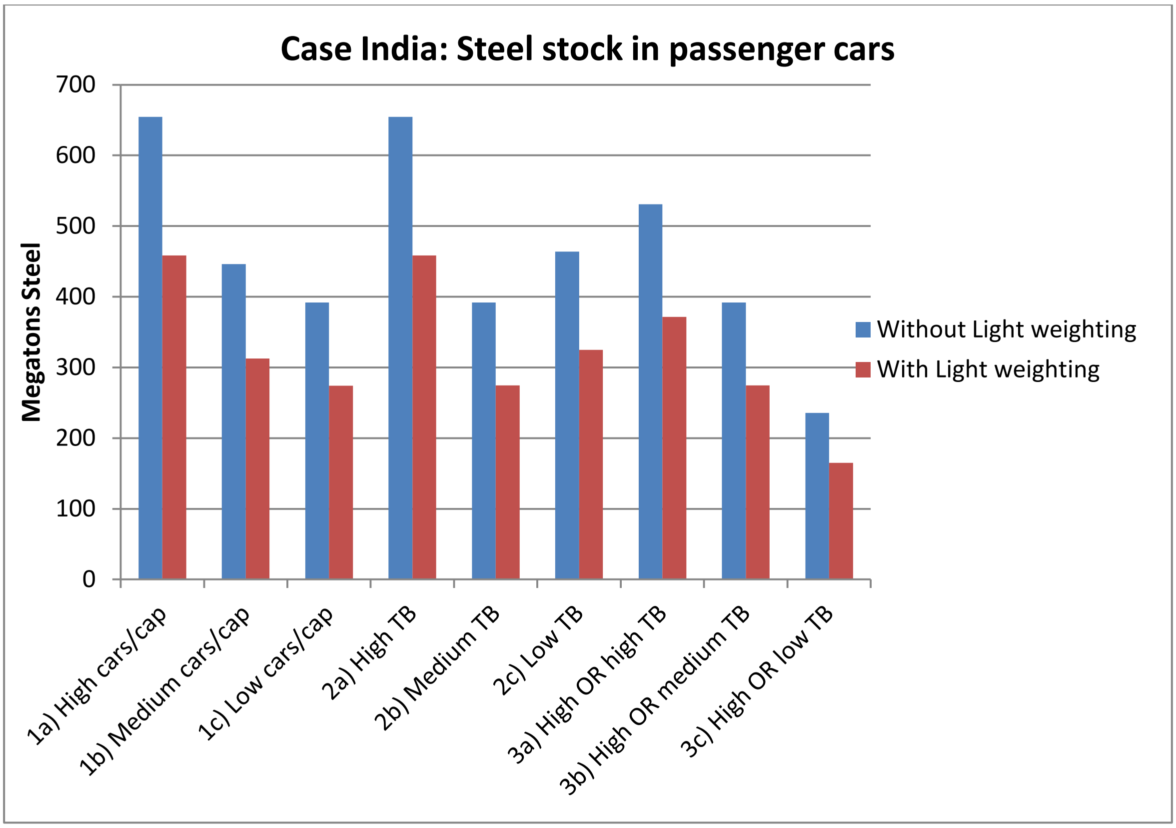


Figure 34: Scenario results for steel stock in passengers in India

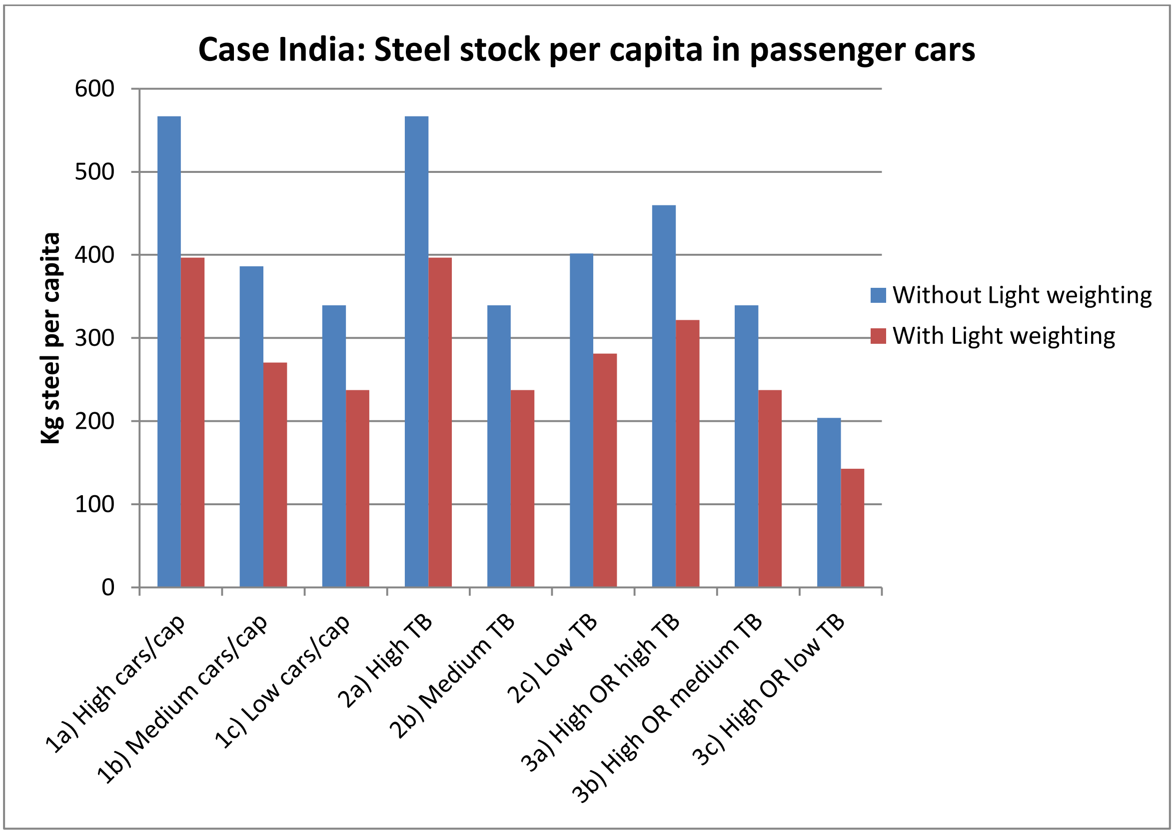


Figure 35: Scenario results for steel stock per capita in passenger cars in India

Emissions embedded in steel stock in passenger cars

Figures 36 and 37 present the scenario results for the total and per-capita emissions embedded in the steel stock of passenger cars in India, and figures 38 and 39 present the total and per-capita energy associated it. Since these are obtained by multiplying the steel stock obtained from figure 34 with the emission and energy factor mentioned in section 2.2, the emission and energy values obtained closely follows the size of the material stocks. The emission per capita ranges from 1.39 tons CO_2-eqiv for Scenario 1a, which is modelled after the US to 0.35 tons CO_2-eqiv for Scenario 3c, which combines high intensity of use of vehicles, low travel budget and lightweighting. Similarly, the embedded energy values range from 15.34 GJ/capita to 3.86 GJ/capita, demonstrating a reduction potential of 75% from the highest case 1a. The comparison made between the different scenarios goes to show what implications material intensive lifestyle has with regard to the associated emissions and energy and how a developing country like India has the option of orienting its development towards a lower material throughput, which may help to lower carbon emissions.

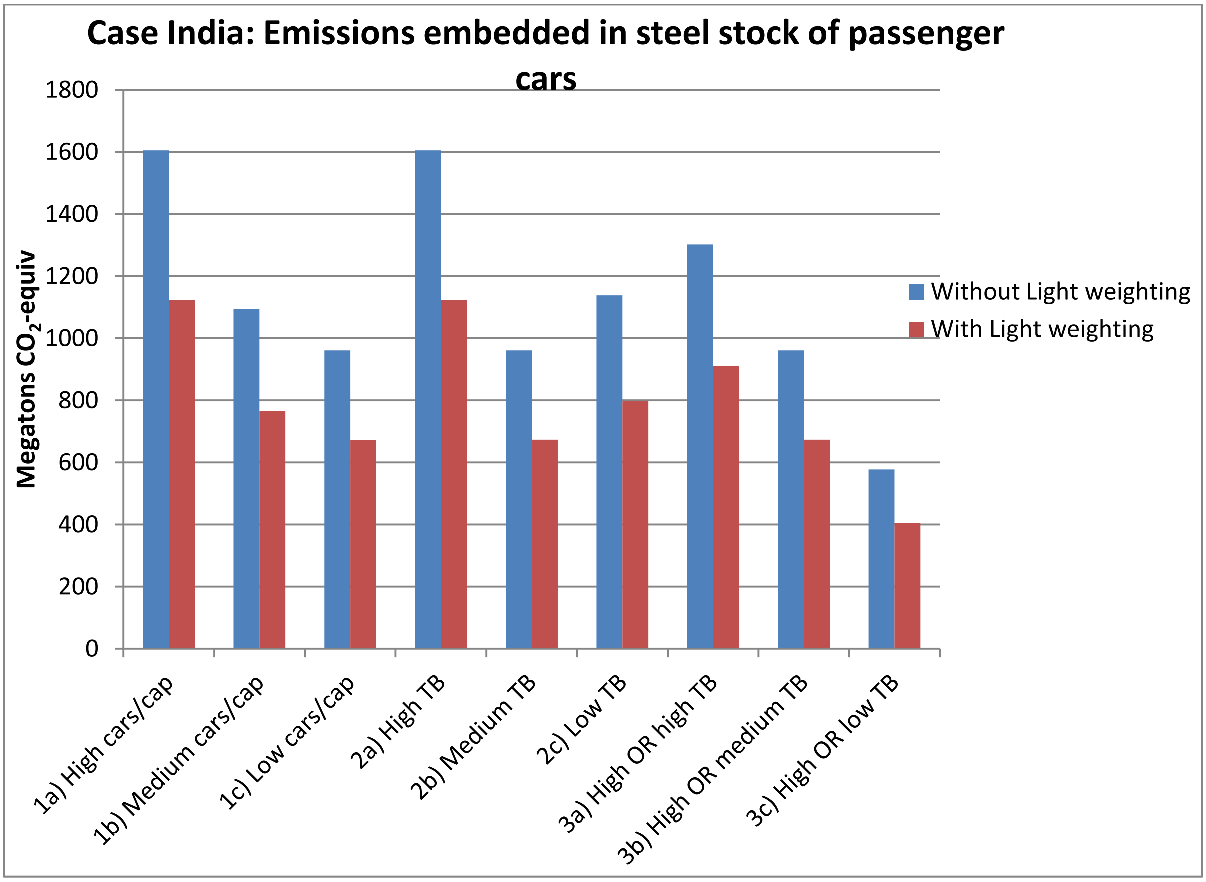


Figure 36: Scenario results for total emissions embedded in steel stock of passenger cars in India

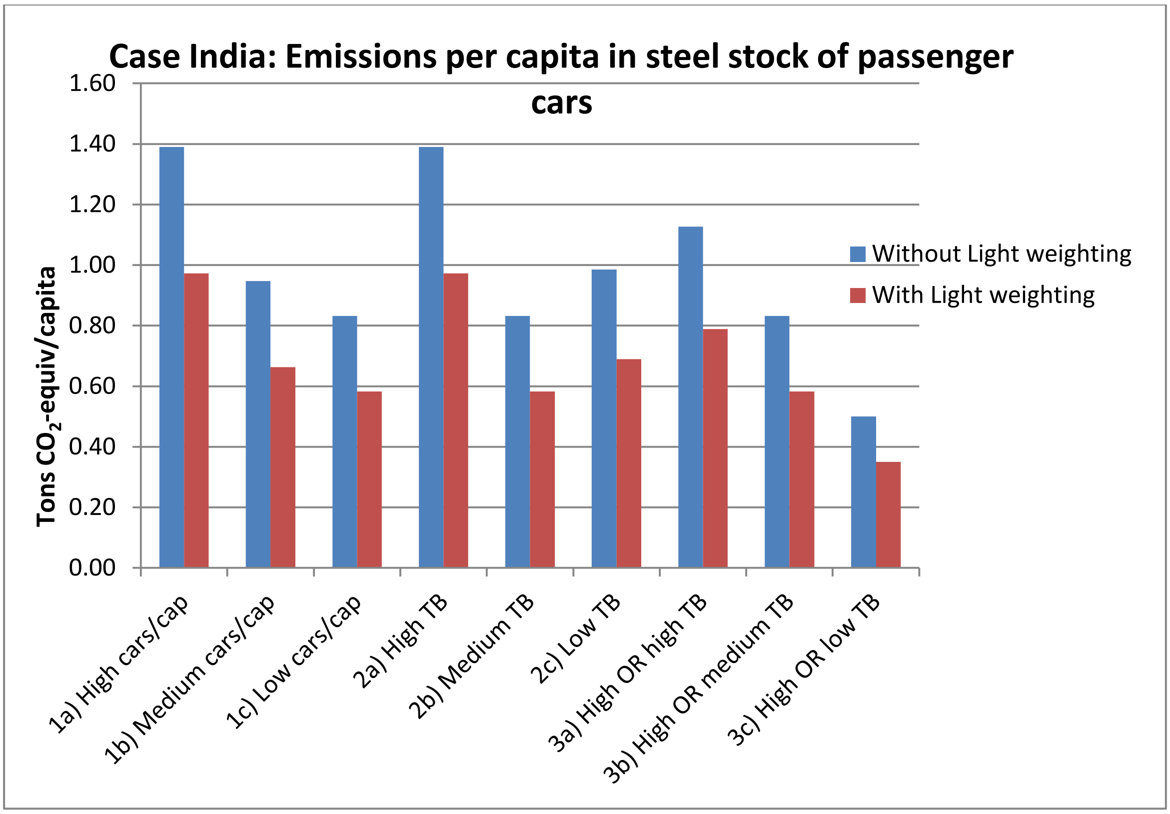


Figure 37: Scenario results for emissions per capita embedded in steel stock of passenger cars in India

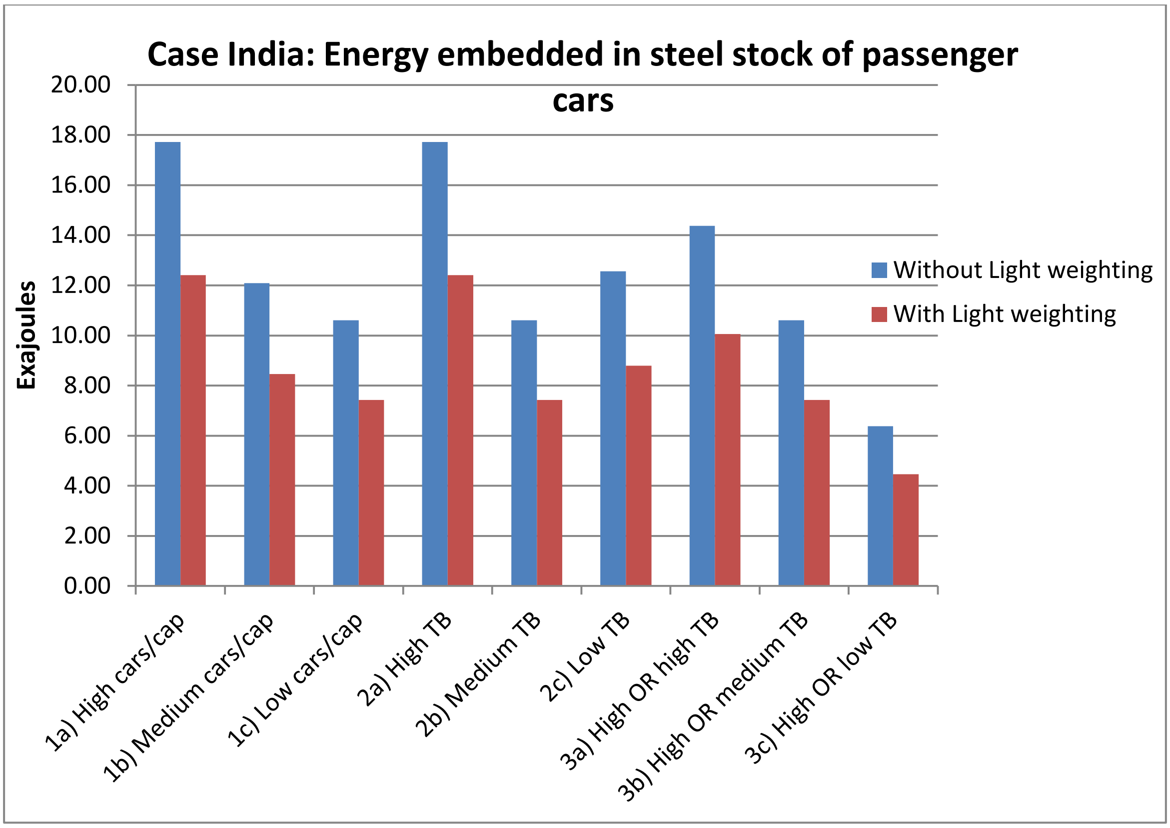


Figure 38: Scenario results for total energy embedded in steel stock of passenger cars in India

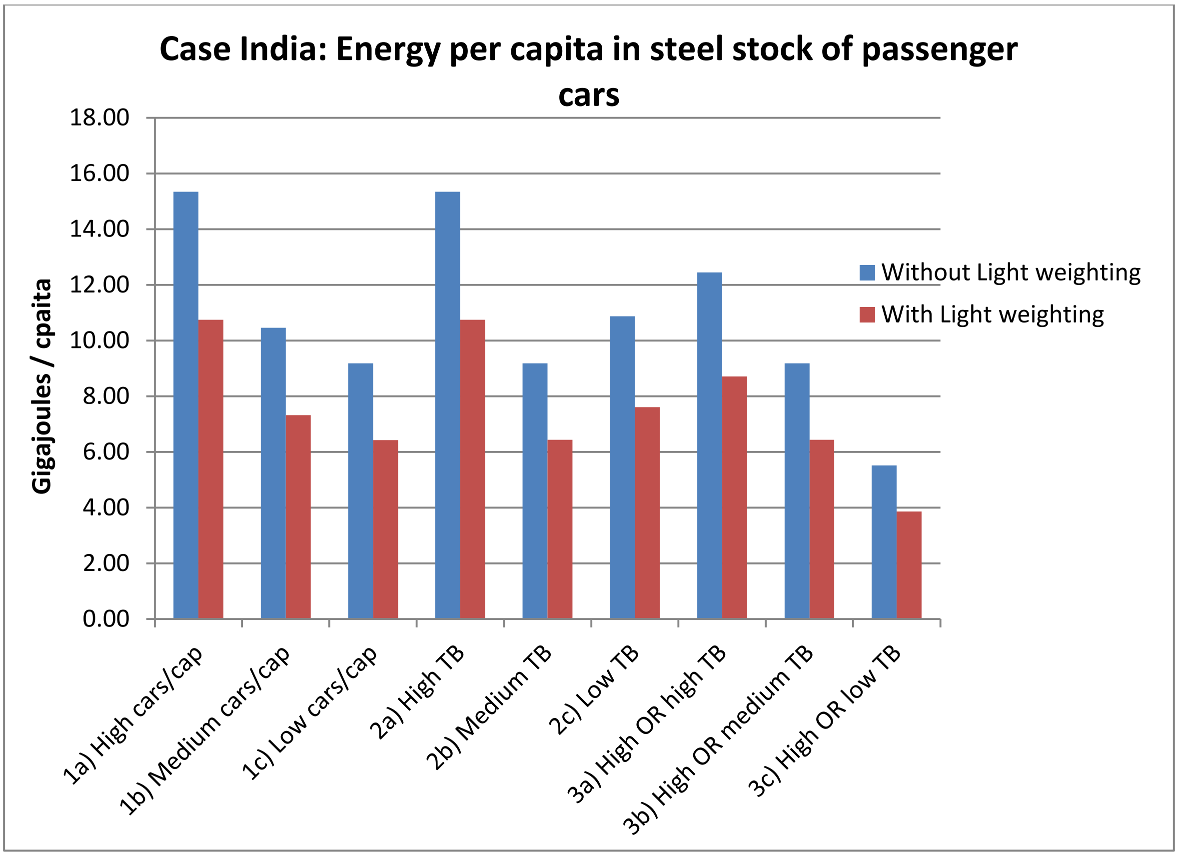


Figure 39: Scenario results for energy per capita embedded in steel stock of passenger cars in India

4. DISCUSSION

The discussion first analyses the results in light of the aim and research questions put forth in the introduction section. It is carried out in three parts, each corresponding to the stages described in section 1.6. Policy implications of the collective outcome are then summarised. This is followed by an analysis of the methodology chosen to carry out the project, bringing to light the strong points and the shortcomings. It then concludes by opening up avenues for future work on the topic.

4.1 Key conclusions from model results

4.1.1 Developed countries

From the results (ref section 3.1 and 3.2) it is clear that within developed countries, there are differences in the levels of vehicle stock per capita (and corresponding steel stock and its associated emissions and energy). The road vehicle stock per capita in Japan and UK is lower than that in US by about 47% and 53% respectively. These lower levels of stock per capita suggest that in developing countries, industrialised levels of transportation could be provided in a more resource efficient manner than the US using existing technologies. Rail rolling stocks are about an order of magnitude smaller than road vehicle stocks. Amongst all road vehicles, passenger cars constitute the largest steel stock. Cars also have the largest share of passenger transport across all countries. However, the dependence on cars for movement also varies from country to country. For instance, in Japan, rail transport has a fairly significant share (30% of all inland passenger transport), even though passenger car ownership is quite high (about 540 cars per 1000 people).

It is indeed a challenge to define one comparable service level for vehicle stocks of industrialised countries. In this work, an attempt was made to define service level for vehicle stocks in two ways. One, by the physical measure of vehicle ownership and the other related to the intensity of use of the vehicles. Vehicle ownership and its use are in fact interconnected; and part of this research was dedicated towards understanding these relationships and discovering factors that influenced them. The results (ref section 3.3) obtained from a thorough review of literature and independent analysis revealed interesting facts which are highlighted below.

4.1.2 Factors affecting automobile dependence

The analysis carried out on a country level showed largely, the differences amongst high, middle and low income countries in terms of car ownership, population density and road network. The most significant observation was that contrary to common belief that wealthy nations will in all probability have high car ownership; there still are some rich countries that have much lower cars per capita than expected. This is an indication to the fact that there may be other factors influencing car ownership levels and the need to depend on cars. Country level data was found insufficient to learn about the possible impacts urban density could have on transportation.

Analysis carried out on the level of individual cities again reconfirmed that wealth alone does not provide a consistent or satisfactory explanation of metropolitan scale transport patterns. The data pointed towards deeper underlying physical differences between cities. Cities with low urban density were found to be associated with higher number of cars per capita. It was also found that the actual use of cars in such cities is higher. Highly dense settlements tend to be associated with lower average trip distances for all modes. Densely built compact urban settlements are more mixed in their land use, implying that they would include not just homes but also stores, offices, parks, making places most oft visited accessible. This is not the case in sprawling low density cities where travelling long distances by car becomes a necessity. Irrespective of income levels, therefore, it seems to be more convenient to walk, cycle or use transit in dense cities. It is noteworthy, that many dense cities have developed improved public transport and enhanced viability for walking and cycling. For example, both Singapore and Hong Kong have extensive mass transit systems, lowering further the dependence on automobiles.

Differences in travel patterns even within cities were observed to be different. For example, it was revealed through this study that the more dense Inner London had lower cars per capita and a low road density as compared to the less dense Outer London. This inference is also consistent with results from other studies on transportation patterns. For example, a study done in 1995 showed that in New York, residents of Manhattan, living at 25100 people per square kilometre with household incomes greater than $US 75,000 own only 0.81 vehicles per household, while those with same income level in outer suburban regions at 1300 people per square kilometre own 2.61 vehicles per household (data from New York Metropolitan Transportation Commission cited in (Kenworthy and Laube 1996)). The probable reason for this difference in personal car dependence between and within cities has been discussed to some extent in literature. Some studies suggest that cities that a well planned city centre with major offices, schools, health centres and entertainment houses all located close-by enable its residents to live a lifestyle free of cars (Kenworthy and Laube 1996; HRM 2009).

In conclusion, urban density was found to be a key factor in determining car ownership and use. City level data demonstrated that the differences in automobile dependence could be explained by differenced in the physical planning and infrastructure of the cities.

4.1.3 Scenarios for developing countries

As mentioned earlier, it was found using a dynamic material flow model that iron stocks in-use for six industrialized countries in 2005 reached a plateau of 8-12 tons per capita (Müller, Wang et al. 2011). Consider an average value of 10 to represent the per capita iron stock in-use in a developed country. Now, if a developing country like India, were to acquire an iron stock of say 10 tons per capita, the potential size of the impacts of this forecasted expansion would be considerable. The resulting emissions accrued would be approximately 28.34 gigatons CO_2-equiv or 24.52 tons CO_2-equiv per capita. In reality, if India were to build the stock over time, the impacts would be even larger, as some of the stock when reaching end of life would need to be replaced. Looking only at the vehicle steel stock, from the bottom-up estimation done in this study, the per capita steel stock in passenger cars alone in the US was found to be about 0.75 tons per capita, which is about 7.5% of its total iron stock of 10 tons per capita. Again, India can build up this level of steel stock, but with associated emissions of 1.83 tons CO_2 -equiv per capita, which is about 20% more than the reported size of Indian direct green house gas emissions in 2008, 1.5 tons CO2 per capita(Worldbank 2012).

Developing countries in their pathway to industrialization cannot disregard the implications it would have with respect to climate change. <u>The goal should not be to acquire the same level of in-use stock as seen in the developed counties, but to attain the same services enjoyed by them with lower material stocks</u>. The scenarios developed in this work describe ways in which India could have a lower carbon foot print of building up steel stocks in passenger cars to the same service level as in developed countries.

In the process of scenario building, different definitions of service level are used, which are represented by different parameters. Varying steel stock levels for passenger cars in India are calculated if India were to have the same level of car ownership/travel budget/intensity of use of vehicles as seen in selected developed countries. In the first two sets of scenarios, individual parameters are looked at and replicated for India. (Cars/capita in scenario 1, and km/capita/year in scenario 2). It is important to state here, that all parameters are in actuality, interconnected and one aspect cannot be looked at in isolation from the other. For example, the travel budget or the distance travelled per person per year depends on the car ownership, the car occupancy rate and intensity of use of the vehicle. And all these factors in turn, are a direct consequence of the need to travel. This 'need' to travel is closely related to how well the land use pattern is integrated with the transport system, thus affecting accessibility. The scenario that attempts to integrate all parameters is the best case scenario 3c, which also leads to the lowest steel stock (a reduction of 75% from the highest case). This case brings together high occupancy rates, lower distances travelled per person assuming high density settlements, which lead to less reliance on cars, and therefore lower car ownership and lastly, includes reducing material intensity through lightweighting of cars.

4.2 Policy implications

Supply-side measures have been the focus of climate change mitigation strategies till now (IPCC 2007). The steel industry has, in the past, been proactive in improving energy use and reducing greenhouse gas emissions for economic reasons. Making better use of readily available and cost-effective technology is necessary, but not in itself sufficient to reach the 2050 emission reduction target recommended by IPCC. Further significant reductions in emissions from the steel industry could be through breakthrough technologies, but it might take many years for their safe and large scale implementation. A potential solution could be to adopt more strategic action in the form of demand side measures through responsible management of the in-use stock. Such measures have the potential to provide equivalent utility to society, with a smaller in-use stock. In this work, the measures used in scenario building to reduce the stock include reducing car ownership, reducing total distance travelled per person and vehicle kilometres travelled, increasing occupancy rate and reducing material intensity per vehicle through lightweighting. As detailed in the results section, lightweighting has the potential of reducing the steel stock by 30%. However, along with the other measures mentioned above, a reduction of 75% can be achieved, decreasing also the embedded emissions and energy by the same amount.

The following paragraphs provide insight into how relevant these measures are in the Indian context and how they can be achieved by citing examples of their successful implementation elsewhere.

Car ownership

With the rapid urbanization of India, the number of vehicles has been on the rise (Ramanathan 2000). Ownership of cars grew at a rate of 9.6% between 1991 and 2009 (MTH 2011) and is continuing to increase rapidly. Scenarios 1a-1c represent the steel stock India would need if it had high, medium and low levels of cars per capita. However, reducing car ownership may not be an easy option for India due to a number of reasons. Rising incomes among the Indian middle classes have made car ownership increasingly affordable. It is also regarded as a status symbol to own cars.

Further, the sprawling, low-density development around Indian cities are making cars increasingly necessary to get around, especially given the undependable and overcrowded public transport services(Pucher, Korattyswaropam et al. 2005). Therefore, addressing such factors, which lead to high dependence on cars, should be made central in policy making.

Urban planning

What has been a clear outcome of this study is that managing transport goes hand in hand with city planning. Urban planning of the future should include energy and carbon footprints of entire settlements in their models and explore to what extent the footprints could be lowered by moving to denser settlements. Adjusting the density of settlements, efficient public transport systems, or mixed use development are planning options that can lead to lower kilometrage and car ownership (Bento, Cropper et al. 2005). Scenarios 2a-2c represent the steel stock in vehicles India would need with high, medium and low levels of kilometrage. Developing countries like India have an advantage of designing cities and road patterns in a way that reduce the need to drive long distances. An example from the developed world that has managed to integrate its land use patterns with its transport system is Stockholm, where residential and commercial buildings are within walking distance from a central terminal where bus and light rail meet. Employment, recreation, services are all within a restricted radius, making it all accessible. In cases where not all residents live close to the city centre or a terminal, some cities have developed local feeder systems to serve the main transportation corridors.

Limiting car usage in cities

As described in the results section, the scenario which demonstrated maximum reduction of steel stock in passenger cars for India, giving a comparable service as seen in developed countries, combined high occupancy rate of cars with a low level of kilometerage. Some case studies mentioned below give an idea of how this has been successfully achieved in some cities and can similarly be adopted in cities of the developing world.

Policies to encourage car-sharing have been effective in optimising transport demand by increasing occupancy rate. A model example is Switzerland, which has the most well-established car-sharing scheme in the world, with 7 times more members per 1000 population than any other European country, and services available in 430 cities and communities (Momo 2010). European research found each car-sharing car replaces between 4.5 to 14 private vehicles (Momo 2010). Vehicle manufacturers like BMW, Ford are also involved in car sharing schemes. Recently, policies aimed at reducing single-car occupancy rates are being given attention in the United States. The instruments used for this have been direct financial incentives or subsidies as well as introducing parking permits (Potter, Enoch et al. 2006).Dedicated right-of-way for transit, high occupancy, and frequent transportation ensures alternatives to single occupancy cars are a fast and convenient choice. 'Street cars' in Portland are a 15-20 occupancy vehicle that drive on dedicated lanes and are an affordable option for road travel (HRM 2009)

Trials of automated road pricing conducted in the Netherlands demonstrated that 70 % of drivers changed behaviour, choosing to avoid peak times for journeys. Full implementation of a national road‐pricing scheme in the Netherlands is predicted to achieve a 15 % reduction in total distances driven (IBM 2010). Modal shifts to rail for transport over medium distances and to bicycles for short distances are also being encouraged in many European cities. For example, in the Netherlands, 31 % of people describe their main means of transport as cycling (SWOV 2010).

Some of these recommendations may seem too ambitious or excessively optimistic to be implemented in Indian cities. Nevertheless, cities in other developing countries have introduced measures that have significantly restricted private car use. For example, the TransMilenio Project in Bogota, Columbia, introduced a bus rapid transit system, bicycle paths and improved pedestrian facilities has been a great success in reducing the number of cars on the road (Pucher, Korattyswaropam et al. 2005).

4.3 Methodological reflections and future work

To obtain a detailed understanding of the composition of steel stock in the selected developed countries, a bottom-up study was conducted. The bottom-up method of stock estimation is inherently hindered by the inability to include each and every item, in this case, the vehicles. Also, there are uncertainties with respect to the metal content in each category. The specific challenges with the data have already been described in section 2.3.2. However, the results obtained are useful as a first estimate of the steel stock in vehicles of selected countries. When compared with the top-down estimations, they are in the same order of magnitude and seem fairly acceptable. For example, as mentioned in section 1.4, in a top-down estimate, the per capita ferrous metal stock in the transportation sector in the US and UK was around 2 and 1 ton respectively (Müller, Wang et al. 2011). In the bottom-up study conducted in this work, the steel stock in only registered, civilian vehicles was found to be around 1 and 0.45 ton per capita for US and UK. Bottom-up results for four other developed countries has been conducted which can be included in future work that might be carried out in stock-estimation.

Stocks build up over a long period of time, and therefore, quantification of emissions embodied in stocks should in essence, be dynamic, in order to account for emissions that actually occurred in the past. However, a simple static model is employed in this work, which excludes the time dimension and assumes a one-time build up of the stock. Further work could be based on actual time series data which would then also include the impacts of replacement and restructuring. Also, the emission and energy factors used are for primary production only. This is justifiable since the initial build up of stocks is through primary production. Secondary production is only possible if mature in-use stocks are available, and will be mainly needed for maintaining and replacing iron stocks in-use. It is possible that in the near future, India may import scrap from economies that may not be able to handle the increasing old scrap as their in-use stock saturates. By exporting its scrap to India, the loop could be closed, thereby lowering overall energy demand and carbon emissions. This aspect could be further explored in following research works. While discussing recycling, it is important differentiate between recycling of pre-consumer scrap (new scrap) and post-consumer scrap (old scrap) (see figure 5). With respect to CO_2 emissions from a total systems perspective, it is only the recycling of old scrap that reduces total emissions as it replaces primary production. Pre-consumer scrap recycling actually reflects inefficiencies in the steel cycle since it requires additional energy for re-melting and in fact, increases GHG emissions. Including new scrap in recycled content yields quite a high recycling figure and this may hinder policy makers from seeing the problem and taking action to increase recycling.

The scope of the current analysis was narrowed down only to transportation, specifically to passenger cars due to the limited time available. It definitely was a good starting point as it enabled the inclusion of user behaviour, product design and also demonstrated a close connection with the rest of the built infrastructure. However, it represents a very small fraction of the total steel stock in-use. For both China and India, the same iron stock ranking was seen in a recent top down study- machinery and appliances, then construction, followed by transportation (Wang, Muller et al.). Inclusion of other sectors like buildings and infrastructure, machinery and appliances would add tremendous value to this work. Since these stocks are much higher, they may even outrule the results from the analysis of the rolling stock. A study of the entire steel stock in-use would be important for looking at the big picture and then recommending development patterns for emerging economies in a climate constrained world.

This topic definitely warrants further research in order to gain deeper insights regarding the quantitative and qualitative relationships between services, stocks in use and lifestyles. The environmental implications of demands for in use stocks are huge and can be used by policy makers to ensure that the needs for services are not met at the cost of environmental damage.

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APPENDICES

A. Top-down stock estimates of iron
B. Steel stock in vehicles and use parameters for six developed countries
C. Patterns of automobile dependence and factors affecting it
D. Data used for scenario building
E. Scenario Results

APPENDIX A: Top down Stock estimates of Iron

	Top-down Stock Estimation of Iron				
S.No.	**Case Study**	**Year**	**In-Use Stock per capita**	**Unit**	**Source**
1	Global Average	1985	2100	kg/cap	Baccini,P;Brunner,P.H. Metabolism of the Anthoposhere.Springer-Verlag:Berlin,1991; p157
2	US	2000	14200	Kg/cap	Sullivan,D.E., Indicators of stocks in-use in the United States for Aluminium,Copper,Gold, Iron, Steel, Lead
3	US	2004	11000-12000	Kg/cap	Müller, D. B., T. Wang, et al. (2006). "Exploring the engine of anthropogenic iron cycles." Proc. Natl. Acad. Sci. USA 103(44): 16111-16116.
4	China	2004	1500	Kg/cap	Wang, T. (2009). Forging the Anthropogennic Iron Cycle. PhD. Dissertation, Yale University
	Urban China	2004	2700	Kg/cap	
	Rural China	2004	640	Kg/cap	
5	Global Average	2005	2500	kg/cap	Hatayama, H., I. Daigo, et al. (2010). "Outlook of the World Steel Cycle Based on the Stock and Flow Dynamics." Environ. Sci. Technol. 44(16): 6457-6463.
	North America	2005	7300	kg/cap	
	US	2005	9100	kg/cap	
	Asia	2005	1600	kg/cap	
	Korea	2005	10200	kg/cap	
	Japan	2005	9100	kg/cap	
	China	2005	1800	kg/cap	
	South-Asian	2005	500	kg/cap	
6	Global Average	2005	1500	kg/cap	Kozawa, S. and F. Tsukihashi (2009). "Analysis of global demand for iron source by estimation of in-use steel
7	Global Average	2005	2700	kg/cap	Müller, D. B., T. Wang, et al. (2011). "Patterns of iron use in societal evolution." Environ. Sci. Technol. 45(1): 182-188.
	Canada	2005	12000	kg/cap	
	Japan	2005	12000	kg/cap	
	US	2005	11000	kg/cap	
	China	2005	2200	kg/cap	
	India	2005	400	kg/cap	
8	China	2009	2800	kg/cap	Wang, T., D. B. Muller, et al. "Iron capital formation in China and India:Historic trends, outlook and consequences." Environmental Science & Technology Submitted.
	India	2009	600	kg/cap	
	Global Average		2200	kg/cap	Average of all values from literature
	MDC		10500	kg/cap	Average from the range (derived from several sources) given in UNEP report, Graedel, T. E. (2010)

APPENDIX B: Steel stock in vehicles and use parameters for six developed countries

1) US road vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (kg/V)	Stock (tonnes)
Light duty Vehicles (short)	Light Vehicle (US)	193979654	988	191651898
Light duty Vehicles (long)		40488025	988	40002169
Single-Unit Trucks	Goods Vehicle	8356097	4851	40534840
Combination Trucks		2617118	4851	12695455
Buses	Bus	841993	4266	3592245
Motorcycles (250 kg)	Motorcycles	7929724	149	1184357

2) US road vehicles use parameters

Types	km driven per vehicle	Vehicle km travelled	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Light duty Vehicles (short)	16704	3240310753684	4502039940335	1.39	0.63	14665	191651898
Light duty Vehicles (long)	24521	992808721852	1326342969835	1.34	0.13	4320	40002169
Single-Unit Trucks	23143	193383153410	193383153410	1.00	0.03	630	40534840
Combination Trucks	103211	270115520615	270115520615	1.00	0.01	880	12695455
Buses	27443	23106699281	489862024759	21.20	0.00	1596	3592245
Motorcycles	4221	33474691207	36056159307	1.08	0.03	117	1184357

3) US rail vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (Tons/V)	Stock (tonnes)
Locomotives	Locomotive	24045	53	1284243
Freight Cars	Wagon	1363433	21	28566648
train-cars	Typical Electric	1214	27	32839
locomotives	Locomotive	274	53	14634
Heavy Rail	Typical Electric	11461	27	310020
Light Rail	Typical Electric	2059	27	55696
Commuter Rail	Typical Electric	6722	27	181830

4) US rail vehicles use parameters

Types	km driven per vehicle	Vehicle km	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Locomotives	..	..	..	..	0.00	..	..
Freight Cars	37908	51685150417	..	..	0.00	..	..
train-cars	507710	616360000	9517555000	15	0.00	31	32839
locomotives	..	..	..	..	..	..	..
Heavy Rail	96128	1101727000	27045202000	25	0.00	88	310020
Light Rail	70580	145325000	3534308000	24	0.00	12	55696
Commuter Rail	80770	542937000	17911063000	33	0.00	58	181830

5) Japan road vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (kg/V)	Stock (tonnes)
Ordinary trucks	Goods	2456000	4851	11913884
Small trucks	Light goods	3907000	869	3394011
Buses	Bus	228000	4266	972730
Special use vehicles	Light good	1512000	869	1313474
Light two wheeled vehicles	Motorcycles	1524000	95	144018
Light motor vehicles	Minicar	28648000	557	15942612
Passenger cars	Car europe	40419000	742	29990898

6) Japan road vehicles use parameters

Types	Vehicle km	Km driven per vehicle	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Ordinary trucks	88055493321	35853	44594273000	0.51	0.02	349	11913884
Small trucks	140078506679	35853	..	..	0.03	..	..
Buses	6549000000	28724	71205000000	10.87	0.00	558	972730
Special use vehicles	..	..	..	..	0.01	..	..
Light two wheeled vehicles	..	..	..	..	0.01	..	..
Light motor vehicles	275346738558	9611	223070521000	0.81	0.22	1748	15942612
Passenger cars	388482261442	9611	559850538000	1.44	0.32	4388	29990898

7) Japan rail vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (Tons/V)	Stock (tonnes)
Passenger cars	Electric	37233	27	1007153
Wagons	Wagon	8566	21	179475

8) Japan rail vehicles use parameters

Types	km driven per vehicle	Vehicle km	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Passenger cars	28044	1044155000	377892000000	362	0.00	2962	1007153
			Ton-km hauled				
Freight trains	7755	66428000	55665000000	..	..	..	..

9) UK road vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (kg/V)	Stock (tonnes)
Cars	European Car	28261029	742	20969684
Motor cycles	Motor cycles	1273171	94	120145
Light goods	Light goods	3188243	869	2769627
Heavy goods	Goods	487907	4851	2366803
Buses & coaches	Bus	174774	4266	745649

10) UK road vehicles use parameters

Types	Vehicle km	Km driven per vehicle	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Cars	400700000000	14179	680180000000	1.70	0.46	11006	20969684
Motor cycles	5200000000	4084	5620000000	1.08	0.02	91	120145
Light goods	66600000000	20889	66600000000	1.00	0.05	1078	2769627
Heavy goods	26400000000	54109	26400000000	1.00	0.01	427	2366803
Buses & coaches	5200000000	29753	36587583920	7.04	0.00	592	745649

11) UK rail vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (Tons/V)	Stock (tonnes)
UK ATOC	Electric	11413	27	308722
UK Eurostar	Electric	198	27	5356
UK NIR	Electric	140	27	3787
UK Network Rail Wagons	Wagons	3074	21	64406

12) UK vehicles use parameters

Types	km driven per vehicle	Vehicle km travelled	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
UK ATOC	41978	479100000	50460451690	105.32	0.00	817	308722
UK Eurostar	10636	2106000	1014000000	481.48	0.00	16	5356
UK NIR	33550	4697000	276130000	58.79	0.00	4	3787
UK Network Rail Wagons	11723	36037843	..	..	0.00	..	..

13) NL road vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (kg/V)	Stock (tonnes)
Passenger Cars	Car European	7542331	742	5596410
Motorcycles	Motorbikes	605604	107	64712
Buses and coaches	Bus	11332	4266	48346
Vans	Light goods	876170	869	761129
Rigid Vehicles	Goods vehicle	75112	4851	364363
Articulated vehicles	Light goods	74624	869	64826
Special vehicles	Light goods	64194	869	55765
Trailers	Goods vehicle	905955	4851	4394724
Semi-trailers	Goods vehicle	132894	4851	644659

14) NL road vehicles use parameters

Types	Category	Vehicle km	km driven per vehicle	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Passenger Cars	Car European	92950202206	12324	94870000000	1.36	0.46	7661	5596410
Motorcycles	Motorbikes	1856781864	3066	1000000000	0.54	0.04	62	66254
Buses and coaches	Bus	623900000	55056	5800000000	9.30	0.00	343	47189
Vans	Light vehicle	17817000000	20335	17817000000	1.00	0.05	1080	761129
Rigid Vehicles	Goods Vehicle	7159000000	6427	7159000000	1.00	0.02	145	1801249
Articulated vehicles Special vehicles	Other Vehicles (light vehicles minus vans)	4617697051	33264	4617697051	1.00	0.00	140	60296

15) NL rail vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (Tons/V)	Stock (tonnes)
Passenger cars	Electric	2531	27	68464
Railway wagons	Wagon	5138	21	107651

16) NL vehicles use parameters

Types	km driven per vehicle	Vehicle km	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Passenger cars	44525	112693000	15400000000	136.65	0.00	933	68464

17) CH road vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (kg/V)	Stock (tonnes)
Passenger cars	Car European	4009602	742	2975125
Passenger vehicles/private cars	Bus	50675	4266	216198
Goods vehicles	Goods vehicle	327808	4851	1590174
Agric. vehicles	Light goods	185902	869	161493
Industrial vehicles	Light goods	56533	869	49110
Motorcycles	Motorbikes	642777	78	50137
Trailers	Goods vehicle	360762	4851	1750031

18) CH road vehicles use parameters

Types	km driven per vehicle	Vehicle km	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Passenger cars	11385	45648248408	71667750000	1.57	0.52	9308	2975125
Passenger vehicles	12630	640000000	4215750000	6.59	0.01	548	216198
Goods vehicles	17458	5723000000	5723000000	1.00	0.04	743	1590174
Motorcycles	4445	2857142857	1686300000	0.59	0.08	219	50137
Trailers	1386	500000000	500000000	1.00	0.05	65	1750031

19) CH rail vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (Tons/V)	Stock (tonnes)
Multiple Units	Electric	339	27	9170
Mainline locomotives	Electric	766	27	20720
Shunting locomotives	Electric	256	27	6925
Passenger coaches	Electric	2989	27	80852
Freight wagons	Wagon	9121	21	191103

20) CH vehicles use parameters

Types	km driven per vehicle	Vehicle km	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Passenger cars	43928	131300000	16677000000	127	0.00	2166	80852
			Ton-km hauled				
Freight trains	3333	30400000	11674000000	..	..	..	..

21) NZ road vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (kg/V)	Stock (tonnes)
Light passenger	Car European	2574589	742	1910345
Light commercial	Light goods	376695	869	327235
MCycle	Motorbikes	114443	120	13745
Trucks	Goods Vehicle	113072	4851	548504
Bus	Bus	8450	4266	36051

22) NZ road vehicles use parameters

Types	Vehicle-km	km driven per vehicle	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Light passenger	30934725581	12015	44360000000	1.43	0.60	11470	2123988
Light commercial	5734413817	15223	5734413817	1.00	0.09	1334	327235
MCycle	327762654	2864	240000000	0.73	0.03	62	15316
Trucks	2477356717	21910	2477356717	1.00	0.03	576	548504
Bus	233175933	27595	1150000000	4.93	0.00	346	46685

23) NZ rail vehicles rolling stock

Types	Categories	No. of vehicles (V)	Material Intensity (Tons/V)	Stock (tonnes)
Passenger cars -Tranz rail	Electric	523	27	14147
Wagons	Wagon	6382	21	133716

24) NZ vehicles use parameters

Types	km driven per vehicle	Vehicle km	Passenger-km travelled	Occupancy Rate (P trav/V)	Vehicles per person	Personal kilometrage (km/Person/yr)	Stock (tonnes)
Passenger cars	12950	6772690	396000000	58	0.00	92	14147
			Ton-km hauled				
Freight trains		8931809	2629000000	..	..	..	..

25) Total vehicle stocks (summarised from tables 1 to 24)

	Road vehicles (millions)	Road vehicles/cap	Rail vehicles (1000s)	Rail vehicles/cap
USA	254.21	0.83	1409.21	0.00459
Japan	78.69	0.62	45.80	0.00036
UK	33.39	0.54	14.83	0.00024
NL	10.29	0.62	7.67	0.00046
CH	5.63	0.73	13.47	0.00175
NZ	3.19	0.74	7.67	0.00178

26) Reference vehicles material (steel) intensity

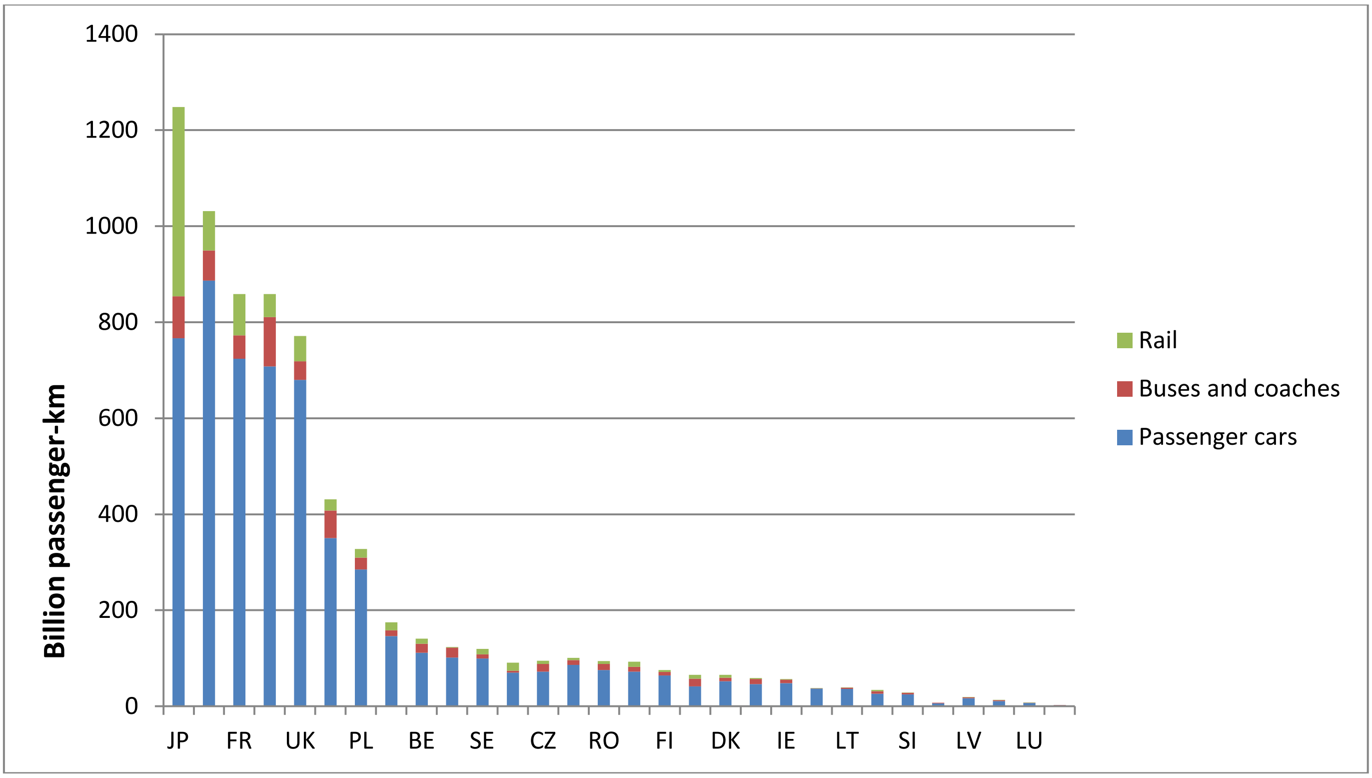
Road Vehicles	
Category	**Material Intensity (kg/v)**
Car European	742
Light Vehicle (US)	988
Bus	4266
Goods Vehicle	4851
Light goods	869
Mini car	557
Rail Vehicles	
Locomotives	53,410
Electric	27,050
Wagon	20,952

27) Passenger km travelled by mode (summarised from tables 1 to 24)

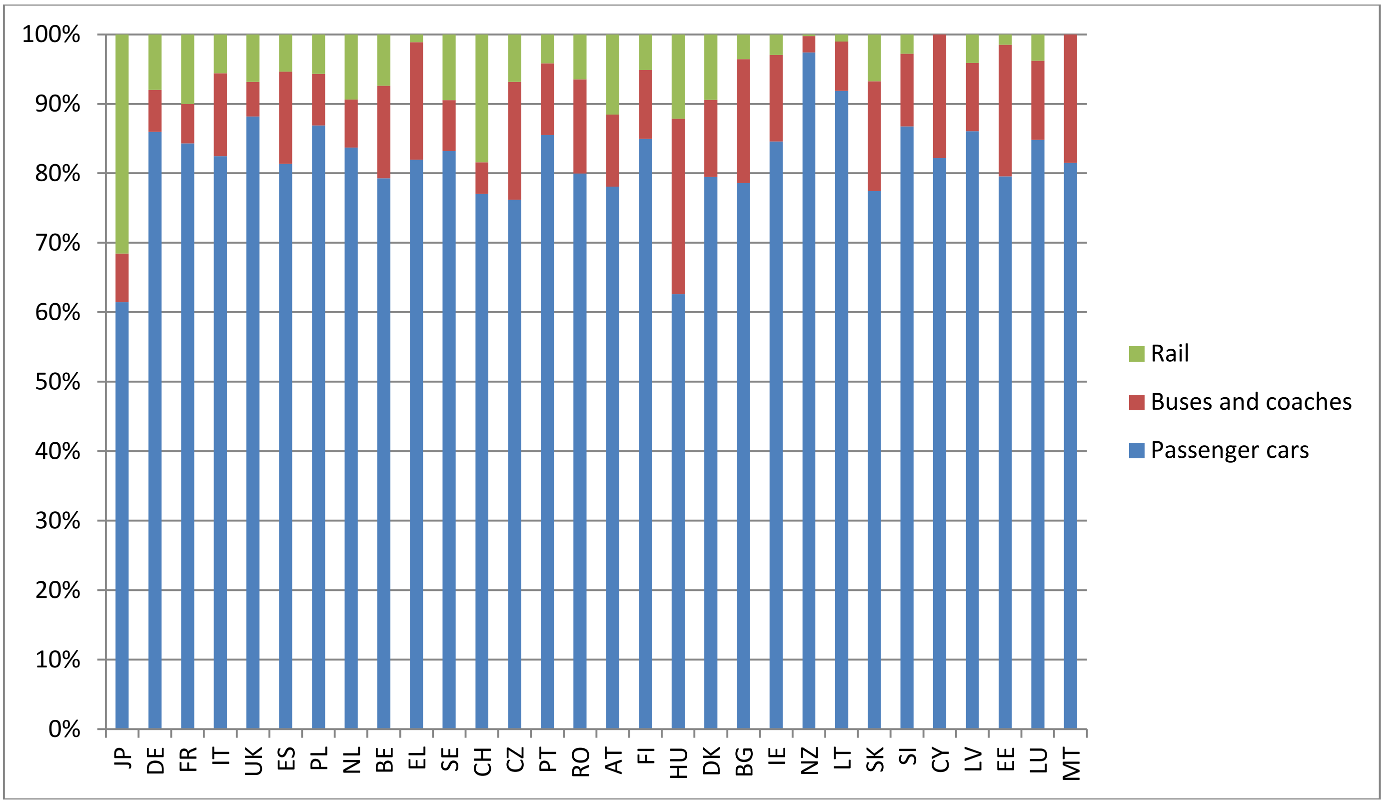
	Cars		Buses		Railways		Total
	Bill pkm	%	Bill pkm	%	Bill pkm	%	Bill pkm
USA	5828	91.41	490	7.68	58	0.91	6376
Japan	783	63.55	71	5.78	378	30.67	1232
UK	680	88.51	37	4.76	52	6.73	769
NL	95	81.74	6	5.00	15	13.27	116
CH	72	77.43	4	4.55	17	18.02	93
NZ	44	96.63	1	2.51	0.40	0.86	46

28) Passenger km travelled by mode for European countries and Japan

Source:ERF European Road Statistics 2011	Data for 2009	passenger cars		buses and coaches		Railways		Urban rail (tram and metro)		Total
		billion pkm	%	billion pkm	%	billion pkm	%	billion pkm	%	billion pkm
Japan	JP	766.725	61.4	87.4	7.0	394	31.6	..	..	1,248.1
germany	DE	886.8	84.6	62.4	6	82.4	7.9	16.5	1.6	1,048.10
france	FR	723.9	83	48.9	5.6	86	9.9	13.2	1.5	871.9
italy	IT	708.1	81.8	102.3	11.8	48.2	5.6	6.9	0.8	865.58
United Kingdom	UK	680.2	87.1	38.5	4.9	52.8	6.8	9.7	1.2	781.14
spain	ES	350.5	80.2	57.2	13.1	23.1	5.3	6.3	1.4	437.18
poland	PL	285	85.8	24.4	7.3	18.6	5.6	4.3	1.3	332.37
netherlands	NL	146.3	83	12.1	6.9	16.4	9.3	1.6	0.9	176.37
belgium	BE	111.5	78.7	18.7	13.2	10.4	7.4	1	0.7	141.57
greece	EL	101.3	80.8	20.9	16.7	1.4	1.1	1.7	1.3	125.3
sweden	SE	99.4	81.7	8.8	7.2	11.3	9.3	2.2	1.8	121.7
switzerland	CH	70.2	67.0	4.2	4.0	16.8	16	..	..	104.8
Czech rep	CZ	72.3	69.6	16.1	15.5	6.5	6.3	9	8.7	103.84
portugal	PT	86	84.6	10.4	10.3	4.2	4.1	1.1	1.1	101.69
romania	RO	75.5	74.4	12.8	12.6	6.1	6	7	6.9	101.48
austria	AT	72.3	74.9	9.6	10	10.7	11	4	4.1	96.52
finland	FI	64.3	84.3	7.5	9.9	3.9	5.1	0.5	0.7	76.28
hungary	HU	41.2	60.5	16.6	24.4	8	11.8	2.3	3.3	68.13
denmark	DK	52.2	79.3	7.3	11	6.2	9.4	0.2	0.3	65.83
bulgaria	BG	46.3	77.7	10.5	17.5	2.1	3.6	0.7	1.2	59.58
ireland	IE	48.3	84.4	7.1	12.4	1.7	2.9	0.1	0.2	57.24
new zealand	NZ	36.8	91.6	0.9	2.2	0.1	0.25	..	..	40.2
lithuania	LT	36.1	92	2.8	7.1	0.4	0.9	-	-	39.3
slovakia	SK	26.4	76.9	5.4	15.6	2.3	6.6	0.3	0.9	34.35
slovenia	SI	24.9	86.6	3	10.5	0.8	2.9	-	-	28.7
cyprus	CY	6	82.4	1.3	17.6		0	-	-	22.3
latvia	LV	16.7	85.4	1.9	9.8	0.8	3.9	0.2	0.9	19.54
estonia	EE	10.5	78.7	2.5	18.9	0.2	1.9	0.1	0.6	13.34
luxemberg	LU	6.7	84.4	0.9	11.4	0.3	4.2	-	-	7.9
malta	MT	2.2	81.9	0.5	18.1		-	-	-	2.7



Graph 1: Passenger kilometres travelled by mode



Graph 2: Modal share of passenger kilometres travelled

29) Embedded emissions and energy in vehicle steel stock in developed countries

	Road vehicles		Rail vehicles	
	Embedded emissions	Embedded energy	Embedded emissions	Embedded energy
	Megaton CO2 eq	Exajoule	Megaton CO2 eq	Exajoule
USA	710.43	7.84	74.67	0.82
Japan	156.16	1.72	2.91	0.03
UK	66.15	0.73	0.94	0.01
NL	29.42	0.32	0.43	0.005
CH	16.66	0.18	0.76	0.01
NZ	6.96	0.08	0.36	0.004

	Road vehicles		Rail vehicles	
	Emissions per capita	Energy per capita	Emissions per capita	Energy per capita
	Ton CO2 eq per capita	GJ per capita	Ton CO2 eq per capita	GJ per capita
USA	2.31	25.54	0.24	2.68
Japan	1.22	13.51	0.02	0.25
UK	1.07	11.82	0.02	0.17
NL	1.78	19.68	0.03	0.29
CH	2.16	23.88	0.10	1.09
NZ	1.62	17.86	0.08	0.93

	Road vehicles		Rail vehicles	
	Emissions per pkm	Energy per pkm	Emissions per pkm	Energy per pkm
	Kg CO2 eq per pkm	MJ per pkm	Kg CO2 eq per pkm	MJ per pkm
USA	0.12	1.24	1.29	14.21
Japan	0.20	2.02	0.01	0.09
UK	0.10	1.02	0.02	0.20
NL	0.31	3.23	0.03	0.31
CH	0.23	2.42	0.05	0.50
NZ	0.16	1.69	0.92	10.11

APPENDIX C: Patterns of automobile dependence and factors affecting it

1) Country level data

Source: World Bank	Roads	Population	Land Area	Pop density	Motor Vehicle		Passenger cars	Road density	GNI	GNI per Capita
http://siteresources.worldbank.org/DATASTATISTICS/Resources/wdi_ebook.pdf	Total Road Network km	Millions	Thousand sq km	People per sq.km	per thousand people	per km of road	per 1000 people	km. of road per 100 sq. km of land area	$billion	$
	2008	2009	2009	2009	2008	2008	2008	2008	2009	2009
Burundi	12,322	8.3	25.7	322.96	6	4	2	48	1.2	150
Liberia	10,600	4	96.3	41.54	3	1	2	11	0.7	160
Malawi	15,451	15.3	94.1	162.59	9	9	4	16	4.4	290
Afghanistan	42,150	29.8	652.2	45.69	27	19	19	6	9.1	310
Eritrea	4,010	5.1	101	50.50	11	14	6	4	1.6	320
Ethiopia	44,359	82.8	1,000.00	82.80	3	6	1	4	27.2	330
Sierra Leone	11,300	5.7	71.6	79.61	5	3	3	16	1.9	340
Niger	18,948	15.3	1,266.70	12.08	5	4	4	1	5.2	340
Zimbabwe	97,267	12.5	386.9	32.31	106	14	91	25	4.6	360
Madagascar	49,827	19.6	581.5	33.71	27	11	8	9	8.5	430
Nepal	17,782	29.3	143.4	204.32	5	8	3	12	13	440
Gambia,	3,742	1.7	10	170.00	7	3	5	37	0.7	440
Togo	11,652	6.6	54.4	121.32	2	1	2	21	2.9	440
Mozambique	30,331	22.9	786.4	29.12	13	10	9	4	10	440
Central African Republic	24,307	4.4	623	7.06	0	0	0	4	2	450
Uganda	70,746	32.7	197.1	165.91	7	3	3	36	15.2	460
Rwanda	14,008	10	24.7	404.86	4	3	2	57	4.9	490
Tanzania	87,524	43.7	885.8	49.33	73	36	4	10	21.4	500
Burkina Faso	92,495	15.8	273.6	57.75	11	2	7	34	8	510
Guinea-Bissau	3,455	1.6	28.1	56.94	33	15	27	12	0.8	510
Bangladesh	2,39,226	162.2	130.2	1245.78	2	1	1	184	93.5	580
Cambodia	38,257	14.8	176.5	83.85	20	8	18	22	9.7	650
Mali	18,912	13	1,220.20	10.65	9	6	7	2	8.9	680
Tajikistan	27,767	7	140	50.00	38	10	29	20	4.8	700
Benin	19,000	8.9	110.6	80.47	21	10	17	17	6.7	750
Kenya	63,265	39.8	569.1	69.93	21	13	15	11	30.3	760
Kyrgyz Republic	34,000	5.3	191.8	27.63	59	9	44	18	4.6	870
Lao PDR	34,994	6.3	230.8	27.30	21	4	2	15	5.6	880
Zambia	66,781	12.9	743.4	17.35	18	3	11	9	12.5	960
Vietnam	1,60,089	87.3	310.1	281.52	13	7	13	52	87.7	1,000
Pakistan	2,60,420	169.7	770.9	220.13	11	7	9	34	169.8	1,000
Nicaragua	20,333	5.7	120.3	47.38	57	16	17	17	5.7	1,000
Senegal	14,805	12.5	192.5	64.94	23	19	17	8	13.1	1,040
Côte d'Ivoire	81,996	21.1	318	66.35	20	5	16	26	22.5	1,070
Papua New Guinea	19,600	6.7	452.9	14.79	9	3	6	4	7.9	1,180
Nigeria	1,93,200	154.7	910.8	169.85	31	25	31	21	184.7	1,190
Cameroon	51,346	19.5	472.7	41.25	..	..	11	11	23.2	1,190
India	42,36,429	1,155.30	2,973.20	388.57	15	4	10	142	1,405.70	1,220
Sudan	11,900	42.3	2,376.00	17.80	28	100	20	1	51.5	1,220
Moldova	12,778	3.6	32.9	109.42	139	39	101	39	5.6	1,560
Bolivia	62,479	9.9	1,083.30	9.14	68	11	18	6	16.1	1,630
Mongolia	49,250	2.7	1,553.60	1.74	72	4	48	3	4.4	1,630
Philippines	2,00,037	92	298.2	308.52	33	15	11	67	164.6	1,790
Honduras	13,600	7.5	111.9	67.02	97	53	69	12	13.5	1,800
Sri Lanka	97,286	20.3	62.7	323.76	61	13	19	155	40.4	1,990
Indonesia	4,37,759	230	1,811.60	126.96	77	40	43	24	471	2,050
Egypt, Arab Rap.	1,04,918	83	995.5	83.38	43	34	31	11	172.1	2,070
Congo, Rep.	17,000	3.7	341.5	10.83	26	6	15	5	7.7	2,080
Paraguay	29,500	6.3	397.3	15.86	82	18	39	7	14.3	2,250
Syrian Arab Republic	64,983	21.1	183.6	114.92	62	20	27	35	50.9	2,410
Swaziland	3,594	1.2	17.2	69.77	89	30	46	21	2.9	2,470
Georgia	20,329	4.3	69.5	61.87	116	25	95	29	11.1	2,530
Morocco	58,256	32	446.3	71.70	71	39	53	13	89.9	2,770
Ukraine	1,69,502	46	579.3	79.41	152	41	138	29	128.9	2,800
Armenia	7,704	3.1	28.5	108.77	105	42	96	27	9.5	3,100
El Salvador	10,029	6.2	20.7	299.52	84	52	41	48	20.8	3,370
Turkmenistan	24,000	5.1	469.9	10.85	106	23	80	5	17.5	3,420
China	37,30,164	1,331.50	9,327.50	142.75	37	13	27	40	4,856.20	3,650
Tunisia	19,371	10.4	155.4	66.92	114	61	76	12	38.9	3,720
Angola	51,429	18.5	1,246.70	14.84	40	14	8	4	69.4	3,750
Thailand	1,80,053	67.8	510.9	132.71	..	..	54	35	254.7	3,760
Ecuador	43,670	13.6	248.4	54.75	63	20	38	18	54.1	3,970
Jordan	7,816	6	88.2	68.03	146	112	102	9	23.7	3,980

Source: World Bank	Roads	Population	Land Area	Pop density	Motor Vehicle		Passenger cars	Road density	GNI	GNI per Capita
http://siteresources.worldbank.org/DATASTATISTICS/Resources/wdi_ebook.pdf	Total Road Network km	Millions	Thousand sq km	People per sq.km	per thousand people	per km of road	per 1000 people	km. of road per 100 sq. km of land area	$billion	$
	2008	2009	2009	2009	2008	2008	2008	2008	2009	2009
Albania	18,000	3.2	27.4	116.79	114	20	84	66	12.6	4,000
Peru	1,02,887	29.2	1,280.00	22.81	55	16	35	8	122.4	4,200
Namibia	66,467	2.2	823.3	2.67	109	4	52	8	9.3	4,270
Macedonia, FYR	13,922	2	25.2	79.37	144	21	129	55	9	4,400
Algeria	1,11,261	34.9	2,381.70	14.65	112	35	72	5	154.2	4,420
Iran, Islamic Rep	1,74,301	72.9	1,628.60	44.76	128	54	113	11	330.6	4,530
Dominican Republic	12,600	10.1	48.3	209.11	123	99	62	26	45.9	4,550
Jamaica	22,210	2.7	10.8	250.00	188	23	138	206	12.4	4,590
Bosnia and Herzegovina	21,846	3.8	51.2	74.22	135	23	119	43	17.7	4,700
Azerbaijan	52,942	8.8	82.6	106.54	89	15	72	64	42.5	4,840
Colombia	1,64,183	45.7	1,109.50	41.19	58	16	41	15	227.8	4,990
Cuba	..	11.2	106.4	105.26	38	..	21	..	62.2	5,550
Belarus	94,797	9.7	202.9	47.81	282	29	240	47	53.7	5,560
South Africa	3,62,099	49.3	1,214.50	40.59	159	22	108	30	284.3	5,760
Serbia	40,130	7.3	88.4	82.58	227	41	202	45	43.9	6,000
Bulgaria	40,231	7.6	108.6	69.98	353	67	310	37	46	6,060
Costa Rica	38,049	4.6	51.1	90.02	163	20	126	74	28.7	6,260
Botswana	25,798	1.9	566.7	3.35	113	8	56	5	12.2	6,260
Panama	13,727	3.5	74.3	47.11	120	31	131	18	22.7	6,570
Kazakhstan	93,612	15.9	2,699.70	5.89	197	33	164	3	110	6,920
Mauritius	2,028	1.3	2	650.00	159	102	123	101	9.2	7,250
Malaysia	98,722	27.5	328.6	83.69	334	93	298	30	201.8	7,350
Brazil	17,51,868	193.7	8,459.40	22.90	198	22	158	21	1,564.20	8,070
Romania	1,98,817	21.5	229.9	93.52	219	24	187	86	178.9	8,330
Turkey	4,26,951	74.8	769.6	97.19	138	24	92	55	652.4	8,720
Mexico	3,66,096	107.4	1,944.00	55.25	264	77	181	19	962.1	8,960
Uruguay	77,732	3.3	175	18.86	176	7	151	44	30.2	9,010
Russian Federation	9,63,000	141.9	16,376.90	8.66	245	36	206	6	1,324.40	9,340
Chile	79,814	17	743.5	22.86	172	37	109	11	160.7	9,470
Venezuela, RB	96,155	28.4	882.1	32.20	147	43	107	11	286.4	10,090
Lithuania	81,030	3.3	62.7	52.63	546	22	498	129	38.1	11,410
Libya	83,200	6.4	1,759.50	3.64	291	22	225	5	77.2	12,020
Poland	3,83,313	38.1	304.2	125.25	495	49	422	126	468	12260
Latvia	69,684	2.3	62.2	36.98	474	16	412	112	28	12390
Hungary	1,97,534	10	89.6	111.61	384	19	304	220	130	12980
Croatia	29,248	4.4	56	78.57	388	58	346	52	61	13770
Estonia	58,034	1.3	42.4	30.66	477	11	412	137	19	14060
Slovak Republic	43,848	5.4	48.1	112.27	319	39	272	91	87	16130
Saudi Arabia	2,21,372	25.4	2,000.00	12.70	..	..	415	11	437	17210
Czech Republic	1,30,573	10.5	77.3	135.83	513	41	424	169	182	17310
Oman	53,430	2.8	309.5	9.05	225	12	174	17	50	17890
Korea, Rep.	1,04,237	48.7	96.9	502.58	346	162	257	108	967	19830
Portugal	82,900	10.6	91.5	115.85	509	65	495	91	233	21910
Slovenia	38,872	2	20.1	99.50	565	29	520	193	48	23520
Israel	18,096	7.4	21.6	342.59	313	128	260	84	192	25790
New Zealand	93,911	4.3	263.3	16.33	733	34	616	36	124	28810
Greece	1,16,711	11.3	128.9	87.66	560	54	443	91	328	29040
Hong Kong SAR, China	2,040	7	1	7000.00	73	250	55	204	221	31570
Spain	6,67,064	46	499.1	92.17	606	42	486	134	1476	32120
Italy	4,87,700	60.2	294.1	204.69	673	83	596	166	2115	35110
Singapore	3,325	5	0.7	7142.86	150	226	114	475	186	37220
Japan	12,00,858	127.6	364.5	350.07	593	63	319	329	4857	38080
United Kingdom	4,19,634	61.8	241.9	255.48	526	77	462	173	2558	41370
Canada	14,09,000	33.7	9,093.50	3.71	605	14	399	15	1416	41980
Germany	6,44,288	81.9	348.6	234.94	554	70	502	185	3476	42450
France	9,51,200	62.6	547.7	114.30	598	39	495	174	2751	42620
Australia	8,18,356	21.9	7,682.30	2.85	687	18	551	11	958	43770
Kuwait	5,749	2.8	17.8	157.30	507	247	282	32	117	43930
Ireland	96,424	4.5	68.9	65.31	534	25	451	140	197	44280
Belgium	1,53,595	10.8	30.3	356.44	543	38	479	507	488	45270
Finland	78,860	5.3	303.9	17.44	534	36	461	26	245	45940
United States	65,06,221	307	9,147.40	33.56	809	38	451	71	14234	46360
Austria	1,10,778	8.4	82.5	101.82	562	43	514	134	389	46450
Netherlands	1,36,135	16.5	33.8	488.17	515	62	449	403	801	48460
Sweden	5,74,741	9.3	410.3	22.67	521	8	464	140	454	48840
Denmark	73,257	5.5	42.4	129.72	477	36	377	173	327	59060
Switzerland	71,355	7.7	40	192.50	567	61	522	178	506	65430
Norway	93,247	4.8	305.5	15.71	575	30	461	31	409	84640
Low income	15,89,817	844.7	17274.1	4582.13	617	260	372	764	372.7	17850
Middle income										
Lower middle income	10689257	5815.5	32547.2	6962.4	2281	3077	1455	1133	8683.1	89360
Upper middle income	5941989	999	47319	3028.41	6110	1140	4160	1365	7482.8	237430
High income	16191425	1086.1	33277	19679.17	19540	2863	15904	5762	41555	1264550

2) Cities comprising regional averages

USA	Canada (CAN)	Australia, New Zea (ANZ)	Western Europe (WEU)	High Income Asia (HIA)	Eastern Europe (EEU)	Middle East (MEA)	Africa (AFR)	Latin America (LAM)	Low Income Asia (LIA)	China (CHN)
Atlanta	Calgary	Brisbane	Graz	Osaka	Prague	Tel Aviv	Dakar	Curitiba	Manila	Beijing
Chicago	Montreal	Melbourne	Vienna	Sapporo	Budapest	Teheran	Cape Town	S.Paulo	Bangkok	Shanghai
Denver	Ottawa	Perth	Brussels	Tokyo	Krakow	Riyadh	Jo'burg	Bogota	Mumbai	Guangzhou
Houston	Toronto	Sydney	Copenhagen	Hong Kong		Cairo	Harare		Chennai	
Los Angeles	Vancouver	Wellington	Helsinki	Singapore		Tunis			K.Lumpur	
New York			Lyon	Taipei					Jakarta	
Phoenix			Nantes						seoul	
San Diego			Paris						Ho Chi Minh City	
San Francisco			Marseilles							
Washington			Berlin							
			Frankfurt							
			Hamburg							
			Dusseldorf							
			Munich							
			Ruhr							
			Stuttgart							
			Athens							
			Milan							
			Bologna							
			Rome							
			Amsterdam					Higher income (US$20 000 to US$32 000)		
			Oslo					Lower income (US$2400 to US$6000)		
			Barcelona							
			Madrid							
			Stockholm							
			Bern							
			Geneva							
			Zurich							
			London							
			Manchester							
			Newcastle							
			Glasgow							

Source: Kenworthy, J. R. (2008). Energy use and CO2 production in the urban passenger transport systems of 84 international cities: Findings and policy implications. Urban energy transition.

3) Summarised data for cities

Source: Kenworthy, J. R. (2008). Energy use and CO2 production in the urban passenger transport systems of 84 international cities: Findings and policy implications. Urban energy transition.		Urban density persons/sq km	GDP/cap (USD $)	Passenger cars per 1000 persons	pkm/person
American cities	USA	1490	31386	587	18155
Canadian cities	CAN	2620	20825	575	11387
Australia, New Zea	ANZ	1500	19775	530	8645
Western European	WEU	5490	32077	414	6202
High Income Asian	HIA	15030	31579	210	3614
Eastern European	EEU	5290	5951	332	2907
Middle Eastern cities	MEA	11880	5479	134	3262
Latin American cities	LAM	7470	4931	202	2862
African cities	AFR	5990	2820	135	2652
Low Income Asian	LIA	20410	3753	105	1855
Chinese cities	CHN	14620	2366	26	814

4) City data: Passenger cars per capita and urban density

	1990 data	Cities	Passenger cars per 1000 ppl	Urban density (ppl per sq km)
Source: Kenworthy, J. R. and F. B. Laube (1999). "Patterns of automobile dependence in cities: an international overview of key physical and economic dimensions with some implications for urban policy." Tranportation research Part A 33: 691-723.	American cities	New York State	483	1800
		Portland	763	1400
	Australian cities	Sydney	488	1680
		Adelaide	537	1400
	Canadian cities	Winnipeg	412	1500
		Calgary	630	2080
	European cities	Copenhagen	283	2860
		Frankfurt	478	3400
	Wealthy Asian	Hong Kong	43	30050
		Tokyo	225	7100
	Develeeping Asian	Surabaya	40	6900
		Bangkok	199	3200
Sources: Passenger cars - EuropeanCommision (2012). Eurostat. Urban density - Demographia (2012). Demographia World Urban Areas.	Extended Dataset	Bruxelles	992	2600
		Praha	515	4400
		Berlin	324	3500
		Bremen	416	2400
		Hamburg	418	2500
		Düsseldorf	469	2800
		Athens	269	4800
		Vienna	366	3800
		Stockholm	400	3400
		Greater Manchester	434	4000
		Merseyside	391	2095
		West Midlands	375	2927
		London	333	5300
		Inner London	239	9580
		Outer London	394	3744
		Istanbul	260	9700
		Los Angeles	535	3040
		Oslo	374	3400
		Madrid	478	5700

5) City data: Length of motorways per capita and urban density

Cities	Road network	Roads per	Roads per	Motorway	Motorway per 1000	Motorway per 1000	Land area	Population	Population density
	km	1000 sq km	1000 ppl	km	sq km	ppl	sq km		ppl/sq.km
Bruxelles	1,860	11,553	1.74	11	68.3	0.01	161	10,68,532	6,702.1
Wien	2,766	6,671	1.64	43	103.7	0.03	415	16,87,271	4,274.1
Greater Manchester	9,010	7,061	3.48	177	138.7	0.07	1,276	25,90,437	2,039.8
Merseyside	4,882	7,570	3.62	64	99.2	0.05	645	13,50,404	2,095.2
West Midlands	7,713	8,555	2.93	81	89.8	0.03	902	26,30,480	2,926.5
London	14,741	9,368	1.91	60	38.1	0.01	1,574	77,10,942	4,929.6
Inner London	4,373	13,696	1.44	0	0.0	0.00	319	30,45,580	9,580.3
Outer London	10,367	8,266	2.22	60	47.8	0.01	1,254	46,65,362	3,744.4
Madrid	589.8	56.1	0.1			0.10	10,510	64,58,684	615
Los Angeles	10,460	8,593.4	2.8				1217	3700000	3039.8
Source: EuropeanCommision (2012). Eurostat									

APPENDIX D: Data used for Scenario Building

Table 1) Parameters for passenger cars in six developed countries (summarised from tables 1 to 24, Appendix B)

Country	Service level definition	1. Physical service (Vehicles per capita)					
US	Formula	P*(V/P)*(kg/V)=kg					
	Population	**Modes**	**Number of Vehicles**	**Vehicles/1000 capita**	**Kg Steel/V**	**Stock (tons)**	**Stock/capita (kg)**
	307000000	Passenger Cars	234467679	763.74	988	231654066	755
		2. Intensity of use (intensity of use of vehicle, occupancy rate of vehicle)					
	Formula	mode*(1/(km/V/yr))*(1/(P/V))*(kg/V) = Kg					
	Modes	**km driven per vehicle**	**Vehicle-km travelled**	**Passenger-km travelled**	**Occupancy Rate**	**Personal kilometrage (km/Person/yr)**	**Stock (tons)**
	Passenger Cars	18054	4233119475536	5828382910169	1.38	18985	231654066

Country	Service level definition	1. Physical service (Vehicles per capita)					
Switzerland	Formula	P*(V/P)*(kg/V)=kg					
	Population	**Modes**	**Number of Vehicles**	**Vehicles/1000 capita**	**Kg Steel/V**	**Stock (tons)**	**Stock/capita (kg)**
	7700000	Passenger Cars	4009602	520.73	742	2975125	386
		2. Intensity of use (intensity of use of vehicle, occupancy rate of vehicle)					
	Formula	mode*(1/(km/V/yr))*(1/(P/V))*(kg/V) = Kg					
	Modes	**km driven per vehicle**	**Vehicle-km travelled**	**Passenger-km travelled**	**Occupancy Rate**	**Personal kilometrage (km/Person/yr)**	**Stock (tons)**
	Passenger Cars	11385	45648248408	71667750000	1.57	9308	2975125

Country	Service level definition	1. Physical service (Vehicles per capita)					
The Netherlands	Formula	P*(V/P)*(kg/V)=kg					
	Population	**Modes**	**Number of Vehicles**	**Vehicles/1000 capita**	**Kg Steel/V**	**Stock (tons)**	**Stock/capita (kg)**
	16500000	Passenger Cars	7542331	457.11	742	5596410	339
		2. Intensity of use (intensity of use of vehicle, occupancy rate of vehicle)					
	Formula	mode*(1/(km/V/yr))*(1/(P/V))*(kg/V) = Kg					
	Modes	**km driven per vehicle**	**Vehicle-km travelled**	**Passenger-km travelled**	**Occupancy Rate**	**Personal kilometrage (km/Person/yr)**	**Stock (tons)**
	Passenger Cars	12324	92950202206	94870000000	1.02	5750	5596410

Country	Service level definition	1. Physical service (Vehicles per capita)					
New Zealand	Formula	P*(V/P)*(kg/V)=kg					
	Population	Modes	Number of Vehicles	Vehicles/1000 capita	Kg Steel/V	Stock (tons)	Stock/capita (kg)
	4300000	Passenger Cars	2574589	598.74	742	1910345	444
		2. Intensity of use (intensity of use of vehicle, occupancy rate of vehicle)					
	Formula	P*(km/person/yr)*%mode*(1/(km/V/yr))*(1/(P/V))*(kg/V) = Kg					
	Modes	km driven per vehicle	Vehicle-km travelled	Passenger-km travelled	Occupancy Rate (P trav/V)	Personal kilometrage (km/Person/yr)	Stock (tons)
	Passenger Cars	12015	30934725581	44360000000	1.43	10316	1910345

Country	Service level definition	1. Physical service (Vehicles per capita)					
Japan	Formula	P*(V/P)*(kg/V)=kg					
	Population	Modes	Number of Vehicles	Vehicles/1000 capita	Kg Steel/V	Stock (tons)	Stock/capita (kg)
	127600000	Passenger Cars	69067000	541.28	649	44841750	351
		2. Intensity of use (intensity of use of vehicle, occupancy rate of vehicle)					
	Formula	P*(km/person/yr)*%mode*(1/(km/V/yr))*(1/(P/V))*(kg/V) = Kg					
	Modes	km driven per vehicle	Vehicle-km travelled	Passenger-km travelled	Occupancy Rate (P trav/V)	Personal kilometrage (km/Person/yr)	Stock (tons)
	Passenger Cars	9611	663829000000	782921059000	1.18	6136	44841750

Country	Service level definition	1. Physical service (Vehicles per capita)					
UK	Formula	P*(V/P)*(kg/V)=kg					
	Population	Modes	Number of Vehicles	Vehicles/1000 capita	Kg Steel/V	Stock (tons)	Stock/capita (kg)
	61800000	Passenger Cars	28261029	457.30	742	20969684	339
		2. Intensity of use (intensity of use of vehicle, occupancy rate of vehicle)					
	Formula	P*(km/person/yr)*%mode*(1/(km/V/yr))*(1/(P/V))*(kg/V) = Kg					
	Modes	km driven per vehicle	Vehicle-km travelled	Passenger-km travelled	Occupancy Rate (P trav/V)	Personal kilometrage (km/Person/yr)	Stock (tons)
	Passenger Cars	14179	400700000000	680180000000	1.70	11006	20969684

APPENDIX E: Scenario Results

1) Scenario results for absolute and per capita steel stock levels in passenger cars for India

Case India: Steel stocks in passenger cars								
Scenario 1: Car ownership same as in selected developed countries			**Scenario 2: Intensity of use same as in selected developed countries**			**Scenario 3 : Combination cases**		
Parameter: Cars/cap	Steel Stock Tg (Megaton)	With Lightweighting Tg (Megaton)	Parameter: Travel budget (km trav/cap/yr and km driven/car/yr)	Steel Stock Tg (Megaton)	With lightweighting Tg (Megaton)	Parameters: Intensity of use of vehicles given by Occupancy Rate (OR) and travel budget (TB)	Steel Stock Tg (Megaton)	With lightweighting Tg (Megaton)
a. High (US)	655	458	a. High (US)	655	458	a. High OR (UK) and high TB (US)	531	372
b.Medium (CH)	446	312	b. Medium (UK)	392	274	b. High OR (UK) and medium TB (NZ)	392	274
c. Low (NL)	392	274	c. Low (JP)	464	325	c. High OR (UK) and low TB (NL)	236	165

Case India: Steel stock per capita in passenger cars								
Scenario 1: Car ownership same as in selected developed countries			**Scenario 2: Intensity of use same as in selected developed countries**			**Scenario 3 : Combination cases**		
Parameter: Cars/cap	Steel Stock per cap Kg steel/cap	With Lightweighting Kg steel/cap	Parameter: Travel budget (km trav/cap/yr and km driven/car/yr)	Steel Stock per cap Kg steel/cap	With lightweighting Kg steel/cap	Parameters: Intensity of use of vehicles given by Occupancy Rate (OR) and travel budget (TB)	Steel Stock per cap Kg steel/cap	With lightweighting Kg steel/cap
a. High (US)	567	397	a. High (US)	567	397	a. High OR (UK) and high TB (US)	460	322
b.Medium (CH)	386	270	b. Medium (UK)	339	238	b. High OR (UK) and medium TB (NZ)	339	238
c. Low (NL)	339	237	c. Low (JP)	402	281	c. High OR (UK) and low TB (NL)	204	143

2) Scenario results for total and per capita emissions embedded in steel stock of passenger cars in India

Case India: Emissions embedded in steel stock of passenger cars								
Scenario 1: Car ownership same as in selected developed countries			**Scenario 2: Intensity of use same as in selected developed countries**			**Scenario 3 : Combination cases**		
Parameter: Cars/cap	Embedded emissions Megaton CO2eq	With Lightweighting Megaton CO2eq	Parameter: Travel budget (km trav/cap/yr and km driven/car/yr)	Embedded emissions Megaton CO2eq	With lightweighting Megaton CO2eq	Parameters: Intensity of use of vehicles given by Occupancy Rate (OR) and travel budget (TB)	Embedded emissions Megaton CO2eq	With lightweighting Megaton CO2eq
a. High (US)	1606	1124	a. High (US)	1606	1124	a. High OR (UK) and high TB (US)	1302	912
b. Medium (CH)	1095	766	b. Medium (UK)	961	673	b. High OR (UK) and medium TB (NZ)	961	673
c. Low (NL)	961	673	c. Low (JP)	1138	797	c. High OR (UK) and low TB (NL)	578	405

Case India: Emissions per capita in steel stock of passenger cars								
Scenario 1: Car ownership same as in selected developed countries			**Scenario 2: Intensity of use same as in selected developed countries**			**Scenario 3 : Combination cases**		
Parameter: Cars/cap	Emissions per capita Ton CO2eq/cap	With Lightweighting Ton CO2eq/cap	Parameter: Travel budget (km trav/cap/yr and km driven/car/yr)	Emissions per capita Ton CO2eq/cap	With lightweighting Ton CO2eq/cap	Parameters: Intensity of use of vehicles given by Occupancy Rate (OR) and travel budget (TB)	Emissions per capita Ton CO2eq/cap	With lightweighting Ton CO2eq/cap
a. High (US)	1.39	0.97	a. High (US)	1.39	0.97	a. High OR (UK) and high TB (US)	1.13	0.79
b. Medium (CH)	0.95	0.66	b. Medium (UK)	0.83	0.58	b. High OR (UK) and medium TB (NZ)	0.83	0.58
c. Low (NL)	0.83	0.58	c. Low (JP)	0.99	0.69	c. High OR (UK) and low TB (NL)	0.50	0.35

3) Scenario results for total and per capita energy embedded in steel stock of passenger cars in India

Case India: Energy embedded in steel stock of passenger cars								
Scenario 1: Car ownership same as in selected developed countries			Scenario 2: Intensity of use same as in selected developed countries			Scenario 3 : Combination cases		
Parameter: Cars/cap	Embedded energy Exajoules	With Lightweighting Exajoules	Parameter: Travel budget (km trav/cap/yr and km driven/car/yr)	Embedded energy Exajoules	With lightweighting Exajoules	Parameters: Intensity of use of vehicles given by Occupancy Rate (OR) and travel budget (TB)	Embedded energy Exajoules	With lightweighting Exajoules
a. High (US)	17.72	12.41	a. High (US)	17.73	12.41	a. High OR (UK) and high TB (US)	14.38	10.06
b. Medium (CH)	12.09	8.46	b. Medium (UK)	10.61	7.43	b. High OR (UK) and medium TB (NZ)	10.61	7.43
c. Low (NL)	10.61	7.43	c. Low (JP)	12.56	8.79	c. High OR (UK) and low TB (NL)	6.38	4.47

Case India: Energy per capita in steel stock of passenger cars								
Scenario 1: Car ownership same as in selected developed countries			Scenario 2: Intensity of use same as in selected developed countries			Scenario 3 : Combination cases		
Parameter: Cars/cap	Energy per capita GJ/cap	With Lightweighting GJ/cap	Parameter: Travel budget (km trav/cap/yr and km driven/car/yr)	Energy per capita GJ/cap	With lightweighting GJ/cap	Parameters: Intensity of use of vehicles given by Occupancy Rate (OR) and travel budget (TB)	Energy per capita GJ/cap	With lightweighting GJ/cap
a. High (US)	15.34	10.74	a. High (US)	15.34	10.74	a. High OR (UK) and high TB (US)	12.44	8.71
b. Medium (CH)	10.46	7.32	b. Medium (UK)	9.19	6.43	b. High OR (UK) and medium TB (NZ)	9.19	6.43
c. Low (NL)	9.18	6.43	c. Low (JP)	10.87	7.61	c. High OR (UK) and low TB (NL)	5.52	3.86