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Transportation Module of Global Change Assessment Model (GCAM): Model Documentation

June 2013

Gouri Shankar Mishra
Page Kyle
Jacob Teter
Geoffrey M. Morrison
Son Kim
Sonia Yeh

Institute of Transportation Studies ◦ University of California, Davis
1605 Tilia Street ◦ Davis, California 95616
PHONE (530) 752-6548 ◦ FAX (530) 752-6572
www.its.ucdavis.edu

Transportation Module of Global Change Assessment Model (GCAM)

Model Documentation – Version 1.0

Gouri Shankar Mishra
Jacob Teter
Geoffrey M. Morrison
Sonia Yeh

Institute of Transportation Studies
University of California, Davis

Page Kyle
Son H. Kim

Joint Global Change Research Institute
Pacific Northwest National Laboratory

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Project Description

The Institute of Transportation Studied (ITS) at the University of California, Davis (UCD) and Pacific Northwest National Laboratory (PNNL) embarked on a project to update and refine the transportation module of the Global Change Assessment Model (GCAM, formerly MiniCAM).

The project broadly encompasses the following four refinements to the transportation sector of GCAM:

1. Increased resolution to include the full spectrum of sub-modes and technologies available in passenger and freight transport;
2. Refined estimates of input parameters so as to better represent real-world heterogeneity in a way consistent with the latest literature on transportation;
3. Refined estimates of base year (2005) estimates of transportation demand, and disaggregation of IEA energy estimates between modes and size classes;
4. Included the non-motorized modes of walking and biking.

The purpose of this document is to describe the methodological approaches taken in this update. No results or foreasts from GCAM are given here.

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Contacts

For more information on this publication, please contact:

Gouri Shankar Mishra
Institute of Transportation Studies
University of California, Davis
1605 Tilia Street, Suite 100, Davis CA 94536
Email: gsmishra@ucdavis.edu

G Page Kyle
Joint Global Change Research Institute
Pacific Northwest National Laboratory
5825 University Research Court, Suite 3500
College Park, MD 20740
Email: pkyle@pnnl.gov

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Executive Summary

This publication provides methodological detail on the new GCAM Transportation Module and contains the following:

(1) Descriptions of the new transportation module in GCAM
(2) Details about the data sources and methodology adopted to estimate the exogeneous input parameters
(3) A summary of the region-specific transportation data for base year (2005)
(4) Comparisons of these estimates across regions and modes.
(5) Highlights of the uncertainty and shortcomings in our estimates

The project broadly encompasses the following four refinements to the transportation sector of GCAM:

1) Increased resolution to include the full spectrum of sub-modes and technologies available in passenger and frieght transport;
2) Refined estimates of input parameters so as to better represent real-world heterogeneity in a way consistent with the latest literature on transportation;
3) Refined estimates of base year (2005) estimates of transportation demand, and disaggregation of IEA energy estimates between modes and size classes;
4) Included the non-motorized modes of walking and biking.

The above refinements will not only allow us to develop better estimates of transportation energy demand and emissions, but will also enable modeling of the impact of policies that induce behavioral change and switching to different size classes within a single fuel type. Existing literature on long-term forecasts of transportation energy demand and emissions have focused on the role of advanced low-emission vehicle technologies and low-carbon energy carriers in achieving climate change goals. In GCAM, modeling the impact of policies in the form of varying levels of carbon prices has, to date, been restricted to consumer choices for different modes (e.g. rail versus personal car) and different vehicle technologies (e.g. internal combustion engine vehicles versus electric vehicle). A more detailed representation of the transportation sector – including various size classes of vehicles -- will allow us to estimate the potential for downsizing in the case of private modes (large LDV to midsize or compact LDVs), transfer to public modes (rail and bus) or to non-motorized transport (walking and biking), and adoption of energy efficient “new” modes like the electric-bikes, which have seen rapid adoption in China and other developing countries.

This project aims to better represent the heterogeneity and flexibility in the transport system to allow the modeling of a broader range of transport policy intruments including subsidies to public transit, government incentives for alternative technology, transportation fuel taxes, and public investments to increase the speed, service frequency/availability, and comfort of public and non-motorized modes.

Contents

Select Acronyms and Abbreviations

2W	Two-wheeler	IEA	International Energy Agency
3W	Three-wheeler	ITS	Institute of Transportation Studies, University of CA at Davis
BEV	Battery Electric Vehicle	ICE	Internal Combustion Engine
CAPEX	Capital Expenditure	LF	Load Factor. Equal to PKT (passenger) or or Tonne-KM (freight) divided by VKT
EI	Energy Intensity - MJ/PKT (passenger) or MJ/Tonne-KM (freight).	LT	Light Truck
EIA	Energy Information Agency, Department of Energy	MER	Market Exchange Rate
GDP	Gross Domestic Product	OPEX	Operating Expenses
GW	Gross Weight (or Gross Vehicle Weight Rating) in Tonnes.	PKM or PKT	Passenger Kilometer Travelled
HEV	Hybrid Electric Vehicle	PNNL	Pacific Northwest National Laboratory
FSU	Former Soviet Union	PPP	Purchasing Power Parity
GUC	Generalized User Cost ($/PKT or $/Tonne-KM)	VKT	Vehicle Kilometer Travelled
HDT	Heavy Duty Trucks.	VOT / VOTT	Value of Travel Time
HSR	High Speed Rail		

1 INTRODUCTION

The Institute of Transportation Studies (ITS) at the University of California, Davis (UCD), and Pacific Northwest National Laboratory (PNNL) embarked upon a project to update and refine the transportation module of Global Change Assessment Model (GCAM, formerly MiniCAM).

GCAM is a long-term, global, technologically detailed, partial-equilibrium model developed and maintained by the Pacific Northwest National Laboratory. It is an integrated assessment model that links representations of global energy supply chains, agriculture, land-use, and climate systems. GCAM runs in 5-years time steps from 2005 through 2095, with energy supply, transformation, and demand modeled at the resolution of 14 world regions. The model calculates equilibria in each time period in all regional and global markets for energy goods and services in three end-use markets – industrial, buildings (commercial and residential), and transportation sectors. It also includes a reduced-form climate model that tracks sixteen greenhouse gases and criteria pollutants, including CO_2, CH_4, N_2O, and SO_2 (Brenkert, Kim et al. 2003).

1.1 Project Objectives

The project broadly encompasses the following three refinements to the transportation sector of GCAM:

1. Increased resolution at which the sector is represented to include the full spectrum of sub-modes and technologies available in passenger and frieght transport;
2. Refined estimates of input parameters so as to better represent real-world heterogeneity in a way consistent with the latest literature on transportation;
3. Refined estimates of base year (2005) estimates of transportation demand, and disaggregation of IEA energy estimates between modes and size classes;
4. Included the non-motorized modes of walking and biking.

The above refinements will not only allow us to develop better estimates of transportation energy demand and emissions, but will also enable modeling of the impact of policies that induce behavioral change and switching of different size classes within a single fuel type. Existing literature on long-term forecasts of transportation energy demand and emissions have focused on the role of advanced low-emission vehicle technologies and low-carbon energy carriers in achieving climate change goals (Schäfer 2012).

In GCAM, modeling the impact of policies in the form of varying levels of carbon prices has, to date, been restricted to consumer choices for different vehicle technologies (e.g. internal combustion engine vehicles versus electric vehicle), and for different mode choices (e.g. car versus rail). A more detailed representation of the transportation sector – including various size classes of vehicles -- will allow us to estimate the potential for downsizing in the case of private modes (large LDV to midsize or compact LDVs), transfer to public modes (rail and bus) or to non-motorized transport (walking and biking), and adoption of energy efficient “new” modes like the electric-bikes and micro (also called ‘mini’, ‘low speed’, or ‘neighborhood’) electric cars – modes which have seen rapid adoption in China and other developing countries.

In addition to carbon price, this project aims to model other policy intruments including subsidies to public transit, government incentives for alternative technology, transportation fuel taxes, and public investments to increase the speed, service frequency/availability, and comfort of public and non-motorized modes.

1.1.1 Purpose of this report

This report serves to achieve the following objectives:

(1) Describe the new transportation module in GCAM;
(2) Detail the data sources and methodology adopted to estimate the exogeneous input parameters;
(3) Compare and contrast these estimates across modes and modes;

(4) Highlight the uncertainty and shortcomings in our estimates.

1.2 Overview of GCAM's transportation module

In this section, we give an overview of the new transportation module in GCAM. The section first describes the disaggregation of the transportation sector. Subsequently, we discuss the key equations that govern the derivation of the price of transportation, determination of overall transportation demand, and allocation of this demand to various modes, size classes, and technologies within each mode.

Table 1.1 summarizes the various modes, size classes, and technologies modeled in the new version of GCAM. The transportation sector is broadly divided into passenger and freight. Long-distance passenger transport serviced by long-distance aviation is treated distinctly from other passenger modes (see Table 1-1). Similarly, long-distance freight serviced by international shipping is independently from freight covered by truck and domestic

Table 1-1:
Summary of modes, size classes and technologies modeled in the transportation sector.

Modes (i)	Size classes (s)	Technologies (j)
Passenger		
Car & Light Truck	The ***car & LT*** mode is disaggregated to four size classes in any given region. There is a total of 9 size classes across all regions.	Liquids ICE, (C)NG, hybrid electric, battery electric, and fuel cell electric vehicles.
Two-wheeler	***Two-wheeler mode*** is typically disaggregated into 2 or 3 size classes. In countries with a small share of two-wheelers, the mode is not disaggregated.	Liquids and battery electric two wheelers. In China, two types of electric bikes are modeled – lithium ion and lead-acid.
Three-wheeler	Relevant only for China, India, Southeast Asia, and Africa.	Liquids and (C)NG three-wheelers
Bus	***Bus*** is not disaggregated into further size classes.	Liquids and (C)NG buses
Passenger Rail	None	Electric and liquids rail.
High Speed Rail	None	Electric
Aviation (short & medium distance)	None	Liquids
Non-motorized	Walking and biking	None
Passenger	**(long-distance)**	
Aviation (long distance)	None	Liquids
Freight		
Freight Truck	Disaggregated into light, medium and heavy freight trucks	Liquids and NG freight trucks
Shipping (domestic, short distance)	None	Liquids
Freight	**(long-distance)**	
Shipping (international, long distance)	None	Liquids
Freight aviation	None	Liquids

shipping.

GCAM's flexible structure allows us to develop heterogeneous sector structures in each region, in order to best represent observed inter-regional diversity in transportation technologies. Thus for example, the car & LT sector is disaggregated into compact-, midsize-, large-, and light truck & SUV-classes in the U.S. In contrast, the Indian car sector is disaggregated to mini-, sub-compact-, compact-, and multi-purpose vehicle classes.

For each region and each of the available combinations of mode, size class, and drivetrain technology, we conducted a detailed literature review to estimate the values of various input parameters, and to calculate the energy consumption and service output in the base year. These input parameters include the levelized non-fuel price ($/VKT), energy intensity (MJ/VKT), load factor (persons or tonnes per vehicle), value of time (VOT) in transit multiplier, and speed. The non-fuel price is built up from a number of components specific to each mode. For private modes like cars and two-wheelers, these components consist of capital costs, operating costs, and fuel taxes. The disaggregation of these cost components will allow us to model the impact of government subsidies towards the purchase of alternate technology cars (e.g. electric car subsidies in the U.S.) or small cars (e.g. the waiver of registration fees for mini or kei cars in Japan), or other similar policies. For public modes like buses and trains, the non-fuel costs are disaggregated into non-fuel operating costs and government subsidies. This will allow us to study the impact of the level of subsidies on, for instance, the mode share of public transit. Figure 1.1 shows the passenger transportation sector (short and medium distance) in the U.S.

1.2.1 Demand for transportation service

The demand for transportation services (e.g. passenger kilometers, tonne-kilometers) is the fundamental driver of future transportation-related energy use and greenhouse gas emissions in GCAM. Demand for passenger transportation (D_p) in region r and future time period t is represented as follows:

$$D_P^{r,t} = \sigma^r (Y_I^{r,t})^\alpha (P_I^{r,t})^\beta (N_I^{r,t}) \quad (1\text{-}1)$$

Where σ is a base year (2005) calibration parameter. Y_I is the index for income in the form of per-capita GDP (defined on a

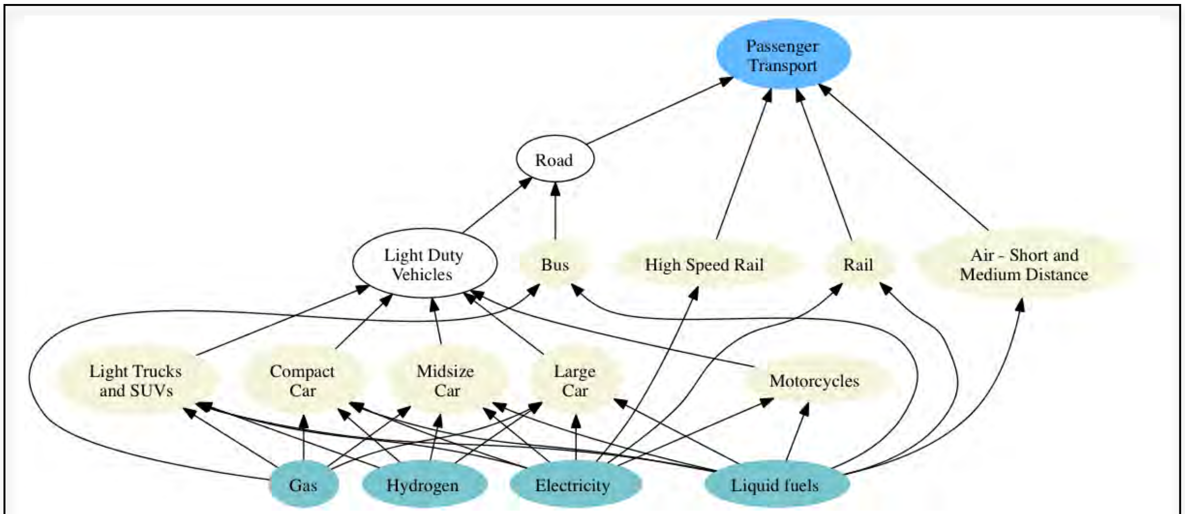

Figure 1-1

Structure of passenger transportation in the U.S. (long distance aviation is not shown in this diagram).

purchasing power parity basis) at time "t" divided by the per-capita GDP in the base year (2005), P_I is the index of price of transportation (or generalized user cost) aggregated across all modes, size classes, and technologies and calculated as the ratio of price in time "t" to the price in base year. N_I is the population in region r, in time t. Finally, *α* and *β* are income and price elasticities, respectively, with respect to per capita passenger demand (Kyle and Kim 2011).

Demand for freight transportation (D_F) in region *r* and future time period *t* is estimated with a very similar equation:

$$D_F^{r,t} = \sigma^r (GDP_I^{r,t})^{\alpha'} (P_I^{r,t})^{\beta'} \quad (1\text{-}2)$$

Demand for freight transportation is determined at an economy-wide level, unlike passenger transportation where it is estimated on a per capita basis and then aggregated across the entire population. Hence, income is represented by the index of total GDP. The Income and price elasticities of freight demand are designated by *α'* and *β'* respectively.

For both passenger and freight demand equations, region-specific GDP (PPP) and population are defined exogenously in GCAM. Income and price elasticities are also defined exogenously and discussed later in this chapter. The price of passenger and freight travel is endogenous and is discussed further in the following section.

1.2.2 Price of transportation service

The price of transportation service, which may be inter-changeably referred to as the generalized user cost, captures the economic and time costs faced by passengers. For freight movement, it captures the economic costs only.

The total generalized cost of transportation services (*P*, in \$/PKT or \$/Tonne-KM) is derived as the weighted average cost of each available mode:

$$P^{\,r,t} = \sum_i (S^i)(P^{\,i,r,t}) \quad (1\text{-}3)$$

where S^i is the share of mode (*i*) in terms of passenger-KM or Tonne-KM.

The costs by mode are calculated as the weighted average costs of all constituent size classes plus the time value costs (value of travel time; VTT) associated with the mode. All size classes and propulsion technologies within a given mode have the same time value cost.

$$P^{\,i,r,t} = P_{time}^{i,r,t} + \sum_i (S^s)(P^{\,s,i,r,t}) \quad (1\text{-}4)$$

where S^s is the share of size class (*s*) under mode (*i*) in terms of passenger-KM or Tonne-KM.

Time value costs are indicated as follows:

$$P_{time}^{i,r,t} = \delta^i \frac{W^{r,t}}{Sp^{i,r,t}} \quad (1\text{-}5)$$

Where *W* is the wage rate (\$/hour)[1] calculated from the per capita GDP; *Sp* is the average door-to-door speed of mode *i* (KM/hour), which varies by mode, region and time; and *δ* is a unitless parameter representing the cost associated with travel expressed as a multiplier of the wage rate (value of time, or VOT). The VOT multiplier is positive – indicating that passengers dislike travel and consider it a disutility. The time cost of travel is currently only associated with passenger transportation in

[1] Note that we consider a uniform wage rate for all modes and size classes – although it may be argued that users of modes may differ in terms of socio-economic characteristics. For example, median income of bus riders in the U.S. is one-third the national income; while rail riders' income is slightly higher than national income Buehler, R. and J. Pucher (2012). "Demand for Public Transport in Germany and the USA: An Analysis of Rider Characteristics." Transport Reviews **32**(5): 541-567.

Similarly, the size-classes in private road transportation may be positively correlated with income (Shires, J. D. and G. C. de Jong (2009). "An international meta-analysis of values of travel time savings." Evaluation and Program Planning **32**(4): 315-325.

GCAM, though a recent meta analysis (Zamparini and Reggiani 2007) provides region- and mode-specific estimates of P_{time} for the freight sector that could be incorporated in future work.

The inclusion of time value costs into the costs of the passenger modes tends to counteract, to some extent, the effect of income on future demand growth, and it also tends to shift the modal composition towards high-speed modes (e.g. air, high-speed rail) as incomes rise. This is consistent with the observed historical trends (Schafer and Victor 1999).

The costs for each size class (*s*), in turn, are calculated as the weighted average costs of all constituent technologies (*j).*

$$P^{s,i,r,t} = \sum_i (S^j)(P^{j,s,i,r,t}) \tag{1-6}$$

Finally, technology costs may be broken down in fuel costs and non-fuel costs:

$$P^{j,s,i,r,t} = \frac{(P^{r,t}_{fuel})(EI^{j,s,i,r,t}) + P^{j,s,i,r,t}_{NF}}{LF^{i,r,t}} \tag{1-7}$$

Where, P_{fuel} is the fuel price ($/MJ), *EI* is the vehicle energy or fuel intensity (MJ/VKT), P_{NF} is the non-fuel price of transportation for the given mode, and *LF* is the load factor defined either as passengers per vehicle or tonnes per vehicle.

Fuel prices are endogenous, and include any carbon emissions penalties (when emissions are priced); all other variables are exogenously specified for each technology and in each time period. The non-fuel cost represents all other costs (other than time costs) faced by the passenger or freight transporter.

The non-fuel price (P_{NF}) of transportation is estimated using two alternative methods.

- For private modes like cars and two-wheelers, a bottom-up approach is adopted where we estimate the purchase cost of vehicles (including taxes and registration fees) as well as variable and fixed annual operating costs. These costs are then "levelized" to $/VKT and $/PKT based on annual VKT per vehicle and load factors (LF).
- For public modes like trucks, buses, air, rail, and ships, we adopt a top-down method whereby the sum of fares and government subsidies are assumed to capture all economic costs – capital & depreciation, financing, and operating (including fuel) costs. We remove the fuel costs to estimate P_{NF} for each mode / region / time.

The report documents assumptions made about the evolution of P_{NF} over the forecast period (2005-2100).

1.2.3 Market shares

In determining market shares of each mode for each region and time period (or size class), technology is endogenous, and determined using a calibrated logit formulation (Kim, Edmonds et al. 2006; Kyle and Kim 2011), shown below:

$$S^{i,r,t} = \frac{(SW^{i,r})(P^{i,r,t})^{\lambda_i}}{\sum_i (SW^{i,r})(P^{i,r,t})^{\lambda_i}} \tag{1-8}$$

where *S* is the market share, *SW* is the share weight, *Pi* is the cost of transport service (as in Equation 2) for a mode *i*, and *λ* is the logit exponent. The share weight is a calibration parameter, and the logit exponent regulates the degree to which future price changes will be reflected in modal shifts.

This methodology is used to determine market shares of (i) various technologies within a size class, (ii) various size classes within a given mode, (iii) various modes.

1.3 Time cost of travel and VOT multiplier

The time cost of travel or value of travel time (VOT) is estimated in the transportation literature either in monetary terms ($/hour) (Shires and de Jong 2009; Abrantes and Wardman 2011), or as a multiplier of wage rate (Zamparini and Reggiani 2007). For the current project, we are interested in the latter representation for two reasons:

(a) *Inter-temporal income elasticity of travel costs*: Within any region, a rise in income over the forecast period will lead to changes in travel costs. This is consistent with results from studies estimating inter-temporal income elasticities (Börjesson, Fosgerau et al. 2009; Abrantes and Wardman 2011).

(b) *Cross-sectional income elasticity*: Travel costs are expected to differ across regions because of differences in income levels (Shires and de Jong 2009). Nearly all studies on travel time costs are based on developed countries; and the estimated travel costs ($/hour) are unlikely to be applicable for developing countries where average incomes are substantially lower.

1.3.1 VOT multipliers for developed countries

The mode-specific VOT multipliers (δ) for developed regions adopted by us for GCAM have been taken from (Zamparini and Reggiani 2007), and are summarized in Table 1. These VOT multipliers are for in-vehicle travel (IVT); for public modes, these multipliers need to be adjusted for time spent waiting for these modes. For bus and trains, the average wait time for intra-city bus and train was around 26% and 12% of average total trip time respectively based on the 2001 National Household Travel Survey in the U.S. (Polzin and Chu 2005). We assumed that inter-city bus and train have similar wait time. Assumptions about wait times (or ratio of wait time to IVT) may be adjusted as part of any scenario analysis investigating the impact of investments in public transits on transportation demand.

For air travel, we assume 2.5 and 4 hours of additional time per domestic and international trip respectively – these hours represent time for airport ingress and egress, transfer time, customs and immigration clearance, etc. Based on average trip time from BTS Airline Statistics, the non-flying time is 54% and 42% of total domestic and international trip time respectively.

These estimates of non-flying time, especially for international trips, seem quite high. This may be partly explained by the fact that BTS Statistics only consider U.S. based airlines and not international airlines that fly to/from the U.S. Since, the assumed VOT for out-of-vehicle time is close to the VOT for in-vehicle time of air trips, the weighted average ratio for air is not substantially affected.

There is no VOT wait time for Walk/Bike modes.

Table 1-2

Assumed mode-specific VOT for developed regions

	IVT VOT	Average Out-of-Vehicle time*	Adjusted VOT
Car & Light Truck	0.82	0%	0.82
Bus	0.77	26%	0.89
Train	0.77	10%	0.82
HSR**	0.77	10%	0.82
Domestic Air	1.45	54%	1.33
International Air	1.45	42%	1.36
2-wheeler+	0.82	0%	0.82
3-wheeler+	0.82	0%	0.82
Walk++	1.07	0%	1.23
Bike++	1.07	0%	1.23

* Percent of total trip time

** HSR values are assumed to be same as passenger rail

+ 2-wheelers and 3-wheelers have same VOT as cars and light trucks

++ Walking time VOT is assumed to be 50% higher than Cars and Light Trucks – slightly lower than 65% – as indicated by (Abrantes and Wardman 2011). Biking VOT is assumed to be same as Walking.

1.3.2 VOT multipliers for developing countries

There are only a few studies covering developing regions' value of travel time. As a result, we adopt the values from the above table, but make two adjustments. Because public transit and non-motorized modes in developing regions has fewer amenities and higher occupancy rates in comparison to the same in developed regions, we assume that in-vehicle travel VOT is 15% higher. This is consistent with literature, which indicates a higher travel cost (disutility) with “unpleasant” conditions (Litman 2011). For non-motorized modes we similarly changed the VOT multipliers. This may be justified by, inter alia, poor quality roads especially for pedestrian and bicycle traffic and higher risk of accidents.

Further, given the aspirational values associated with ownership of vehicles, we assume a 15% lower VOT for cars and 2-wheelers.

1.3.3 Shortcomings

Our approach to computing time costs has four key shortcomings, which we hope to address in our future work.

(1) Travel liking
Equation 1-5 essentially assumes a linear relationship between travel time and travel costs that passes through the origin. However, a number of studies (including many conducted at the University of California Davis) have concluded that people may actually derive positive utility from travel due to a variety of reasons like adventure seeking, variety seeking, and independence (Mokhtarian and Chen 2004; Ory and Mokhtarian 2005).

Incorporation of such travel liking will reduce the average generalized user cost of transportation, and increase total travel.

(2) Trip purpose
In GCAM, transportation demand is not analyzed at the trip level. However, the disutility associated with travel depends on the purpose of the trip with commuting and business travel having a higher disutility (VOT multiplier or δ) than personal or leisure trips (Zamparini and Reggiani 2007). The VOT multiplier adopted in GCAM may be considered the weighted average disutility from all trip types.

The share of personal / leisure trips increases with income as witnessed in the U.S. (Schäfer, Heywood et al. 2009). Per the National Household Travel survey, commuter trips accounted for 22% of total trips in 2009, down from 31% in 1969. In terms of annual household Vehicle Kilometers Traveled (VKT), the share of commute trips fell from 34% to 28% in the same time period (Santos, McGuckin et al. 2011).

Assuming that such a trend could be extrapolated to developing countries like India and China, the share of personal trips will increase and the weighted average VOT multiplier should decrease during the forecast period. This will reduce the user cost and increase the overall transportation demand.

We have not incorporated this trend and assumed that VOT multiplier remains constant over time.

(3) *Variability of wage rate*
A uniform wage rate is assumed for all modes of travel (and is equal to the per capita GDP PPP divided by 2000 hours). However, it may be reasonably argued that the income level of an average bus or rail traveler is different from that of an average car or air traveler (Zamparini and Reggiani 2007).

Buehler and Pucher (2012) reviewed the results of national travel surveys in Germany and the U.S. and found that in 2008-2009, bus and rail passengers in Germany had the same median income as each other and the national average. In contrast, in the U.S., bus passengers’ income was one-third the national average; while rail passengers had higher income than national average.

We do not consider such differences and assume a uniform wage rate across all modes within a given region for any specific year.

(4) Spatial heterogeneity
We assume that all developed and developing countries have the same mode-specific VOT multiplier. However, there are likely to be differences between regions. Zamparini and Reggiani (2007) found that the overall VOT multiplier is higher for

Centre-South Europe (Germany, Netherlands) in comparison to North Europe (UK, Sweden, etc.). North America and Australia had the lowest figures. The differences may be partly explained by the relative shares of different modes – i.e. by the higher share of public transit modes in Europe relative to North America and Australia. But differences in VOT may also highlight differences in attitudes and/or quality of service. For example, Germany has a higher quality of public transit service compared to the U.S. in terms of in-vehicle amenities and level of coordination of schedules and routes across modes & operators (Buehler and Pucher 2012). As a result, the perceived time cost is likely to be lower in Germany compared to the U.S.

1.4 Speed of travel

Travel speeds for passenger modes are required to calculate time costs as given in equation 1-5. Our methods, assumptions, and data sources are given below. The final assumed speeds are listed in Table 1-3

a) **Private modes:**
For the U.S., *car and light truck speeds* are based on Schafer and Victor (1999) and Davis, Diegel et al. (2011). These studies have estimated nationwide-average car travel speeds from National Household Travel Surveys. We assumed that two-wheelers have same speed as cars and light trucks. For low powered two-wheelers (mopeds), we assumed that speeds are 75% of speed of regular two-wheelers (scooters and motorcycles)

b) **Public Transit:**
For *public transit* in the U.S., the speeds are based on Polzin and Chu (2005). The speeds were adjusted for average mode-specific waiting time, which can range from 52% of total trip time for intra-city buses to less than 20% for commuter rail. Based on relative shares of sub-sectors (like commuter, heavy, light and intra-city rail; and intra-city and inter-city buses), we calculate the weighted average mode-specific door-to-door speeds.

c) **Domestic and International Air**
The gate-to-gate speed for all U.S. airport based domestic and international air travel (650 and 760 km/hour) are based on data from BTS (BTS 2012). Assuming an out-of-vehicle time of 2 and 4 hours for domestic and international air trips, respectively (airport ingress and egress, baggage collection, check-in, security, customs and immigration, etc.), the door-to-door speed drops to 300 and 450 km/hour for domestic and international air, respectively. Travel to/from airport is counted under road and rail travel and not considered for speed calculations.

We adopted the above speeds from the U.S. for other developed countries except for Western Europe and Japan. For these countries, we assumed lower speeds for road-based travel, similar to Schafer and Victor (1999).

For developing countries, we assumed that speeds of private road modes – car and two-wheeler are 60% and bus speed is 50% of the level of U.S. Air speed is assumed to be 75% - this lower airspeed accounts for poorer airport infrastructure and hence longer out-of-vehicle time and ground inefficiencies when the plane is not in the air.

Table 1-3

Assumed door-to-door speeds

	Car & 2W+	Bus	Rail (HSR)++	Air (D)	Air (I)
US, Canada, ANZ	55	42	42 (175)	302	450
Korea, Japan, West Europe	47	35	42 (175)	302	450
All others	33	22	42 (175)	225	340

+ For less powerful two-wheelers like moped in India and lead-acid electric bikes in China, we assumed slower speeds.
++ HSR is not present in all regions in the base year. For the U.S., the speed of HSR

(Amtrak's Acela Express) in 2005 is taken as 120 km/hour, but assumed to increase to 175 in future.

We also assumed that alternative technology road vehicles would have the same speed as the conventional technology (Internal combustion engine).

Speeds are assumed constant over time at present, but that this could be modified to model scenarios wherein the speeds of travel do evolve over time.

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2 Introduction to the Roads sector

The roads sector encompasses the following five modes – car and light truck (or simply cars), two-wheeler, three-wheeler, bus, and freight truck. The five modes need to be handled simultaneously because the GCAM model base year estimates are calibrated to International Energy Agency (IEA)'s World Energy Statistics (IEA 2007)[1]. IEA's road energy statistics are not disaggregated between different sectors / modes (car, two-wheeler, three-wheeler, bus, and truck). Neither are they divided between freight and passenger road transportation.

In this chapter, we discuss various issues that are relevant to all the road-based modes.

2.1 Calibration with IEA Road Energy Statistics

2.1.1 Methodology

We review the literature to estimate the transportation service, energy consumption and energy intensity of each mode/size-class in the base year (2005). The following equation gives our bottom-up estimate of energy consumption:

$$\sum_i \sum_s E^{s,i} = \sum_i \sum_s (T^{s,i})(EI^{s,i}) \qquad (2\text{-}1)$$

where,

E is energy in PJ,

T is road transportation service and in units of either passenger-kilometer or tonne-kilometer,

EI is the energy intensity i.e. MJ/PKM or MJ/TKM (stock-average),

Subscripts *i* and *s* represent the *mode* and *size class within a given mode*, respectively.

[1] The 2005 statistics reported in this report are based on calibration to 2007 version of IEA's World Energy Statistics (henceforward reported as IEA Energy Statistics).

Our bottom-up energy estimate $\sum\sum E^{s,i}$ is then calibrated to match IEA energy statistics by either (i) fixing the Energy Intensity (EI) values collected from literature and scaling up or down the transportation services for all road modes; or alternatively (ii) keeping the total transportation service fixed and scaling up or down the EI. The choice between the two approaches depends upon region / mode. For example, in the case of the U.S. LDV sector, the total transportation service is based on U.S. Department of Transportation Statistics (U.S. DOT 2012), while the *EI*s for each mode and size class are based on estimates by the American Automobile Association (AAA 2012). The total road sector energy estimates by U.S. DOT and IEA Energy Statistics are very close. Given the high level of confidence in U.S. DOT's transportation service estimates, we scaled up AAA's EI by around 15% to ensure that bottom-up $\sum\sum E^{s,i}$ estimates match IEA energy estimates.[2]

An alternate example is ANZ – our EI estimates are based on driving costs in Australia (NRMA 2011), and we allowed the scaling of PKM and TKM to include transportation in New Zealand. Further, the EI estimates for Australia are an average of EIs of all (or most) makes/models sold in that segment, unlike the estimates from AAA for the U.S. where only the top five make/models are considered.

2.1.2 Region-specific adjustments

1. Africa
   There is limited information about service estimates and Energy Intensity (EI) in the base year for nearly all the road-based modes. We adopted the following methodology for Africa for base year calibration (i) We breakup total road energy between road passenger (cars & light trucks, two-wheelers, three-wheelers and bus combined), and road freight based on International Energy Agency's MoMo

[2] Our weighted average EI for all cars and light trucks matches BTS estimates.

Model (IEA 2012)[3] and International Council for Clean Transport (ICCT)'s Roadmap model (ICCT 2012) (ii) We disaggregate travel demand (PKT) between modes based largely on personal discussions with Dr. Andreas Schafer (UCL Energy Institute, London). (iii) We adopted the same size classes for cars & light trucks as India and assumed that Energy Intensities and share of base year travel are similar to India. Other parameter values like load factors and monetary costs were also adopted from India.

2. Australia and New Zealand (ANZ)
   We did not find any information on New Zealand's road sector composition and energy consumption. As a result, our estimates are based on detailed statistics available for Australia. We adopted EIs, Load Factors (LF), share of modes/size classes in energy consumption, etc. from Australia. Passenger and freight service estimates for base year were calibrated based on IEA energy statistics for the entire region.

3. Canada
   No issues. Small differences in total road energy estimates resolved by adopting EI and LF from literature, and scaling up or down the service level in base year to calibrate to IEA total energy estimates.

4. China
   Our estimate of total bottom-up road energy consumption for China in 2005 is more than twice the IEA estimate. In the current version of the model, we adopted EIs from relevant literature and scaled down the service estimates calibrated to IEA energy statistics (i.e. cut them roughly in half). In the future, we plan to expand the energy consumption by China's road sector instead of calibrating to IEA estimates. Moreover, the IEA is currently re-evaluating and most likely will update its data for China's road fuel consumption to more accurately reflect credible consumption (i.e. substantially higher) estimates.

5. Eastern Europe
   Our bottom-up energy consumption estimates for Eastern Europe, largely based on the TREMOVE model (EC 2010), is around 30% lower than IEA. The TREMOVE database covers all countries in Eastern Europe except Bosnia and Herzegovina, Macedonia and Yugoslavia. However, we do not believe these countries could account for 30% of the region's road energy consumption.

   We adopt the EI and LF from TREMOVE, and we scale up the service estimates while calibrating to IEA road energy estimates.

6. FSU
   EI and monetary cost estimates are largely based on Europe.

7. India
   Same as China. See Section 2.4

8. Japan
   Same as Canada.

9. Korea
   No issues.

10. Latin America
    Data availability (uncertainty) and variability across regions is a concern. Quality of input data could be substantially improved.

11. Middle East
    Data availability and variability across regions is a concern. The methodology adopted is similar to Africa (see above). Vehicle size classes and energy intensities are partly based on various publications focused on Iran, and partly by adopting statistics from other regions.

12. South East Asia
    Same as Africa above.

13. U.S.A.
    Same as Canada.

14. Western Europe

[3] We should note that IEA MoMo database is different from the IEA World Energy Statistics.

Same as Canada.

2.2 NG - vehicle stock and fuel consumption in base year

Based on national statistics of NG vehicle stocks (Palmer, Hill et al. 2010; NGV Global 2012), and disaggregation of NG vehicles into specific modes (Orlov and Kozak 2006), we estimated the penetration of NG vehicles in various countries / regions.

The following table gives the share of NG vehicles in the total transportation service provided by various modes in 2005 in each of the 14 regions in GCAM.

Table 2-1 :
Share of NG vehicles in transportation service provided by various modes in 2005

	Car	Bus	Truck
Africa	0.86%	0.04%	0.04%
ANZ		9.04%	
Canada	0.06%	1.85%	
China*	0.25%	2.17%	<0.001%
EE		1.49%	
FSU	0.02%	1.16%	1.26%
India*	1.56%	4.94%	0.02%
Japan			
Korea	0.03%	6.60%	
LatAM	8.95%	1.48%	
ME	1.05%		
SE Asia	0.34%	1.09%	
USA		7.59%	
West EUR	0.00%	3.77%	

* Shares before calibration to IEA energy statistics

2.3 Non-fuel costs

The non-fuel price P_{NF} of transportation is calculated using two alternative methods. For cars, two-wheelers, and three-wheelers, a bottom-up approach is adopted where we estimate the purchase cost of vehicles (including taxes and registration fees) as well as variable and fixed annual operating costs. These costs are then "levelized" to $/VKT and $/PKT based on annual VKT per vehicle and load factors. The method is discussed in detail in Chapter 3.

For trucks and buses (and also railways and airlines), we adopt a top-down method. In this method we calculate P_{NF} based on reported operating expenses and operating revenue. In the case of bus, a number of countries report average fares and operating expenses on a $/PKT basis. In the case of trucks, we reviewed the literature for

Table 2.2:
Estimates of road-based transportation service in India in 2000

	Schipper, Banerjee et al. (2009)	Singh (2006)	Zhou and McNeil (2009)	Arora, Vyas et al. (2011)	Srivastava, Mathur et al. (2006)	ICCT (2012)	IEA Energy Statistics
Total Road PKT (Billion)	**2,123**	**3,079**	**3,255**		**1,650**	**1,975**	
Share of road-modes in total road PKT							
- Cars	10%	9%	9%		6%	6%	
- 2W	14%	12%	12%		15%	18%	
- 3W	4%	3%	3%		7%	9%	
- Buses	73%	76%	76%		72%	67%	
Energy Consumption (PJ)							
- Passenger road		954	~1,050	~920		847	
- Road freight			1,100 to 2,200	~1380		902	
- Total PJ			2,150 – 3,250	~2,300		1,749	~1,100

average freight rates ($/Tonne-KM). Operating expenses include fuel costs; we exclude those to derive P_{NF}. It should be noted that annualized operating expenses and/or fares already encompass purchase (P_{CAPEX}) costs through depreciation (a proxy for purchase costs), and annual interest payments and net profits (a proxy for financing costs).

In the case of Western Europe, we were able to calculate both top-down and bottom-up costs for buses and trucks from different data sources and the derived values were very similar – the discrepancy did not exceed 10% (see relevant chapters).

2.4 Uncertainties

We ignore many of the uncertainties associated with estimates of transportation service and energy consumption, as well as values of various other input parameters, for the base year 2005. Such uncertainties are especially large for developing countries like India and China; and for the road sector.

Our estimate of any given variable is usually based on review of a number of studies for the region and identification of a mid-point or median value. In some cases, the authors relied upon their experience (or perhaps personal biases) to select a value that may not be a median estimate (example: load factors for cars and two-wheelers in India).

In this section, we focus on two countries – India and China – and highlight the range of estimates for the base year.

2.4.1 India

Table 2.2 summarizes the estimates of total road transportation demand (PKT and Tonne-KM) and energy consumption for year 2000.

The IEA energy estimates, to which the GCAM model is currently calibrated, is around 50-75% of the estimates by other studies relying on a bottom-up methodology to estimate energy consumption and emissions from the transportation sector.

2.4.2 China

Table 2.3 summarizes the estimates of total road transportation demand (PKT), vehicle-kilometers-travelled (VKT), and energy consumption (PJ). Similar to the case of India, IEA energy estimates are lower than those of recent bottom-up studies. In fact, the IEA is currently working with Chinese counterparts on reassessing survey

Table 2.2:
Estimates of road-based transportation service in China in 2005

	China Ministry of Transport (2011)	FEEI (Huo and Wang 2012)	IEA MoMo (IEA 2012)	IEA Energy Statistics (IEA 2007)	ICCT (2012)	Our Estimates
Total Road PKT (Billion)	**9,292**				**6,368**	
Total Road Tonne-KM (Billion)					996	
Energy Consumption (PJ)						
Passenger road						
- Car		1,475	933		1,504	984
- 2W			458		377	745
- Bus		1,521	900		2,070	1,602
Road Freight						
- 3W Rural			48			541
- Trucks		2,933	2,037		2,725	2,455
Total		**~5,930**	**~4,375**	**~3,865**	**6,678**	**6,328**

instruments for gasoline consumption estimation and on reapportioning diesel demand among en-use sectors. We expect that future IEA estimates will be more in line with those of other researchers in the near future.

2.4.3 Other Regions

For Middle East, IEA road energy consumption estimate is around 4,000PJ. The corresponding numbers per IEA MoMo model and ICCT Roadmap are around 2,500 PJ and 2000 PJ respectively. For Eastern Europe, the differences in estimate are of a much lower magnitude. IEA road energy estimates are around 1,500 PJ. The corresponding figure from TREMOVE is less than 1,200 PJ.

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3 CAR & LIGHT TRUCK

The following section discusses various aspects of the methodology adopted for the car and light truck mode across the GCAM regions.

3.1 Disaggregation of cars & light trucks

We segment the car & light truck mode in each region into four size classes primarily based on size as proxied by engine displacement. For each size-class, we reviewed the literature to estimate the following parameters for the base year: (i) total passenger kilometers travelled (PKM), (ii) load factor (average number of occupants per car), (iii) fleet average Energy Intensity (EI), (iv) annual average vehicle kilometers traveled (VKT), and (iv) non-fuel costs, i.e. capital, financial, and non-fuel operating costs. Further, we define the configuration of a representative liquids Internal Combustion Engine (ICE) car for each size-class (specifically engine displacement, power and curb weight)

The size classes may vary across regions. For example, the U.S. car market is segmented into four size classes: compact, midsize, and large cars, and light trucks and SUVs. The reference compact car profile is based on the Honda Civic (2010 model). In India, the four sub-segments are mini, subcompact, and compact cars, and multipurpose vehicles.[1]

3.1.1 Data Sources for disaggregated statistics:

Disaggregated statistics are available for some regions like Western and Eastern Europe (EC 2010) and Canada (Transport Canada 2012). For some countries, we used information on vehicle stock to calculate the share of PKM of various size-classes – examples include the U.S. (Davis, Diegel et al. 2011) and Japan (JAMA 2011)[2]. If disaggregated vehicle stock information was not available, we used vehicle sales statistics over the available number of years. Examples include India (Arora, Vyas et al. 2011), FSU (Ernst & Young 2007, Cuenot and Fulton 2011, Nureev and Kondratov 2011), South Korea (KAMA 2003, KAMA 2006), and Australia (Australian Government 2008).

In the case of China, we used analysis conducted by one of our authors for the IEA's Energy Technology Perspectives Transportation group during 2012 focusing on China's light-duty market and road sector in general. This research draws most heavily on proprietary data from Segment Y and from Wards, as well as a series of papers published by Hong Huo from Tsinghua University in Beijing and co-researchers (Huo, Wang et al. 2011, Huo, Yao et al. 2011, Huo, He et al. 2012, Huo and Wang 2012, Huo, Wang et al. 2012, Huo, Zhang et al. 2012)

For Latin America, we used vehicle stock information for Brazil (Fouto and Franciscol 2011)[3] and sales information for other

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[1] The following criteria was used to segment the market – mini car: below 1000 cc; subcompact car: 1,000-1,500 cc; compact car: 1,500-2,000 cc; midsize car: 2,000 cc to 2,500 cc; large car: above 2,500 cc. Additional segments include Large Car & SUV, Van, and Multipurpose Vehicle (MPV).

[2] The implicit assumption is that annual VKT is same across all sub-segments. We acknowledge that may not be a very good assumption. For example, in the U.S., light trucks & SUVs have an annual VKT of 20,000 km versus around 17,500 for cars in general (Davis, Diesel, et al. 2011). Similarly, in Canada, cars in general average an annual 15,000 km versus 17,500 for light trucks and SUVs (Transport Canada 2012). In China, private cars average about 17,000 km per year, while business vehicles travel about 22,000 km and taxis around 95,000 km. To the extent that business vehicles tend to be larger, and private cars and taxis are mid-sized and smaller, this is likely to skew the size-specific VKT. Similarly in Japan, the Kei (mini) cars are largely used for intra-city driving and hence likely to have lower annual VKT than larger cars.

[3] The paper by Foutol and Franciscol (2012) highlights the pitfalls of using vehicle sales

Table 3.1: Car sector and assumed sub-segments

	Market Sub-segments	Engine displacement (Liters)	Curb Weight (Tons)
Africa	Assumed same as India		
ANZ	Compact, Midsize, Large, and Light truck & SUV	1.8, 2.3, 3.5, 3.5	1.2, 1.5, 1.9. 2.0
Canada	(Midsize) Car, Van, Light Truck & SUV	2.4, 3.5, 3.5	1.5, 1.9, 2.0
China	Mini, Subcompact, Compact, Large car & SUV	0.8, 1.3, 1.7, 2.5	0.65, 1.1, 1.3, 1.7
EE	Subcompact, Compact, Van, Large car & SUV	1.2, 1.8, 1.8, 2.4	1.1, 1.2, 1.3, 1.6
FSU	Subcompact, Compact, Midsize, Large car & SUV	1.4, 1.6, 2.0, 3.8	1.2, 1.3, 1.6, 2.1
India	Mini, Subcompact, Compact, Multipurpose vehicle	0.8, 1.2, 1.5, 2.3	0.7, 1.0, 1.2, 1.7
Japan	Mini, Subcompact, Compact, Large car & SUV	0.65, 1.2, 1.4, 2.8	0.6, 1.1, 1.3, 2.3
Korea	Subcompact, Compact, Large, and Light truck & SUV	1.4, 1.6, 3.0, 3.5	1.1, 1.2, 1.6, 2.1
LatAM	Subcompact, Compact, Midsize, Large car & SUV	1.0, 1.5, 2.0, 3.5	0.9, 1.1, 1.5, 1.6
ME	Mini, Subcompact, Compact, Large car & SUV	0.8, 1.2, 1.5, 2.3	0.7, 1.0, 1.2, 1.7
SE Asia	Assumed same as India		
USA	Compact, Midsize, Large, and Light truck & SUV	1.8, 2.3, 3.5, 3.5	1.2, 1.5, 1.9. 2.0
W. EUR	Compact, Midsize, Van, Large car & SUV	1.4, 1.8, 2.0. 2.1	1.1, 1.3, 2.4, 2.6

countries from the Global Fuel Economy Initiative (Cuenot and Fulton 2011) and various Latin America focused reports by BBVA Research. For the Middle East, we relied on total car registrations from the World Bank. For Iran, which had about 40% of the cars in the Middle East GCAM region in 2005, details of market sub-segments are discussed by Houri Jafari and Baratimalayeri (2008).

3.2 Alternative car technologies

For each car sub-segment, we build configuration profiles for four different alternative technologies – compressed natural gas ICE (NG), Hybrid Electric Vehicle (HEV), Battery Electric Vehicle (BEV), and hydrogen powered Fuel Cell Electric Vehicle (FCEV). The alternative cars are assumed to provide the same "utility" as the ICE equivalent – this manifests itself in form of similar curb (kerb) weight (CW) and "equivalent" engine/motor power as the reference ICE vehicle.

As an example, the following table gives the profiles of a mini (Kei) car in Japan. The profile of a Kei Liquids ICE is based on the Daihatsu Mira and the Honda NBox (both 2010 models). The corresponding profiles of alternative technology cars are calculated based on relationships described later in this chapter.

Table 3.2: Configuration of Mini (Kei) car in Japan

	Liquid	NG	BEV	HEV	FC-HEV
Engine (cc)	650				
CW (kg)	621	661	641	673	804
Power (HP)	58	58			
Power (kW)	43	43			39
Range (km)			100		400
Battery (kWh)			12.64	0.75	0.76
H2 fuel tank (kWh)					72.89
EI (MJ/km, 2005)	1.80	1.82	0.47	1.35	0.93
Life (years)	15	15	15	15	15

statistics for a few years as a proxy for share of various sub-segments in overall vehicle registrations in a rapidly changing market. In Brazil, the share of Mini Cars (1000 cc) in annual sales increased from 5% in 1990 to 80% in 2000 and 47% in 2009.

For the alternative technologies, we review literature for (i) EI, (ii) capital and non-fuel operating costs. These values will depend upon the vehicle size / segment. We assume that vehicle load factors and annual VKT for alternative technology cars are the same as that of ICE cars.

One uncertainty not addressed in the literature is the issue of differences in cost of advanced technologies between developed and developing countries. We assume that cost of key components – the battery, hydrogen fuel cell, and hydrogen storage will be same globally, implying a global market for these technologies as well as learning spillovers. Publicly available details about cost of BEVs in China (BYD) and India (Reva) indicate similar levels of battery costs as indicated in literature as well as those derived from costs of various electric cars launched in 2011 and 2012 (see BEV section for more details).

3.2.1 HEV and CNG in the base year

To calculate the share of HEVs in 2005, we relied on the country-wise stock of Toyota Prius.[4] Statistics on the total stock of CNG vehicles in each region are taken from NGV Global (2012), and the breakup of NGV vehicles in a region into cars, buses and trucks are based on Orlov and Kozak (2006).

3.3 Car & light truck non-fuel costs

The following section describes the non-fuel component of Generalized User Cost of car and light truck. The same principles apply to other modes where a bottom-up approach has been adopted – 2W and 3W.

Vehicle non-fuel ownership costs are divided into four components:

a) Purchase costs – including depreciation and financing costs
b) Non-fuel annual operating costs including both fixed and variable components
c) Fuel taxes
d) Infrastructure costs

[4] As published in Wikipedia http://en.wikipedia.org/wiki/Toyota_Prius

Depreciation and financing costs and certain parts of annual operating costs are fixed – they do not vary with vehicle use. In GCAM, we represent transportation costs (as well as various other parameters like energy intensity) on a per PKT basis (or per Ton-KM in case of freight) – this implies that the level of transportation costs ($/PKT) is sensitive to assumed annual VKT (VKT per vehicle per year). However, assumptions about annual VKT vary considerably in literature especially for developing countries. For example, Arora, Vyas et al. (2011) indicate that estimates of annual VKT for cars in India (personal car) range from 10,000 to 15,000 km. This implies that purchase and fixed annual costs can reduce by 33% if we change our assumption from 10,000 km (based on Arora, Vyas et al. (2011)) to 15,000 km. Similarly, for Australia, NRMA assumes 15,000 annual VKT to calculate vehicle ownership costs while statistics based on survey (Australian Government 2008, ABS 2011) indicate an annual VKT for 12,300 km. We assumed the latter figure.

The non-fuel costs are given by (we remove the subscripts *i*, *j*, and *k* for simplicity):

$$\boldsymbol{P_{NF}^{Car}} = (\boldsymbol{P_{CAPEX}^{Car}} + \boldsymbol{P_{OPEX-Fuel}^{Car}}) + \boldsymbol{P_{Fuel\,Tax}^{Car}} \tag{3-1}$$

Total non-fuel vehicle ownership costs $\boldsymbol{P_{NF}^{Car}}$ (in terms of $/PKT) includes vehicle purchase costs ($\boldsymbol{P_{CAPEX}^{Car}}$), non-fuel operating costs ($\boldsymbol{P_{OPEX-Fuel}^{Car}}$), and fuel taxes.

3.3.1 Vehicle purchase costs

Vehicle purchase costs include the pre-tax price of a vehicle and various taxes, fees and/or subsidies, which vary by region and may also vary by vehicle sub-segments. For pre-tax prices, we reviewed manufacturers' region-specific website for the selected representative car. For example, we adopted Honda Civic as a representative compact car in the U.S., Australia, Western Europe, Japan, and Eastern Europe. We reviewed Honda Car's website for the U.S., Australia, Germany, Japan and Poland to build the reference car profile and get pre-tax purchase costs.[5] Costs for cars in the Chinese fleet were taken from a weighted average detailed disaggregated sales data from 2002, 2009, and 2010.

Within any region/sub-segment, there is considerable variability in taxes and fees – for example the vehicle sales tax level in the U.S. varies by state and city; while vehicle registration fees vary by state. For regions with multiple countries – like Latin America, there is likely to be even higher variability. This represents a data and modeling challenge.

The levelized vehicle purchase costs are calculated using the following formula[6]

$$P_{CAPEX} = \frac{I[r(1+r)^n]}{[(1+r)^n - 1]} * \frac{1}{VKT} * \frac{1}{LF} \quad (3\text{-}2)$$

Where

- P_{CAPEX} : Purchase cost in terms of $/PKM,
- *I* : Vehicle purchase cost $/car,
- *n* : Assumed life of car. We uniformly assumed 15 years for cars covering all technologies and across regions,
- *r* : Interest rate. Consistent with GCAM's assumptions, we use a 10% interest rate,
- *VKT* : Annual vehicle kilometer travelled,
- *LF* : Load factor.

Vehicle purchase costs includes taxes and registration fees, as well as government subsidies and incentives (for example the U.S. $7,500 of subsidies offered by the federal government to buyers of electric cars in 2012).

[5] For any given trim, we found that engine displacement and power were similar across countries. However, vehicle Curb Weight (CW) varies substantially – for example the Civic 1.8 l weight in U.S., Australia, Germany, and Poland are 1,225 kg, 1,230 kg, 1,183 kg, and 1,322 kg, respectively. The differences in CW have implications on vehicle profiles – calculated fuel economy and price of alternative technology cars in the same sub-segment.

[6] The above method differs from the one adopted by TOSCA and AAA (U.S.) where vehicle cost is depreciated linearly over its vehicle lifetime (I/n), and financing costs are calculated based on initial investments (I.r)

3.3.2 Non-fuel annual operating costs

Annual operating expenses primarily include vehicle insurance, repair and maintenance costs, and vehicle registration fees.

Detailed operating expenses statistics are usually available for developed nations – the *American Automobile Association* for the U.S. (AAA 2012), the *National Roads and Motorists' Association Limited* for Australia (NRMA 2011), the *Canadian Automobile Association* for Canada (CAA 2010), and finally the *Allgemeiner Deutscher Automobil Club* or ADAC for Germany.

For Eastern Europe, we depended upon costs from the TREMOVE model (EC 2010), which were then adopted for Russia (after adjusting for differences in Purchasing Power).

Vehicle operating costs for India were taken from the TERI report (Srivastava, Mathur et al. 2006), and were then adopted for many other developing countries including Africa, South East Asia, and Middle East. Costs in Japan were based on Fedak (2005) as well review of new cars on Gizmag.[7] Costs in South Korea were adopted from Japan.

The following graph highlights the sensitivity of energy intensity to assumed annual VKT. In the U.S. and Australia, the non-fuel operating costs in terms of $/car are similar for all four sub-sectors. The annual VKT are around 19,000 and 16,600 km for cars and SUVs respectively in the U.S. (Davis, Diegel et al. 2011); and only 12,300 km for all sub-sectors in Australia (Australian Government 2008, ABS 2011). As a result, the costs in terms of $/VKM are around 30-60% higher for Australia.

Maintenance, operating, and licensing costs for China were estimated on the basis of information provided on a number of websites.[8]

[7] http://www.gizmag.com/about/

[8] http://www.autohome.com.cn/buycar.html
http://car.autohome.com.cn/baoyang/index.html
http://data.auto.sina.com.cn/baoyang/
http://sh.auto.sina.com.cn/z/automaintenance/
http://www.carxoo.com/tool/baoyang.asp
http://www.hzins.com/special/qichebaoyang/

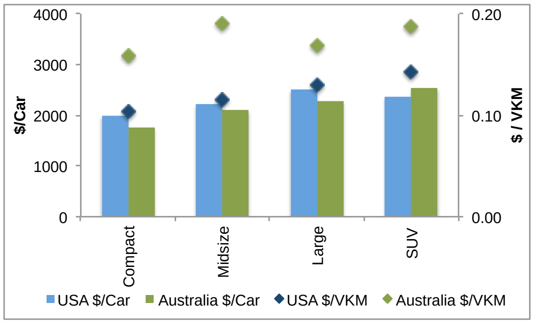

Figure 3.3: Assumed non-fuel operating costs in terms of $/Car and $/VKM (right axis) in the U.S. and Australia in 2005.

3.3.3 Non-vehicle related costs

There are two major categories of non-vehicle costs – infrastructure costs and R&D investments (both public and private R&D). In theory, these costs are borne by the travellers in a market economy (in practice the costs are more likely distributed among taxpayers) – the infrastructure costs are either reflected in road tolls or in form of fuel taxes; R&D costs by for-profit vehicle manufacturers are reflected in vehicle purchase costs. For new technologies, especially electric and hydrogen vehicles, R&D may be funded or subsidized by the government and the cost of R&D may not be fully borne by travellers. Further, the level of costs depends upon vehicle penetration. Given these uncertainties, we do not include R&D costs in the current version of the model.

Infrastructure costs include road infrastructure and fueling stations. For Europe, Safarianova, Noembrini et al. (2011) estimated the road infrastructure costs to be around 2 cents per vehicle kilometer (their estimate includes passenger and freight vehicle-KM).

Fueling infrastructure costs differ for different technologies – for liquids the marginal costs are likely to be low given the well-established infrastructure. Fueling infrastructure for NG, electricity and H2 are likely to be high especially when vehicle penetration is lower – however, there is considerable uncertainty in projected trajectories of these costs. For electric cars, costs include (i) investments in the grid (transformers and wiring infrastructure) by utilities, which in turn depends upon level of EV penetration, the presence or absence of smart charging, and charging voltage (e.g. level 1, level 2, etc.) ; (ii) residential charging infrastructure, (iii) public charging stations. For hydrogen and NG cars, infrastructure costs include fueling stations as well as transportation and distribution networks.

We largely ignore these costs in the current version of the model.

3.4 Assumptions for each technology

This section summarizes our assumptions about various alternative technologies. These assumptions are required to calculate the energy intensities and non-fuel costs of various cars & light trucks relative to the corresponding liquids ICE vehicles. Most of our assumptions are based on a report by National Research Council (NRC 2013), the TOSCA study (Safarianova, Noembrini et al. 2011), assumptions in the National Energy Modeling System (NEMS) model of the Energy Information Administration (EIA 2012), and a review of various make/models of alternative technology cars currently available in various markets.

3.4.1 Internal Combustion Engine

We make one key assumption about base year's ICE: that the powertrain efficiency η_{ICE} is equal to 18%, based on Safarianova, Noembrini et al. (2011).

3.4.2 CNG Cars

The energy intensity of a CNG car is calculated based on the following:

$$EI_{CNG} = EI_{ICE} * CW_{CNG} / CW_{ICE} * \eta_{ICE} / \eta_{CNG} \qquad (3\text{-}3)$$

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http://sh.auto.sina.com.cn/z/automaintenance/
http://news.shangdu.com/203/20110209/17_205187.shtml
http://auto.sohu.com/20060725/n244430653.shtml

The above equation makes the implicit assumption that all the primary ‘contextual’ drivers of energy intensity of an ICE vehicle – the quality of road infrastructure, congestion levels, driving patterns, etc. – are equally applicable to a CNG vehicle. Aside from these factors, the EI of a CNG car will differ from an equivalent ICE car for two reasons – differences in powertrain efficiency and curb weight.

The following table summarizes our key assumptions about CNG vehicles in the base year. The assumptions are based on the TOSCA study (Safarianova, Noembrini et al. 2011).

Table 3.3: Summary of assumptions for conventional ICE car (2005)

Parameter		Assumed value
Powertrain Efficiency η_{CNG}		19%
Additional purchase cost of CNG car	$/vehicle (% of ICE car)	14%
Annual Maintenance cost	$/vehicle (% of ICE maintenance)	95%
Additional mass of engine & NG storage	kg (% of CW_{ICE})	6%

3.4.3 Battery Electric Vehicles (BEVs)

The incremental cost of a BEV is largely dependent upon the cost of a battery pack. The required battery size is estimated by the following equation:

$$EV\_kWh_{BEV} = CW_{BEV} * (Range/1000) * KWHperKMperCW / Depthodis_{year} \quad (3\text{-}4)$$

where,

EV_kWh_{BEV}: Required battery size in kWh,

CW_{BEV} : BEV curb weight (CW in kg),

Range : Range of the BEV in km. The range is exogenously defined and may vary across sub-segments / regions,

kWhperKMperCW: The reciprocal of specific energy. This represents the energy intensity of a BEV measured in terms of kWh of energy per km of vehicle travel per kg of curb weight,

Depthodis: The maximum depth of discharge of a battery in percent. The year subscript indicates that this parameter changes over time.

The curb weight (in kg) of a BEV is calculated based on the following:

$$CW_{BEV} = CW_{ICE} + KGperkWh_{BEV} * EV\_kWh_{BEV} - ICE + EM \quad (3\text{-}5)$$

where:

CW_{BEV} & CW_{ICE}: Curb Weight of BEV & ICE representative cars, respectively,

$KGperkWh_{BEV}$: The reciprocal of specific energy or the energy density of a battery pack,

ICE : Mass of the combustion engine, transmission parts and gearbox not required in a BEV,

EM : Weight of additional components in a BEV – primarily the electric motor.

The energy intensity of a BEV car is calculated in a similar manner as that of the CNG car:

$$EI_{BEV} = EI_{ICE} * CW_{BEV}/CW_{ICE} * \eta_{ICE}/\eta_{BEV} \quad (3\text{-}6)$$

We assume that a Li-ion or more advanced batteries for BEVs – although we realize that BEVs with lead-acid battery are gaining popularity in China (REUTERS 2012).

Table 3.4: Summary of assumptions for BEV car

Parameter	2005	2050	2095	Notes
Powertrain Efficiency η_{BEV}	71%	73%	74%	The efficiency is assumed to increase annually by 0.05% until 2050 and 0.01% thereafter in Baseline Scenario.
	71%	75%	77%	Advanced Scenario
Battery Cost ($/kWh)	1,000	160	137	Baseline Scenario. Based on NRC (2013)
	1,000	150	109	Advanced Tech Scenario. Based on NRC (2013)
Charger cost ($/car)	1,000	1,000	1,000	
Savings due to ICE and gearbox (% of total cost)	15.2%	15.2%	15.2%	
Annual Maintenance cost (% of ICE costs)	80%	80%	80%	Per TOSCA, because of elimination of ICE, transmissions and rotating parts, no oil change is needed.
Battery Mass (KG/kWh)	4.76	4.76	4.76	Based on TOSCA and review of EVs
Additional mass due to electric motor (% of total BEV CW)	6.3%	6.3%	6.3%	Based on TOSCA
Reduced mass due to ICE and gearbox removal (% of total ICE CW)	12.59%	12.59%	12.59%	Based on TOSCA

Table 3.4 summarizes our assumptions about BEVs and are based on a number of studies including research sponsored by the European Commission to study the evolution of EU Transport GHG emissions to 2050 (Schroten, Essen et al. 2011), the European Union funded TOSCA study (Safarianova, Noembrini et al. 2011), and finally the IEA study on transportation energy and emissions (Fulton, Cazzola et al. 2009), and the NRC Study (NRC 2013)

This study also benefits from the launch of a number of BEV cars in 2011 and 2012 with a direct liquids-ICE equivalent – allowing us to estimate the incremental costs of battery and electric configuration. These include the Ford Focus, Honda Fit, Nissan Leaf (Versa), and Toyota Rav4.

3.4.4 Hybrid Electric Vehicles (HEV)

The required battery size for a HEV is given by

$$EV\_kWh_{HEV} = CW_{HEV} * KWHperCW \tag{3-7}$$

where:
EV_kWh_{HEV} : Required battery size in kWh,
CW_{HEV} : BEV curb weight (CW in kg),
kWhperCW : Battery size per kg of Curb Weight of the HEV.

The curb weight of a HEV (in kg) is given by

$$CW_{HEV} = CW_{ICE} + EM_{HEV} + (KGperkWh_{HEV} * EV\_kWh_{HEV}) \tag{3-8}$$

where:
CW_{HEV} & CW_{ICE} : Curb weight of HEV & ICE representative cars, respectively,
EM_{HEV} : Weight of additional components in a HEV – primarily the electric motors,
$KGperkWh_{HEV}$: Reciprocal of specific energy or energy density of a battery pack for a HEV,
EV_kWh_{HEV} : Required battery size for a HEV based on the previous equation.

The energy intensity of a HEV car is calculated in a similar manner as that of the CNG and BEV car:

Table 3.5: Summary of assumptions for HEV car

Parameter	2005	2050	2095	Notes
Powertrain Efficiency η_{HEV}	26%	33%	34%	The efficiency is assumed to increase annually by 0.1% until 2050 and 0.03% thereafter in Baseline Scenario.
	26%	40%	42%	Advanced Scenario. Improvements rates are 0.2% and 0.05%
Battery Cost ($/kWh)	2000	650	474	Baseline Scenario. Based on NRC (2013)
	2000	650	557	Advanced Tech Scenario. Based on NRC (2013)
Battery Mass (KG/kWh)	16.7	16.7	16.7	Based on TOSCA
Additional mass due to electric motor (% of total HEV CW)	6.3%	6.3%	6.3%	Based on TOSCA
Assumed kWh/CW (Battery size)	0.001102	0.001102	0.001102	Based on EIA

$$EI_{HEV} = EI_{ICE} * {CW_{HEV}}/{CW_{ICE}} * {\eta_{ICE}}/{\eta_{HEV}} \quad (3\text{-}9)$$

3.4.5 Fuel Cell Electric Vehicles (FCEV)

For fuel cell vehicles, we explicitly calculate the power requirements (given the power of corresponding liquids ICE car) as well as the battery size. The FCEV power requirements are given by

$$FCEV\_kW = (ICE\_kW) * ({CW_{FCEV}}/{CW_{ICE}}) * FAC \quad (3\text{-}10)$$

where,
FCEV_kW : Power requirement of a FCEV,
ICE_kW : Power requirements of a equivalent liquids ICE vehicle,
FAC : Adjustment factor for vehicle power requirements based on the EIA NEMS model. Assumed to be 0.8.

The FCEV battery requirements are given by:

$$EV\_kWh_{FCEV} = CW_{FCEV} * KWHperCW_{FCEV} \quad (3\text{-}11)$$

where,
EV_kWh_{FCEV} : Battery size in kWh for a FCEV,

CW_{FCEV} : Curb weight of a FCEV,
$KWHperCW_{FCEV}$: Battery size per kg of curb weight.

The curb weight of a FCEV (in kg) is given by:

$$CW_{FCEV} = CW_{ICE} + (KGperkW_{FCEV} * FCEV\_kW) - ICE + EM_{FCEV} + H2S \tag{3-12}$$

where:
CW_{FCEV} : Curb weight of FCEV,
$KGperkW_{FCEV}$: The reciprocal of specific power of H2 fuel cells,
EM_{FCEV} : Mass of electric components of a FCEV, including battery mass,
H2S : Mass of the hydrogen storage tank.

3.5 Appendix: Country specific data sources

The following appendix lists the sources of various country-specific input parameters. We also do a qualitative assessment of the accuracy of the input values using the *Harvey Balls* approach where ● represents high levels of confidence, while ○ represents low levels of confidence.

3.5.1 Africa

Limited data available for Africa. Most assumptions are based on India.

3.5.2 Australia and New Zealand (ANZ)

For ANZ, we completely relied on statistics from Australia, which accounted for 85% of total road energy consumption in 2005 according to IEA statistics. For the base year, various statistics – EIs, LFs, share of size classes and modes, etc. – are based on

Table 3.5: Summary of assumptions for FCEV car

Parameter	2005	2050	2095	Notes
Powertrain Efficiency η_{BEV}	45%	61%	65%	The efficiency is assumed to increase annually by 0.05% until 2050 and 0.01% thereafter in Baseline Scenario.
	45%	64%	62%	Advanced Scenario. Improvements at 0.1% and 0.025%
Battery Cost ($/kWh)	1,275	425	364	Baseline Scenario. Based on NRC (2013)
	1,275	420	306	Advanced Tech. Based on NRC (2013)
Fuel Cell ($/kW)	150	25	21	Baseline Scenario. Based on NRC (2013)
	150	22	16	Advanced Tech. Based on NRC (2013)
H2 Storage tank ($/kWh)	500	17	15	Baseline Scenario. Based on NRC (2013)
	500	16	12	Advanced Tech. Based on NRC (2013)
Savings due to ICE and gearbox (% of total cost)	15.2%	15.2%	15.2%	
Annual Maintenance cost (% of ICE costs)	90%	90%	90%	Per TOSCA, because of elimination of ICE, transmissions and rotating parts, no oil change is needed.
Battery Mass (KG/kWh)	4.76	4.76	4.76	Based on TOSCA and EIA
H2 Fuel tank specific weight (kWh/Kg of H2)	1.60	1.60	1.60	As above
Additional mass due to electric motor and battery (Kg)	85	85	85	Based on TOSCA
Reduced mass due to ICE and gearbox removal (% of total ICE CW)	12.59%	12.59%	12.59%	Based on TOSCA

Australia and assumed to hold for the entire ANZ region. Total service in 2005 is then estimated based on energy consumption statistics for 2005.

Parameter	Source(s)
Service (base year)	BITRE Australia (2009)
EI (base year)	NRMA (2011); BITRE Australia (2009)
Disaggregation to size classes	Shares are based on market stock from Australian Government (2008) and ABS (2011). EIs of specific size-classes from NRMA.
Load factor	Based on U.S.
Annual VKT	Australian Government (2008) and ABS (2011). Single number for all size classes.
Car purchase costs	Review of Honda, Toyota and Holden websites.
Operating costs	NRMA (2011)

3.5.3 Canada

Transport Canada (2012) does not disaggregate the cars & light truck market into size classes but into functional categories – cars, vans, SUVs, and light trucks. We adopt this classification.

Parameter	Source(s)
Service (base year)	Transport Canada (2012)
EI (base year)	CAA (2010) and Transport Canada (2012)
Disaggregation to size classes	Transport Canada (2012)
Load factor	Transport Canada (2012) LFs vary across “size classes.”
Annual VKT	Transport Canada (2012). Annual VKT varies across “size classes.”
Car purchase costs	Review of Honda (Canada) website.
Operating costs	CAA (2010)

For light trucks, we assumed that 18% of the VKT is freight traffic based on the 2002 Vehicle Inventory and Use Survey (VIUS) for the U.S. market (Davis, Diegel et al. 2011).

3.5.4 China

Data for China comes primarily from a series of papers published in Energy Policy from 2011-2012 (Huo, Wang et al. 2011, Huo, Yao et al. 2011, Huo, He et al. 2012, Huo and Wang 2012, Huo, Wang et al. 2012, Huo, Zhang et al. 2012). These articles, released by a group of researchers affiliated with Tsinghua University, Argonne National Laboratory, and China Automotive Technology and Research Center (CATARC), are a substantial contribution to the literature, in that they rely upon primary data sources and surveys. The vehicle stock, energy intensity, and vehicle use intensity (VKT) estimates yield aggregate energy use estimates that are substantially higher than those generated by the IEA. However, there is still a dearth of reliable, publicly available data on PKT and load factors as well as financial characteristics.

Parameter	Source(s)
Service (base year)	Low
EI (base year)	Huo, He et al. (2011) and other papers by the same lead author.
Disaggregation to size classes	Author’s analysis based on data from different sources
Load factor	Based on India
Annual VKT	Huo, Zhang et al. (2012)
Car purchase costs	Review of Chinese websites (see footnote 8 above).
Operating costs	Review of Chinese websites (see footnote 8 above).

3.5.5 Eastern Europe (EE)

For EE, we depend upon the European Commission's TREMOVE Database v3.3.2 (EC 2010). The database covers the following countries in Eastern Europe – Bulgaria, Czech Republic, Hungary, Poland, Romania, Croatia, Slovenia, and Slovakia. However, it does not include Bosnia and Herzegovina, nor Macedonia and Yugoslavia.

Parameter	Source(s)
Service (base year)	TREMOVE database v3.2.2. Calibrated based on IEA energy statistics and EI (see below).
EI (base year)	TREMOVE database v3.2.2.
Disaggregation to size classes	As above
Load factor	As above
Annual VKT	As above
Car purchase costs	Polish websites of Honda and Renault.
Operating costs	TREMOVE database v3.2.2

The energy estimates from IEA are around 30% higher than TREMOVE estimates. We found a similar difference in case of railroads. To address this discrepancy, we adopted the EIs from TREMOVE and calibrated the transportation service estimates.

3.5.6 Former Soviet Union (FSU)

Parameter	Source(s)
Service (base year)	VKT estimates from UNECE (2012).
EI (base year)	Estimated from Western Europe assuming a 3% lower technical efficiency. Weighted average matches Bashmakov (2009).
Disaggregation to size classes	Cuenot and Fulton (2011) and Nureev and Kondratov (2011) give information for Russia and Ukraine which have 92% of stock of cars. Based on vehicle stock in base year.
Load factor	Adopted from Eastern Europe (TREMOVE)
Annual VKT	Based on service estimates from UNECE (2012) and car stock estimates from the World Bank.
Car purchase costs	Review of Russian websites of Ford, Kia and Honda.
Operating costs	Adopted from Eastern Europe.

3.5.7 India

Parameter	Source(s)
Service (base year)	Arora, Vyas et al. (2011)
EI (base year)	As above
Disaggregation to size classes	As above
Load factor	Singh (2006) and Srivastava, Mathur et al. (2006)
Annual VKT	Arora, Vyas et al. (2011)
Car purchase costs	Review of Indian websites of Maruti Suzuki, Tata Motors and Hyundai.
Operating costs	Srivastava, Mathur et al. (2006)

Bottom-up estimates of total road sector energy consumption in 2005 based on literature ((Singh 2006, Srivastava, Mathur et al. 2006, Arora, Vyas et al. 2011) is twice the IEA estimates (2.4 versus 1.2 EJ).

3.5.8 Japan

Parameter	Source(s)
Service (base year)	(Japan Statistics Bureau 2011)
EI (base year)	Schipper (2011)
Disaggregation to size classes	JAMA (2011), (Schipper 2011). Based on vehicle stock in base year.

Load factor	(Japan Statistics Bureau 2011) Single number for all size classes.
Annual VKT	(JAMA 2011, Japan Statistics Bureau 2011) Single number for all size classes.
Car purchase costs	Review of Japanese websites of Subaru, Daihatsu and Honda
Operating costs	Review of various articles in www.gizmag.com

3.5.9 Korea

Parameter	Source(s)
Service (base year)	Eom and Schipper (2010).
EI (base year)	Adopted EI from Western Europe and the U.S. Weighted average EI matches estimates from Eom and Schipper (2010).
Disaggregation to size classes	Based on vehicle stock from (KAMA 2003, KAMA 2006).
Load factor	Eom and Schipper (2010). Single estimate for all size classes.
Annual VKT	(KAMA 2003, KAMA 2006) Single estimate for all size classes.
Car purchase costs	Review of Korean website of Hyundai. Taxes etc. are based on KAMA (2006)
Operating costs	Based on U.S. and West Europe.

3.5.10 Latin America

The Latin American car market is very diverse – for example it is dominated by mini (<1000 cc) cars in Brazil (Fouto and Franciscol 2011), subcompact and compacts in Argentina and Chile, and compacts, midsize and large cars in Mexico (Cuenot and Fulton 2011). The availability of data, and the quality of available data also varies between countries.

Parameter	Source(s)
Service (base year)	Initial estimates from vehicle stock from World Bank database, BBVA Research (2010), ICCT (2012), (Fouto and Franciscol 2011), and Cuenot and Fulton (2011).
EI (base year)	Based on Western Europe and U.S. adjusted assuming a 5% lower technical efficiency.
Disaggregation to size classes	Fouto and Franciscol (2011), and Cuenot and Fulton (2011).
Load factor	Based on Western Europe (assumed to be 10% higher).
Annual VKT	Assumed based on other developing countries
Car purchase costs	Review of Brazilian websites of Ford and Honda.
Operating costs	Based on costs from Eastern Europe.

3.5.11 Middle East

Parameter	Source(s)
Service (base year)	Based on vehicle stock information from World Bank database, IRTU (2010), Houri Jafari and Baratimalayeri (2008), and Israel - CBS (2012).
EI (base year)	Based on Houri Jafari and Baratimalayeri (2008), and Western Europe EI adjusted assuming a 5% lower technical efficiency.
Disaggregation to size classes	Based largely on the car market in Iran (Houri Jafari and Baratimalayeri 2008) which constitutes 40% of total cars in ME.

Load factor	Based on India
Annual VKT	Assumed based on other regions
Car purchase costs	Based on India
Operating costs	Based on India

3.5.12 South East Asia

All assumptions are based on India.

3.5.13 U.S.A.

Parameter	Source(s)
Service (base year)	U.S. DOT (2012). 18% of the light truck VKT is moved to freight based on the 2002 VIUS for the U.S. market (Davis, Diegel et al. 2011). Passenger traffic in medium and heavy freight trucks, reported by BTS, is not considered.
EI (base year)	U.S. DOT (2012) and AAA (2012)
Disaggregation to size classes	Davis, Diegel et al. (2011) and U.S. DOT (2012)
Load factor	Davis, Diegel et al. (2011)
Annual VKT	Davis, Diegel et al. (2011)
Car purchase costs	Review of U.S. websites of Ford, Honda, Chevrolet, Toyota.
Operating costs	AAA (2012)

3.5.14 Western Europe

For Western Europe, variability across regions may not be captured by our assumptions.

Parameter	Source(s)
Service (base year)	TREMOVE Database V3.2.2. (EC 2010)
EI (base year)	As above
Disaggregation to size classes	As above
Load factor	As above
Annual VKT	As above
Car purchase costs	Review of German websites of Honda and Volkswagen.
Operating costs	EC (2010), and, Hill and Morris (2012)

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4 Two-wheelers (2W)

Non-financial statistics for the two-wheelers (2W) mode in the base year– service estimates, annual VKT, load factor, EI – are available for most developed regions. However, comprehensive financial data is available only for Western Europe from the TREMOVE model. Moreover, only limited data is available for developing countries – primarily for China, India, Eastern Europe, and FSU. Most of the statistics for developing regions are based on estimates for India. The following table uses *Harvey Balls* to assess the quality of two-wheeler inputs.

4.1 Methodology and assumptions

- For most developed countries, we created a single size class because of the low share of 2W in overall transportation service.

Table 1: Qualitative assessment of parameter value quality for the base year (2005)

	Service	Energy Intensity	Non-fuel costs	Notes
Africa	○	○	○	Based on India.
ANZ	◕	◕	◔	Non-financial statistics for Australia from BITRE Australia (2009). Financial statistics based on Western Europe.
Canada	◕	◕	◔	Based on Transport Canada (2012) and ICCT's Roadmap (ICCT 2012; Transport Canada 2012). Financial statistics based on Western Europe.
China	◑	◕	◔	Usage (VKT) estimates from Cherry and Cervero (2007). Energy Intensity data from Cherry, Weinert et al. (2009). Financial statistics based on various popular media websites.
EE	◑	◑	◑	Based on TREMOVE (EC 2010) and SULTAN (Hill and Morris 2012). Calibration to IEA's energy statistics led to a 30% increase in PKT.
FSU	◕	◕	◔	Non-financial statistics based on UNECE (2012) and FSSS - Russian Federation (2012). Financial statistics based on Eastern Europe.
India	◑	◑	◑	Non-financial statistics based on (Singh 2006; Srivastava, Mathur et al. 2006; Arora, Vyas et al. 2011), but service estimates vary substantially. Financial statistics based on Srivastava, Mathur et al. (2006).
Japan	◕	◕	◕	Non-financial statistics from Japan Statistics Bureau (2011). Financial statistics based on various popular media websites.
Korea	◕	◕	◔	Non-financial statistics from Eom and Schipper (2010). Financial statistics based on Western Europe.
LatAM	◑	◑	○	Non-financial estimates are based on ICCT Roadmap (ICCT 2012).
ME	○	○	○	Based on India.
SE Asia	○	○	○	Based on India.
USA	●	●	◕	Detailed financial and non-financial statistics for intra-city transit buses from APTA (2011). For inter-city long distance buses, non-financial statistics from BTS (U.S. DOT 2012). Financial data for inter-city buses based on review of bus fares from Greyhound.
W. EUR	◕	◕	◕	Based on TREMOVE (EC 2010) and SULTAN (Hill and Morris 2012).

- Two alternative 2W technologies – liquids and electric – are considered. For China, two types of electric two-wheelers are considered – lithium ion and lead-acid. For all other countries, we only considered lithium-ion.

- A bottom-up approach is adopted to calculate the total non-fuel generalized user costs. We adopt the same set of assumptions for a liquids ICE and lithium-ion battery driven electric powertrains as that of cars & light trucks (Chapter 3). Lead-acid battery powered electric 2Ws are discussed later in the chapter.

4.2 Country specific assumptions

In this section, we detail out country-specific data sources and assumptions for some of the key countries.

4.2.1 Africa

All assumptions are based on India. Also see Chapter 2 for methodology adopted for Africa's road sector.

4.2.2 Australia and New Zealand (ANZ)

The non-financial statistics for the 2W sector – service output, energy intensity, load factor, etc. – are taken from BITRE Australia (2009). We do not disaggregate the mode into size-classes given that 2W is less than 1% of total PKT in 2005.

Estimates of P_{NF} are based on the TREMOVE model for Western Europe.

4.2.3 Canada

Transportation service in the base year is based on the 2W vehicle stock (ICCT 2012; NATS 2012; Transport Canada 2012), and average annual VKT from other developed countries (primarily TREMOVE database for Europe).

The financial statistics are based on TREMOVE.

4.2.4 China

Vehicle stock data comes from various Chinese industry websites and annual sales based upon the China Automotive Energy Outlook (2012), and assume a mean vehicle lifetime of ~11.5 years for motorcycles. Estimated vehicle kilometers travelled are from Cherry and Cervero (2007). Energy intensity and sales data for motorcycles and 2W lead-acid vehicles are from Cherry and Weinert (2009).

4.2.5 Eastern Europe (EE)

Statistics for Eastern Europe are based on the EC sponsored TREMOVE model (EC 2010). As mentioned in Chapter 2, the road energy estimates from the IEA are around 30% higher than estimates in TREMOVE database for 2005. We calibrate by taking the energy estimates from IEA and energy intensity estimates from TREMOVE.

4.2.6 Former Soviet Union (FSU)

The 2W vehicle stock for FSU nations are taken from the transportation database maintained by United Nations Economic Commission for Europe (UNECE 2012). The database disaggregates the 2W stock into mopeds and motorcycles. We further disaggregate the motorcycles into two size classes, 50-250 cc and greater than 250 cc, based on market shares in Western Europe.

The annual VKT and load factors are taken from TREMOVE database for Eastern Europe; as are the non-financial statistics.

4.2.7 India

Transportation service (VKT) and energy intensity estimates for 2W market in India are taken from Arora, Vyas et al. (2011), who have also disaggregated the 2W market into size-classes. We consider three size classes – mopeds (~75 cc), scooters (~100 cc) and motorcycles (~100-150 cc).

As indicated in Chapter 2, there is uncertainty around total 2W PKT services and its share of total road-based PKT. For example, for year 2000, the total PKT estimate varies from around 250 to 400 billion PKT. The share of total road PKT varies from 12% to 18%. The load factor also varies from a low of 1.2 (Srivastava, Mathur et al. 2006) to a high of 1.5 (Singh 2006; Zhou and McNeil 2009).

Annual non-fuel operating costs are based on the TERI Study (Srivastava, Mathur et al. 2006), while purchase costs are based on current market prices of best selling models - TVS

Scooty and Mahindra Kine for mopeds, Honda Activa for scooters, and Bajaj Pulsar and Hero Splendor Super for motorcycles.

4.2.8 Japan

The share of 2Ws in overall transportation service in 2005 is estimated based on vehicle stock information from Japan Automobile Manufacturers Association (JAMA 2011). Annual VKT is assumed to be 40% of annual VKT of cars based on statistics for Western Europe from TREMOVE. Load factors and energy intensities are also based on TREMOVE. 2Ws accounted for more than 4% of overall motorized passenger transportation service consumed in Japan.

The market disaggregation is based on vehicle stocks from JAMA. The market is dominated by mopeds (<50cc, Gentsuki), which accounted for 65% of the market in 2005.

The financial data are partly based on various websites like this one from Nagasaki University (http://www.is.nagasaki-u.ac.jp/eng/magazines/lifeguide/2010-24.pdf) and this one summarizing biking information in Japan (http://www.thejapanfaq.com/bikerfaq-classes.html). The purchase costs and other vehicle information was based on review of various models available at Honda Motorcycle (Japan) website.

4.2.9 Korea (South)

While Korea Automobile Manufacturers' Association (KAMA 2003; KAMA 2006) provides detailed information about cars & light trucks, buses, and heavy-duty trucks, no information is provided about two-wheelers. Similarly, Eom and Schipper (2010) do not provide travel demand and energy intensity estimates for two-wheelers

Our base year travel demand estimates are based on ratio of 2W PKT to total road-based PKT from IEA MoMo and ICCT Roadmap models. Energy intensities, costs, and load factors are based on Japan.

4.2.10 Middle East

All assumptions are based on India. Also see Chapter 2 for methodology adopted for Middle East road sector.

4.2.11 South East Asia

All assumptions are based on India. Also see Chapter 2 for methodology adopted for South East Asia road sector.

4.2.12 U.S.A.

For the U.S., detailed passenger traffic, energy consumption and energy intensity estimates are provided by U.S. DOT (2012). However, BTS changed its methodology for data collection starting 2007 (Davis, Diegel et al. 2011) leading to large changes in VKT and PKT as summarized in the table below.

Table 4.2: Key non-financial statistics for 2W in the U.S.

	PKT (Billion)	VKT (Billion)	LF	MJ/PKT
2000	25	17	1.47	1.02
2005	28	**17**	**1.65**	**0.82**
2007	44	**34**	**1.29**	**1.32**
2009	36	34	1.06	1.63

Source: U.S. DOT (2012).

The above table highlights the uncertainty in data related to motorcycles in the U.S. We adopted the load factors and EI (MJ/PKT and MJ/VKT) from 2007 instead of 2005.

We do not disaggregate the U.S. 2W market into further size classes. Nearly 90% of the market share in terms of sales in 2003 is for motorcycles with engine size greater than 350 cc (Morris 2009). Within that, most of the motorcycles have engine size greater than 750 cc. Further, the overall motorcycle market in the U.S. is very small – less than 0.5% of the total transportation in PKT in 2005.

Annual fixed and variable non-fuel operating costs were adopted from TREMOVE for the Western Europe market. The purchase costs are based on price of Kawasaki Vulcan (1,000 cc).

4.2.13 Western Europe

Statistics for Western Europe, both financial and non-financial, are based on the European Commission sponsored TREMOVE model (EC 2010) and European Union sponsored SULTAN model (Hill and Morris 2012).

Unlike the U.S., two wheelers have a much larger share of passenger transportation market (around 1.6%). Further, the 2W market is roughly equally distributed between moped (<50 cc), small motorcycles (50-250 cc), and large motorcycles (>250 cc) .

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5 3-Wheelers

The three-wheeler passenger mode is modeled for three regions: Africa, Southeast Asia and India. The three-wheeler market in India and China has been covered in some detail in a number of studies and models. For both Africa and Southeast Asia, we relied largely on values from the Indian market.

5.1 Methodology and assumptions

- Information about three-wheeler markets is available for India and China only. For South East Asia and Africa – the two other markets where three-wheelers have a presence, we made assumed that values of all input parameters – EI, LF and P_{NF} – are same as that of India.
- Two alternative 3W technologies – liquids and NG are considered.
- A bottom-up approach is adopted to calculate the total non-fuel generalized user costs. We adopt the same set of assumptions for a liquids ICE and NG powertrains as that of cars and light trucks (Chapter 3).

5.2 Country specific assumptions

In this section, we detail country-specific data sources and assumptions for some of the key countries.

5.2.1 Africa

No information is available about the three-wheeler market in Africa. Other input parameters – load factors, energy intensity, non-financial

Table 1: Qualitative assessment of quality of parameter values for the base year (2005)

	Service	Energy Intensity	Non-fuel costs	Notes
Africa	○	○	○	Largely based on India.
ANZ				Not applicable
Canada				Not applicable
China	◔	◑	◔	Stock and energy intensity estimates based on industry websites and personal communications between Sun Li, China University of Technology and Jacob Teter during 2012).
EE				Not applicable
FSU				Not applicable
India	◑	◑	◑	Non-financial statistics based on (Singh 2006; Srivastava, Mathur et al. 2006; Arora, Vyas et al. 2011; ICRA 2012), but service estimates vary substantially. Financial statistics based on (Srivastava, Mathur et al. 2006; ICRA 2012).
Japan				Not applicable
Korea				Not applicable
LatAM				Not applicable
ME				Not applicable
SE Asia	○	○	○	Primarily based on India.
USA				Not applicable
W. EUR				Not applicable

Note: ● reflects high levels of confidence; and ○ reflects low levels of confidence.

costs – are based on India. Size of the market, in terms of PKT in base year relative of LDV, is based on the IEA MoMo model (IEA 2012) and ICCT Roadmap (ICCT 2012).

5.2.2 China

Three-wheeled rural vehicles are largely used as freight carriers and considered under road freight. This is based on personal experience of one of the authors (Jacob Teter) who conducted an extensive survey of rural 3W vehicle owners in summer of 2010. However, sales of 3W electric motorcarts for passenger (and cargo) transport have grown concomitant with the growth of the electric 2W market (personal communications with Sun Li).

5.2.3 India

As with other road modes, there is considerable uncertainty about passenger transportation service provided by three-wheeler mode in the base year (2005). As indicated in Chapter 2, the service estimates range from 85 to 180 billion PKT for year 2000. The estimated share of 3W PKT to total road-based PKT for year 2000 ranges from a low of 3% (Singh 2006; Zhou and McNeil 2009) to a high of 9% (ICCT 2012).

We take the total VKT and energy use estimate from Arora, Vyas et al. (2011) which is broken down by fuel – liquids and CNG. We assume that 25% of the VKT is freight movement given that around 25% of new sales since 2003 are for freight three-wheelers (ICRA 2012). Adopted load factors are an average of estimates from Srivastava, Mathur et al. (2006) and Singh (2006).

The non-fuel financial costs are based largely on ICRA (2012) and Srivastava, Mathur et al. (2006).

5.2.4 South East Asia

Same as Africa.

5.3 References

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6 BUS

Data on bus mode are available for most developed regions. However, only limited data are available for developing countries – primarily for India, Eastern Europe, China and FSU. Most of the assumed statistics for developing regions are based on estimates for India. The following table uses *Harvey Balls* to assess the quality of bus inputs.

Table 6.1: Qualitative assessment of quality of parameter values for the base year (2005)

	Service	Energy Intensity	Non-fuel costs	Notes
Africa	○	○	○	Based on India
ANZ	◕	◕	◔	Non-financial statistics for Australia from BITRE Australia (2009) and on ABS (2011); (ICCT 2012) Financial statistics based on Japan, U.S., Western EUR, and Canada.
Canada	◕	◕	◕	Based on Transport Canada (2012) and ICCT's Roadmap (ICCT 2012).
China	◑	◑	◔	Stock and Energy Intensity estimates from (Huo, He et al. 2011) and (Huo, Zhang et al. 2011). Financial statistics based on other developing countries.
EE	◑	◑	◑	Based on TREMOVE (EC 2010) and SULTAN (Hill and Morris 2012). Calibration to IEA's energy statistics led to a 30% increase in PKT.
FSU	◕	◕	◔	Non-financial statistics based on UNECE (2012) and FSSS - Russian Federation (2012). Financial statistics based on Eastern Europe.
India	◑	◑	◑	Non-financial statistics based on (Singh 2006; Srivastava, Mathur et al. 2006; Arora, Vyas et al. 2011), but service estimates vary by a factor of two – we take the lower estimates. Financial statistics based on (Srivastava, Mathur et al. 2006) and travel website www.makemytrip.com.
Japan	◕	◕	◕	Non-financial statistics from Japan Statistics Bureau (2011). Financial statistics based on (Mizutani and Urakami 2002).
Korea	◕	◕	◔	Non-financial statistics from Eom and Schipper (2010). Financial statistics based on Japan, U.S., Western EUR, and Canada.
LatAM	◑	◑	○	Non-financial estimates are based on ICCT Roadmap (ICCT 2012).
ME	○	○	○	Based on India
SE Asia	○	○	○	Based on India
USA	●	●	◕	Detailed financial and non-financial statistics for intra-city transit buses from APTA (2011). For inter-city long distance buses, non-financial statistics from BTS (U.S. DOT 2012). Financial data for inter-city buses based on review of bus fares from Greyhound.
W. EUR	◕	◕	◕	Based on TREMOVE (EC 2010) and SULTAN (Hill and Morris 2012).

Note: ● reflects high levels of confidence; and ○ reflects low levels of confidence.

6.1 Methodology and assumptions

- For bus mode, we consider one generic size-class.

- Two alternative propulsion technologies are considered: liquids and natural gas. Electric and Hydrogen Fuel Cell buses will be added in later versions of the model.

- A top-down approach is adopted to calculate the total non-fuel generalized user costs. This is further discussed in Section below.

- For some regions – the U.S., Western Europe, Japan, Canada, Eastern Europe, and Australia – we found literature estimates for public subsidies. For other regions, we assumed a subsidy of 10% (as a placeholder estimate pending better data).

6.2 Non-fuel ownership costs

This section describes the top-down approach adopted to determine the non-fuel component of generalized user costs.

- We reviewed the literature to estimate the overall industry's fare revenue and public subsidies to the industry.

- Costs incurred by the bus passenger are equal to the fare paid; while *overall expenses* incurred to provide the service (ownership costs) is equal to the sum of fare revenue and subsidies provided. As explained in Chapter 2, *overall expenses* calculated in this manner are expected to incorporate operating costs, depreciation as well as financing costs. We exclude fuel expenses from overall expenses (since fuel costs are calculated endogenously by GCAM) to get the non-fuel component of overall expenses (P_{NF}) to provide the service.

- We also explicitly represent subsidies ($P_{subsidy}$). A fare paid by the bus passenger is equal to the overall expenses incurred minus the subsidies paid. Hence, the non-fuel component of Generalized User Cost for Bus may be written as:

$$\boldsymbol{P_{NF}^{Bus}} = (\boldsymbol{P_{OPEX-Fuel}^{Bus}} + \boldsymbol{P_{CAPEX}^{Bus}}) - \boldsymbol{S^{Bus}} \qquad \textbf{(6-1)}$$

To model different propulsion technologies, we make the following simplifying assumptions

- Energy intensities and overall ownership costs differ between technologies. We assume that NG buses have a 10% higher intensity based on (Hesterberg, Bunn et al. 2009; Hill and Morris 2012). Overall ownership costs are assumed to be 8% higher for NG buses based on (Hill and Morris 2012). We should note the uncertainty around these estimates – for example per the TREMOVE model (EC 2010). NG buses have 10% lower energy intensity than diesel buses.

- Fares charged (and hence generalized user costs) do not vary between technologies.

- The difference is then adjusted in the level of subsidies. For simplicity, and given that fuel costs are endogenously calculated, we ensure that sum of non-fuel ownership costs and subsidies are equal across propulsion technologies.

6.3 Country specific assumptions

In this section, we detail the country-specific data sources and assumptions for the GCAM regions and countries.

6.3.1 Africa

All assumptions are based on India.

6.3.2 Australia and New Zealand (ANZ)

The non-financial statistics for the bus industry as a whole – service in passenger kilometers (PKT), energy intensity, load factor, etc. – are taken from BITRE Australia (2009). Estimates of P_{NF} are assumed to be equal to the average P_{NF} for other developed countries.

6.3.3 Canada

The statistics are primarily based on Transport Canada (2012) and the International Council for Clean Transportation's *Transportation Roadmap* from (ICCT (2012)

6.3.4 China

Following Huo, Zhang et al. (2012), we split buses into small, medium, and large classes based upon length (<10 meters and >10 meters) and calculate real-world fuel consumption and VKT as weighted-averages based upon this split using data reported therein. NG vehicle stocks are from (Orlov and Kozak 2006).

We added three-wheeled rural vehicles as a separate category of trucks, based on their large stock numbers, high proportion of energy use, and dominance in rural road freight (Teter, 2012).

Bus stock estimates are from the China Statistical Yearbook (CSB 2006), Huo, Wang et al. (2011), CAERC (2012), and IEA *MoMo* analysis (IEA 2012).

6.3.5 Eastern Europe (EE)

Statistics for Eastern Europe are based on the European Commission sponsored TREMOVE model (EC 2010). As mentioned in Chapter 2, the road energy estimates from the IEA are around 30% higher than estimates in TREMOVE database for 2005. As before, we calibrate by taking the energy estimates from the IEA and energy intensity estimates from TREMOVE.

6.3.6 Former Soviet Union (FSU)

We adopt fuel intensities and non-fuel costs from Eastern Europe.

6.3.7 India

Service estimates for India's bus sector in 2005 range from 1,600 (Srivastava, Mathur et al. 2006) to 3,200 billion PKT (Singh 2006); highlighting the large uncertainty for a mode which constitutes the majority of road-based passenger travel in developing countries. Schipper, Banerjee et al. (2009) also estimated the service in 2000 to be around 1,600 billion PKT.

We adopted the energy intensity estimates using the simple average of the above-mentioned studies.

As mentioned in Chapter 2, the IEA energy estimates for the road sector are around 50% of conservative bottom-up estimates from a literature review – as a result, the base year service level currently adopted in GCAM is around 890 billion PKT.

To estimate P_{NF} including subsidy levels we reviewed the literature for inter-city and intra-city services. For inter-city services, we took fares between various origin-destination fares from www.makemytrip.com, one of the largest travel websites in India and one used by one of the authors quite frequently for both air and bus travel. Fares differ based on amenities and bus conditions; Volvo-based bus fares command two- to three times the fare of regular buses. Nevertheless, the fares are around $0.02/PKT, substantially lower than levels in developed countries. Since inter-city bus services in India are largely privatized, we assumed no additional public subsidy.

On the other hand, intra-city bus services are heavily subsidized. Based on revenue and cost estimates given by (Srivastava, Mathur et al. 2006); Korattyswaroopam (2010), we estimate subsidy levels to be around 50% for intra-city bus operations.

Based on the above papers, we estimate intra-city bus service to be around 10% of total bus service in India. Thus, the average subsidy is estimated to be around 5%.

6.3.8 Japan

The non-financial statistics for the bus industry as a whole – service consumed, energy intensity, load factor, etc. – are taken from the Japan Statistics Bureau (2011).

Financial statistics are based on a report on inter-city bus operations by Mizutani and Urakami (2002) which indicates that operations are dominated by private operators who are heavily subsidized by the government. Based on available statistics, we calculated the subsidy to be 70% of P_{NF}. We assume that the level of P_{NF} and subsidies are the same for intra-city bus services.

6.3.9 Middle East

All assumptions are based on India.

6.3.10 South East Asia

All assumptions are based on India.

6.3.11 U.S.A.

For the U.S., detailed passenger traffic, energy consumption and energy intensity estimates are provided by the U.S. DOT (2012) and APTA (2011). The latter provides details of intra-city bus services, which are further disaggregated into urban transit, trolley bus, and paratransit. For inter-city bus service, BTS changed its methodology for data collection starting 2007 (Davis, Diegel et al. 2011) leading to large changes in VKT and load factors as summarized in the table below. In light of this updated methodology, we adopted the load factors and EI (MJ/PKT and MJ/VKT) from 2007 instead of 2005. There was no similar change in APTA's methodology (applicable for intra-city).

Table 6.2: Key operating statistics of inter-city bus in the U.S.

	PKT (Billion)	VKT (Billion)	LF	MJ/PKT
2000	505	12	41.36	0.29
2005	449	**11**	**39.95**	**0.33**
2007	495	**23**	**21.20**	**0.54**
2010	470	22	21.21	0.54

Source: U.S. DOT (2012)

APTA provides detailed operating revenues and expenses information for intra-city bus operations. The difference between the two provides a ballpark estimate of public subsidy to the sector. For inter-city bus operations, we reviewed fares between various origin-destination pairs offered by scheduled bus services like Greyhound (www.greyhound.com/) and Trailways (www.trailways.com). The bus fares were usually between US $0.45 – US $0.80/PKT. Since these companies are privatized and for-profit operations, we assumed that inter-city bus services are not subsidized. In 2001, the total inter-city bus sector had an operating revenue of $1.11 billion and expenses of $1.08 billion (Lindly 2009).

The following summarizes the 2005 statistics for the entire U.S. bus industry:

Table 6.3: Statistics for the bus mode in the U.S. in 2005, for both inter and intra-city operations

	PKT (billion)	LF	MJ/VKT	P_{NF} (before subsidy) ($/PKT)	Subsidy (% of P_{NF})
Intra-city	495	6.6	5.3	0.41	66.2%
Inter-city	37	21.2	11.4	0.07	0%
Total	532	18.4	10.2	0.09	4.6%

Source: U.S. DOT (2012)

The table highlights the large differences in the characteristics of inter-city and intra-city bus operations.

6.3.12 Western Europe

Statistics for Western Europe are based on the EC sponsored TREMOVE model (EC 2010) and the EU sponsored SULTAN model (Hill and Morris 2012).

The share of intra-city bus traffic (in terms of PKT) is around 30% for Western Europe, compared to only 5% for the U.S. This is partly explained by the much higher subsidies for public bus transit in Western Europe (as well as by myriad other historical, cultural, and geographic factors).

Table 6.4: Statistics for bus mode in Western Europe in 2005 broken up by inter- and intra-city operations

	PKT (Billion)	LF	MJ/VKT	P_{NF} (before subsidy) ($/PKT)	Subsidy (% of P_{NF})
Intra-city	237	16.5	11.0	0.12	
Inter-city	601	16.5	8.6	0.14	
Total	838	16.5	9.4	0.13	44%

Source: (EC 2010)

For developing countries, data on bus fares and ridership are quite limited. Statistics for countries in the FSU block are based on the UNECE database, although for some countries the estimates are for years prior to 2005. For Latin America, the estimates are based on the ICCT's Roadmap.

For Africa and Southeast Asia, for which very limited information is available, we assumed that the relative ratio of bus service to total passenger service is the same as in India (See Chapter 2 – Introduction to Roads Sector).

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7 Walk and Bike

7.1 Methodology and assumptions

The following methodology was adopted for estimating total walk and bike distances in the base year (2005).

- Time spent walking or biking was determined based on the concept of the Travel Time Budget (TTB). Research on TTB has determined that on average individuals budget a fixed amount of time every day on travel – 1.1 to 1.3 hours a day – and that this budget is invariant across societies and over time. While specific individuals or small groups may spend more or less time travelling (like urban residents in cities with congested traffic conditions), the society as a whole reliably averages within the above Travel Time Budget range (Schafer and Victor 2000; Mokhtarian and Chen 2004).

- Time available for walking and biking is calculated based on estimated mode specific speeds (Chapter 1) and travel demand in the base year. Note that average speeds include time spent waiting for public transit.

- For some regions, like the U.S. and Western Europe, daily walking and biking distances have been estimated by national or regional travel surveys (such as the National Household Travel Survey in the U.S.). We adopted estimates from these surveys as summarized by papers published by researchers at Rutgers, New Jersey. (Pucher and Buehler 2006; Bassett Jr, Pucher et al. 2008; Buehler, Pucher et al. 2011).[1]

- Based on travel surveys conducted in developed countries, 80-90% of the travel time in non-motorized modes is spent walking (after excluding European countries like The Netherlands, Denmark and Belgium). We adopted similar ratios for developing countries.

- For India and China, we have estimated two sets of travel demand values in base year – one calibrated to IEA Energy Consumption statistics ((IEA 2007), and other based on bottom-up literature estimates. Bottom-up estimates of energy consumption are around twice the IEA energy statistics, implying that travel time “available” for non-motorized modes are half those assigned in the calibrated versions.

  Even in the later case, the non-motorized travel estimates are quite high – around 800 km and 1,200 km per person per capita for China and India, respectively. We adopted these numbers even in the scenario where energy estimates are calibrated to IEA Energy Statistics.

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[1] Our walking and biking travel estimates based on Travel Time Budget were usually very close to estimates from National Travel Surveys.

8 ROAD FREIGHT

8.1 Data availability and quality

Among all modes, data on trucking is the most difficult to obtain – particularly for developing countries. Even for developed countries, available statistics have a number of limitations. For example, statistics for the U.S. report vehicle kilometers travelled (VKT) but not tonne-kilometers (Tonne-KM). Average non-fuel costs are available for the entire trucking sector, but not for various segments. Similarly, we did not find any non-fuel cost estimates for Australia, although base year service and energy intensities (EI) are available at a high level of resolution. For developing countries, limited statistics were available and there are considerable differences between studies. For example, Zhou and McNeil (2009) report that Indian road freight estimates for 1999 range from 520 to 807 billion Tonne-KM. We have attempted to take mid-point estimates wherever possible. The scope for improving road freight assumptions is large.

The following table uses *Harvey Balls* to assess the quality of rail inputs.

Table 8.1: Qualitative assessment of quality of parameter values for the base year (2005)

	Service	Energy Intensity	Non-fuel costs	Notes
Africa	○	○	◔	A few World Bank reports contain country-specific information about trucking freight rates. All other parameter values based on India. Total proportion of energy on road freight based on statistics from IEA MoMo and ICCT Roadmap models. Disaggregation of size classes based on India.
ANZ	●	●	◑	Detailed Tonne-KM and EI statistics for various market segments available from BITRE Australia (2009), which in turn are based on the annual *Survey of Motor Vehicle Use*. Non-fuel costs were estimated.
Canada	◕	◕	◑	Detailed VKT and EI statistics for various market segments based on *2008 Canadian Vehicle Survey* (Transport Canada 2012). Tonne-KM and non-fuel costs were estimated.
China	◔	◕	◔	Detailed real-world fuel economy (Energy Intensity), stock, and annual VKT survey-based estimates were taken from the series of papers published in Energy Policy (Huo, Wang et al. 2011, Huo, Yao et al. 2011, Huo, He et al. 2012, Huo and Wang 2012, Huo, Wang et al. 2012, Huo, Zhang et al. 2012). Segmentation follows the Chinese classification system (by Gross Vehicle Weight, three classes). To this we add 3W-low-speed (freight) vehicles (also known as "Chinese Rural Vehicles"), for which Energy Intensity, stock, and VKT estimates are all from Teter and Sperling (2013).
EE	◕	◕	◕	Detailed statistics from the TREMOVE Database (EC 2010).
FSU	◑	◔	◔	Total VKT and Tonne-KM statistics from UNECE (2012). Market segmentation, costs and EI were estimated.

India	◑	◑	◑	Large uncertainties in service and energy consumption estimates as highlighted in Chapter 2. Financial estimates are based on various World Bank Studies, and also popular media.
Japan	●	◕	◑	Detailed Tonne-KM for two market segments from Japan Statistics Bureau (2011). Non-fuel costs and EI derived.
Korea	◕	◑	◔	Non financial statistics largely based on Eom, Schipper et al. (2012) and personal communications with Jiyong Eom (PNNL). Financial data based on other countries.
LatAM	◔	○	○	Service estimates partly based on the International Council on Clean Transportation's *Roadmap* (ICCT 2012) and the IEA MoMo Model. Mexico-specific service statistics available from (Mexico - Ministry of Communications and Transport 2012)
ME	○	○	○	Total proportion of energy on road freight based on statistics from IEA MoMo and ICCT Roadmap models. However, total road energy estimates from IEA Energy Statistics are nearly 2X the estimates of MoMo and roadmap. Disaggregation of size classes based on India.
SE Asia	○	○	○	Total proportion of energy on road freight based on statistics from IEA MoMo and ICCT Roadmap models. Disaggregation of size classes based on India.
USA	●	◕	◑	Detailed VKT and EI statistics for various market segments based on *2002 Vehicle Inventory and Use Survey* by U.S. Department of Commerce (Davis, Diegel et al. 2011). Total Tonne-KM consistent with *2007 Commodity Flow Survey* (Davis, Diegel et al. 2011). Non-fuel costs were estimated.
W. EUR	●	◕	◕	Detailed statistics from the TREMOVE Database (EC 2010).

Note: ● reflects high levels of confidence; and ○ reflects low levels of confidence.

8.2 Methodology

8.2.1 Truck load factors

We start by defining the following three terms – vehicle gross weight (GW, also Gross Vehicle Weight Rating or GVWR), payload capacity, and finally load factor (LF, or average payload). GW represents the maximum allowable weight of a vehicle – this includes the vehicle curb weight and the maximum cargo that can be carried (or payload capacity). Truck statistics from various sources are usually segregated based on GW and we follow this practice in GCAM.

Truck payload capacity, defined earlier as the maximum cargo that can be carried, may be calculated at a economy-wide level in terms of available tonne-kilometers divided by total vehicle (truck) kilometers - $TK_{available}/VKT$ (Gucwa and Schäfer 2013). The load factor (LF) is the actual tonne-kilometers divided by vehicle kilometers travelled over a given time period (TK_{actual}/VKT).[1]

[1] In some literature, the load factor may be defined as the ratio of $TK_{actual}/TK_{available}$, as in the case of Gucwa and Schäfer (2013).

The ratio of payload capacity to GW is a physical property and can be established with reasonable certainty for a vehicle or fleet. For small freight carriers like 3-wheelers in India and light trucks in the U.S., the payload capacity is a small percentage of the GW – it could be as low as 30%; while for larger trucks like tractor-trailer, the ratio could reach 65-70% (NRC 2010).

The ratio of load factor to payload capacity ($TK_{actual}/TK_{available}$) is highly variable over time and space, and depends upon multitude of factors like the level of competition, regulatory constraints, management practices, the penetration of information and communication technologies (ICT), etc. Gucwa and Schäfer (2013) indicate that this ratio varies between 50-70% in industrialized countries and holds in such regions for other modes like shipping and rail as well. In developing countries, the ratio might be either higher and lower – on the one hand, truck overloading is common in developing countries (Bansal, Chatterton et al. 2005, Londoño-Kent 2009)[2]; on the other hand, these countries have less sophisticated ICT and management practices, leading to more non-productive empty miles.

On the basis of the above discussion, we assume that the LF to GW ratio ranges from ~25% for small freight carriers to 50% for larger trucks.

The following table summarizes the LF/GW ratios derived from the TREMOVE Database for all of Europe:

Table 8.2: Relationship between Gross Weight and Load Factor (both in metric tonnes)

	Assumed median GW	Average LF (2005)	LF/GW
Light Trucks (<3.5t)	2.5 t	0.80 t	32%
HDT 3.5-7.5 t	5.5 t	1.53 t	28%
HDT 7.5-16 t	12.0 t	4.03 t	33%
HDT 16-32 t	24.0 t	12.26 t	51%
HDT >32 t	32.0 t	16.19 t	51%

[2] Bansal et al. (2005) assume a value of 100% for the ratio $TK_{actual}/TK_{available}$ for India due to the combined effect of overloading ("…typically 30-40% of trucks are overloaded by between 25% and 50%...") and a reluctance of most operators to travel without load, leading to a low utilization rate of trucks in India. We consider this value to be an overestimate, as it does not account for empty returns.

Some countries report road freight statistics in terms of total Vehicle Kilometer Travelled (VKT) for various GW classes instead of Tonne-Kilometers (Tonne-KM). Examples include the U.S. and Canada. We use the ratios in the table above to derive the total freight transportation service delivered in the base year from available VKT statistics disaggregated by truck size in terms of GW.

8.2.2 Segmentation

We segment the trucking sector into three broad categories based on GW – light, medium, and heavy trucks. However, the range of GW and hence LF encompassed by any sub-segment varies across regions. Detailed statistics of market sub-segments are available for the Australia, Canada, Eastern Europe, the U.S., and Western Europe. In the case of Japan, road freight market is divided into private and business use. Some statistics are available for market sub-segments in India and China, and we assume a similar segmentation as India in the other developing regions including Middle East, Africa, SE Asia and Latin America. Segmentation in the FSU is based on Eastern Europe.

8.2.3 Energy Intensity (MJ/Tonne-KM)

Economy-wide energy intensities for road freight are available for various OECD countries – for example (Eom, Schipper et al. 2012). To derive EI for specific truck segments, we rely upon the inverse exponential relationship derived by (Gucwa and Schäfer 2013). based on survey statistics from eight industrialized countries. The relationship is given below

$$LN(EI) = 2.089 - 0.591\,LN(LF) - 0.332\,DS \qquad (8\text{-}1)$$

Where DS is the diesel share and LN represents the natural logarithm. If data on diesel shares are not available in a region, then we assume a 25% share for light trucks and a 100% share for medium and heavy trucks. In addition, there is a country specific dummy variable, which is significant for Japan (coefficient of -0.225).

While the above relationship was derived based on 135 observations from developed countries, we also apply this relationship to developing countries. Prima facie, we expect the energy intensity (EI) in developing countries to be higher, given lower standards of vehicle maintenance, worst road infrastructure, and less sophisticated logistical systems relative to developed countries. For example, a World Bank study (Bansal, Chatterton et al. 2005) reports that trucks in India lose around 15-20% of line-haul time at government checkpoints.

We acknowledge the uncertainty in adopting this relationship to developing countries. offer the following caveat "[U]sing these relationships, our assessment of energy intensity data from the literature has resulted in mixed outcomes. Multiplying inconsistent energy intensities with transportation demand will lead to over- or underestimates of energy use and thus potentially misguided policy recommendations."

Further, the non-linear nature of Equation 8-1 implies that it may be used when the trucking segments are analyzed at a high level of resolution; and/or the distribution of load factors within a selected sub-segment is not very wide. For example, the economy-wide EI and average LF for South Korea is 1.0 t and 2.20 MJ/Tonne-KM respectively (Eom, Schipper et al. 2012). Per Equation 8-2, the EI for the given LF will be around 6 MJ/Tonne-KM.

We compare the results derived from this model with others from our literature review and usually adopt an average estimate.

8.2.4 Non-fuel cost ($/Tonne-KM)

Based on non-fuel costs (operating costs, capital depreciation, and financing costs) for road freight in Western and Eastern Europe (EC 2010, Hill and Morris 2012) and in the U.S. (Fender and Pierce 2011), we estimated the following relationship between non-fuel costs and LF

$$P_{NF}^{Tr} = 1.1324 * LF^{-0.935} \quad (8\text{-}2)$$

where, P_{NF}^{Tr} is equal to the sum of capital and operating expenses ($\boldsymbol{P_{OPEX-Fuel}^{Tr} + P_{CAPEX}^{Tr}}$).

The above relationship is applied to developed countries where segment-specific non-fuel costs are not available – in Korea, Japan, Canada, and the U.S.

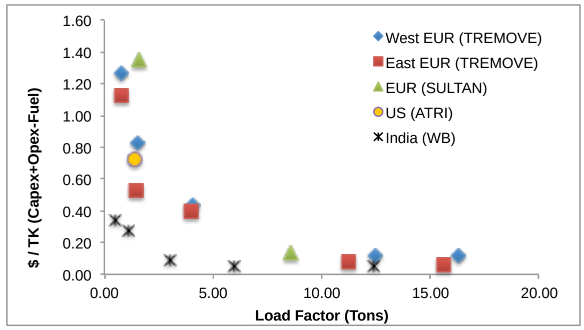

Figure 8.1: Relationship between load factor (LF) and non-fuel costs of road freight transportation (P_{NF})

The non-fuel costs for India in Figure 8.1 are based on freight rates from a World Bank Study (Bansal, Chatterton et al. 2005). The study indicates that the Indian trucking industry is deregulated, fragmented, and highly competitive, which implies that the market operators have zero economic profits. This justifies our decision to use the freight rates, adjusted for fuel costs, as a proxy for P_{NF}^{Tr}.

Figure 8.1 above further indicates that non-fuel costs for India are not consistent with the relationship assumed for developed countries in Equation 8.2. Hence for developing countries, we adopt P_{NF}^{Tr} based on India's data, adjusted for the difference in freight rates between the given country/region and India. The "current" freight rates in various developing countries are taken from another World Bank Study (Londoño-Kent 2009) and are given below:

Table 8.3: Average current truck freight rates in various countries for long-distance truck transportation

		Freight costs (US cents / Tonne-KM)
India	- India	1.9-2.7
SE Asia	- Bangladesh	5.5
	- Indonesia	3.5-8.5
	- Pakistan	1.5-2.1
LatAM	- Brazil	2.5-4.8
	- Argentina	1.8-3.8
	- Mexico	10
Africa	- Cameroon	8
	- Ethopia	4.0-6.0
	- Ivory Coast	8.0-14.0

	- Nigeria	15-18
	- Tanzania	8.0-14.0
China	- China	4.0-6.0

Source: World Bank Study (Londoño-Kent 2009)

Given India's segment-specific freight rates (Bansal, Chatterton et al. 2005), we assume that P_{NF}^{Tr} for other regions are a multiple of P_{NF}^{Tr} in India, where the multiple is based on differences in freight rates as summarized in Table 8.3. We also assume that the differences in non-fuel costs (freight rates) will gradually converge to levels in India based on the following table.

Table 8.4: Non-fuel trucking costs in various regions as a multiple of India's costs

	2005	**2050**	**2095**
India	1.000	1.000	1.000
Africa	2.500	2.000	1.800
China	2.000	1.600	1.440
FSU	1.500	1.200	1.080
Latin America	2.000	1.600	1.440
Middle East	1.500	1.200	1.080
SE Asia	1.500	1.200	1.080

Source: Our assumptions

8.3 References

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9 RAILWAYS

9.1 Data availability and quality

In comparison to data on the road sector, data on passenger and freight rail transportation are more readily available. The World Bank maintains a comprehensive database of rail transportation volumes (train-kilometers, passenger-kilometers, and freight-kilometers) and revenues for nearly all countries (http://data.worldbank.org/). The Bank has also played a role in modernizing and privatizing rail assets in a number of developing countries. Detailed analysis and information about these projects were quite valuable in our formulation of rail assumptions. Further, the rail sector in many countries is a monopoly or oligopoly; as a result data collection is easier and statistical uncertainties are lower than in the road sector. For example, the railway sector in India is dominated by the publicly owned Indian Railways, which publishes a comprehensive statistical compendium on all aspects of rail operations. In the United States, freight rail transportation is dominated by a handful of Class I rail operators, most of which are listed on the stock market. This means that those operators' Annual Reports, and Form 10K, are publically available. However, there are a number challenges in formulating assumptions for rail – we discuss these throughout the report.

The following table uses *Harvey Balls* to assess the quality of rail inputs.

Table 1: Qualitative assessment of quality of parameter values for the base year (2005)

	Service	Non-fuel costs	Subsidies	Energy Intensity	Notes
Africa	◑	◔	◔	◔	Limited statistics from the World Bank. Most values were adopted from India.
Australia and New Zealand (ANZ)	●	◑	◔	●	Detailed non-financial statistics from BITRE Australia (2009). Financial statistics from the World Bank and (QR National 2011).
Canada	◕	◑	◕	◕	Detailed inter-city and limited intra-city statistics from (Transport Canada 2012). Some values adopted from the U.S.
China	◕	◔	◔	◑	Service and EI estimates from the UIC (International Union of Railways) (http://www.uic.org).
Eastern Europe (EE)	◕	◑	◑	◕	Detailed statistics from the EU sponsored SULTAN project (Hill and Morris 2012).
Former Soviet Union (FSU)	◕	◑	◕	◔	Various financial and non-financial statistics from Russian Railways (Russian Railways 2011), the UN Economic Commission for Europe (UNECE 2012), and the Russian Government (FSSS - Russian Federation 2012).
India	●	◕	◕	●	Detailed statistics from Indian Railways annual reports (Indian Railway Board 2010).

Japan	●	◑	◑	◕	Non-financial statistics from (Japan Statistics Bureau 2011). Financial statistics based on a review of Japan Railway's annual reports (JR-East, JR-West, JR-Central and JR-Freight).
Korea	◕	◔	◔	◕	Non-financial statistics from (Eom and Schipper 2010). Financial values were adopted from Japan and West EUR.
Latin America	◑	○	○	◔	The World Bank Statistics. The Rail sector, especially passenger rail, has gone through tumultuous phase over last 2 decades and witnessed privatization / renationalization in various countries. Passenger traffic has declined along with public subsidies and larger macroeconomic indicators. Given the tumultuous phase, all statistics for 2005 are suspect.
ME	◑	○	○	◔	IEA energy statistics show no rail in the Middle East, but World Bank statistics show limited freight and passenger movements in Iran, Syria, Jordan and Saudi Arabia. We calibrate to IEA Energy Statistics
SE Asia	◑	◔	◔	◔	The World Bank. Values adopted from India.
USA	●	◕	◕	●	Detailed statistics from various Amtrak (intra-city) and APTA (inter-city, (APTA 2011)) reports.
Western Europe	●	◕	◕	◕	Detailed statistics from the EU sponsored SULTAN project (Hill and Morris 2012), and the European Commission's TREMOVE Database (EC 2010).

Note: ● reflects high levels of confidence; and ○ reflects low levels of confidence.

9.2 Methodology

9.2.1 Background

IEA rail energy statistics are aggregated at the level of total diesel, electricity, and coal consumed by the entire railroad sector in the country. The following constraint needs to hold

$$\sum_i E_i = \sum_i T_i^{PR} EI_i^{PR} + \sum_i T_i^{FR} EI_i^{FR} \tag{9-1}$$

where

Subscript *i* stands for fuel/energy carrier (diesel, electricity, and coal),

E is the total energy consumed by rail in PJ and is from IEA Energy Statistics,

T is rail transportation service in either passenger-kilometers (superscript PR) or tonne-kilometers (FR),

EI is the energy intensity in MJ/PKT or MJ/TKM, which differs for each technology *i*,

As with the other energy use data, GCAM's base year rail energy consumption values are calibrated to IEA energy statistics (Citation, IEA, year).

One of the key uncertainties to be handled in rail statistics is how to disaggregate total diesel and electricity use between freight and passenger rail operations. Similarly, electricity use in passenger rail must be disaggregated between conventional- and High Speed Rail.

In some cases, the fuel/energy carrier split for passenger versus freight rail is available in the literature (e.g. India, United States, Canada, Australia, Western Europe, Eastern Europe). In most others, we had to make assumptions based on the ratios evident in the above countries and on anecdotes indicating that higher proportion of electricity (diesel) is used in passenger (freight) operations. This is clearly an area for future improvement as data becomes available in other countries.

9.2.2 Transportation service in base year

Passenger and freight rail service (in billion PKT and TKM) for various countries and regions are the most easily available statistics in this entire project covering all transportation modes. However, the GCAM service output in 2005 may not match the statistics from our literature review. The typically small differences arise from three sources – (i) the IEA energy statistics may not match the energy statistics from region-specific literature, (ii) assumptions disaggregating diesel and electricity use between freight and passenger may not be accurate, and (iii) assumed relative energy intensities of diesel and electric rails "lead to differing service estimates (see latter section).

Refer to the section on Energy Intensity (below) for further discussion on this topic.

9.2.3 Non-fuel cost and subsidies in the base year – Conventional Passenger rail

The non-fuel conventional passenger rail cost is

Table 1: Rail transportation service in 2005 (base year) – literature estimates and values adopted in GCAM.

	Tonne-KM		PKT			Notes
	Literature Review	GCAM calibrated	Literature Review	Share of HSR	GCAM calibrated	
Africa	138	128	50		57	We adopted EIs so that calculated energy service matches World Bank and UIC Statistics
ANZ	227	246	12		10	
Canada	352	351	3	0%	3	
China	1953	2155	600		658	Source: International Union of Railroads (UIC)
EE	114	168	50		73	Reason for discrepancy unknown. TREMOVE and World Bank estimates are very similar. We adopted TREMOVE estimates of EI – implying that IEA energy consumption estimates are higher than TREMOVE.
FSU	2,263	2,391	256		253	EI calculated based on literature-cited service estimates and energy estimates from the IEA.
India	442	506	616	0%	677	Total energy consumption from Indian Railways matches IEA value. However relative shares of liquids and electricity do not match.
Japan	23	23	391	20%	370	No adjustments.
Korea	10	12	55	16%	60	
LatAM	315	334	10	0%	11	EI calculated based on literature-cited service estimates; energy use from IEA.
ME	24	0	12		-	IEA statistics indicates zero rail energy use in ME.
SE Asia	19	20	77		80	EI calculated based on literature-cited service estimates; energy use from IEA.
USA	2,692	2,194	53	0.4%	48	IEA Energy statistics are around 20% lower than AAR and BTS statistics.
W. EUR	330	419	377	5%	529	Reason for discrepancy unknown. We adopted TREMOVE estimates of EI – implying that IEA energy consumption estimates are higher than TREMOVE.

estimated using a top-down approach similar to that taken for freight rail and buses.

$$\boldsymbol{P_{NF}^{PR} = (P_{OPEX-Fuel}^{PR} + P_{CAPEX}^{PR}) + P_{Fuel\,Tax}^{PR} - S^{PR}} \tag{9-2}$$

Estimates are dependent upon two parameters – the revenue estimates and the extent of public funding/subsidy. Rail revenues were estimated from individual annual reports (India, Japan, Russia, and the U.S.), or detailed publicly available databases like the World Bank and APTA (APTA 2011).

The level of public subsidy is equal to the difference in fare revenues and operating expenses and was estimated at around 50% for the U.S. and Canada, 67% for Russian Railways, and 72% for Indian Railways. For Japan, (Mizutani 1999) reviewed the 1995 annual reports of all Japanese Railways (JR) and estimated operating profits in the range of 16-50% for JRs operating on the main island (Honshu JR), which accounted for 93% of total JR traffic and 60% of total traffic in Japan. We reviewed many of the 2005 JR annual reports and concluded that fare revenues cover operating expenses (including depreciation and interest expenses). A similar conclusion was reached by (Oum and Yu 1994) who reviewed the JR financials in the 1980s. Given the above, we assume a subsidy level of only 20% for Japan to account for loss making in the routes covering the three islands (Mizutani 1999). This high cost recovery ratio in Japan may be attributed to high load factors[1] (around 300 persons per train).

For Latin America, we assumed a subsidy level of 25% taking into account the privatization and reduced government involvement after the Latin American financial crisis in 1990s[2] based on the following references (Carbajo and Estache 1996; Sharp 2005). For South Korea, we adopted the financial numbers and load factors from Japan – and consequently, a subsidy level of 20% as well.

For all other countries, relevant data is not available; we simply assume a 50% average passenger rail subsidy. Non-fuel expenses are the sum of revenues and public subsidies.

There are two distinct kinds of passenger rail services – long distance inter-city and short-distance transit or suburban operations. The two are expected to differ in terms of occupancy factors, costs, energy intensities, etc. Thus transit operations in the U.S. – which are further subdivided into commuter rail, heavy rail, and light rail – have an average non-fuel cost of 25 cents/passenger-km versus 33 cents/passenger-km for Amtrak's inter-city operations. The corresponding fares are 12 cents and 24 cents. Countries also differ in terms of the relative shares of the two passenger services in the base year; and in the evolution of the shares over the past several years.[3] Our input parameters represent weighted average values over the time-period for which data were available in each country.

The following graph shows the assumed non-fuel passenger rail cost before subsidies $(\boldsymbol{P_{OPEX-Fuel}^{PR} + P_{CAPEX}^{PR}})$, and the level of subsidy for each of the 14 regions in GCAM.

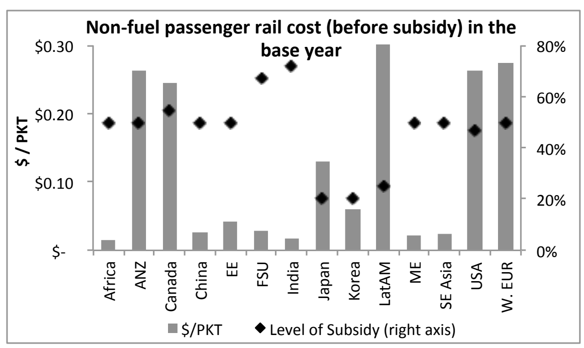

Figure 9.1: Non-fuel passenger cost (before subsidy) in 2005

The difference in $/PKT is partly explained by differences in average train load factors – which

[1] For rail, we define load factor as the number of passengers per train. Occupancy rate is defined as the capacity utilization factor, i.e. the number of seats occupied on average.

[2] For example, in Argentina, subsidies fell from around US $2 billion in late 1980s to around US $100 million in 1990s (Carbajo and Estache 1996). However, total passenger-km fell from around 50 billion in 1980s (Sharp 2005) to around 12 billion in 2005 – the greatest decline being in Mexico and Brazil where inter-city rail movement is negligible.

[3] The share of long distance rail in total rail PKM ranges from low levels in North America (~0% in Mexico, 20% in the US, and 38% in Canada) to 72% in European Union and 85% in India. It should be noted that the definitions of sub-urban and inter-city traffic might differ among these regions.

range from a low of 30 passengers/train in the U.S. to around 120 in Western Europe, 300 in Japan, and 1,150 in India. Differences in cost may also be the result of differences in the level of amenities provided – for example trains in the developed countries are usually air conditioned unlike developing countries. Railroads in developing countries rarely have independent dining and lounge cars as are seen in inter-city rail in developed countries (like Amtrak in the U.S.).

The above graph represents the average non-fuel costs for passenger rail transportation.

As in case of buses, we make the following simplifying assumptions to model different propulsion technologies (liquids and electricity):

- To differentiate between diesel and electric rail operations, we assume that diesel rail is 25% more expensive than electric rail based on the European Union funded TOSCA project (Andersson, Berg et al. 2011).
- Fares charged (and hence generalized user costs) do not vary between technologies.
- The difference is then adjusted in the level of subsidies.

9.2.4 Non-fuel cost and subsidies in the base year – Freight rail

$$\boldsymbol{P_{NF}^{FR}} = (\boldsymbol{P_{OPEX-Fuel}^{FR}} + \boldsymbol{P_{CAPEX}^{FR}}) + \boldsymbol{P_{Fuel\,Tax}^{FR}} - \boldsymbol{S^{FR}} \qquad (9\text{-}3)$$

As with all other modes, total non-fuel freight rail cost ($\boldsymbol{P_{NF}^{FR}}$) includes levelized capital costs ($\boldsymbol{P_{CAPEX}^{FR}}$), non-fuel operating costs ($\boldsymbol{P_{OPEX-Fuel}^{FR}}$), fuel taxes ($\boldsymbol{P_{Fuel\,Tax}^{FR}}$), and any government subsidies ($\boldsymbol{S^{FR}}$).[4]

Unlike car and 2W markets, non-fuel costs are estimated using a top-down approach based on reported operating expenses and/or operating revenues. For countries and companies with detailed financial disclosures (e.g. the U.S., Russia, Canada, and India), we take the non-fuel operating expenses from the annual reports. We use depreciation as a proxy for capital investments. Finally, as a proxy for financing costs we use annual interest expenses and net profits. In each of the above countries, the railroad operators are responsible for both rolling stock and fixed stock – thus our non-fuel cost estimates include both.

In India and Russia, national rail operators provide both freight and passenger services. While revenues and transportation service estimates are published in each of the two markets, expenses are aggregated. Due to lack of data, we divided the expenses between freight and passenger services based on train-km travelled.

For all other countries, we depend upon the total freight revenue and freight tonne-KM statistics from the World Bank and assume a fixed percentage of revenues are used to cover fuel – this value is subtracted to obtain non-fuel freight rail costs. This percentage is the average rate for the various rail operators we studied in detail and is around 27%.[5]

Subsidies to freight railroads are assumed to be zero. This is based on a review of annual reports of dedicated freight rail operators in North America and Australia like UP and BNSF, as well as both freight and passenger operators like Indian Railways and Russian Railroads; and financial statistics from TREMOVE covering freight rail operations in Europe. Our analysis indicates that freight operations are competitive without government support and generate positive returns.[6] An exception may be JR Freight – the freight railroad operator in Japan (Fukui 2008). We did not find any information about the level of subsidies for JR Freight and assume it to be zero.

The following graph summarizes the non-fuel costs ($\boldsymbol{P_{NF}^{FR}}$) we adopted in GCAM.

[4] All cost-related and energy intensity parameters for both freight and passenger rail are on a per Passenger-KM basis unless explicitly mentioned.

[5] The implicit assumption in such an approach is that freight operations are profitable and provide positive returns to both lenders and equity investors. A further assumption is that the net profit (and net share of fuel costs) of freight operations is constant across countries.

[6] We acknowledge that this assumption may not be correct across all regions – national railroads like Indian Railways receive implicit subsidies in form of low cost funds, or explicit subsidies to build rail tracks which may be used for both passenger and rail operations.

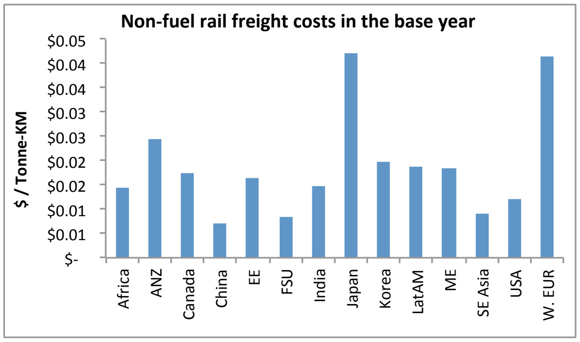

Figure 9.2: Non-fuel freight rail costs in 2005

The differences between countries may be attributed to differences in labor productivity (e.g. tonne-km per person-hour), capital productivity (e.g. load factor – tonnes per train-km), and the type of freight carried (e.g. raw minerals versus manufactured goods). Thus, for example, the labor costs are around $8/hour in India versus $50/hour in the U.S. (2005 dollars) However, total non-fuel costs in the two countries are similar due to large differences in labor productivity – 500 and 10,000 net tonne-km / person-hour in India and the U.S. respectively.[7]

The above graph represents the average non-fuel costs for freight rail transportation. To differentiate between diesel and electric rail operations, we assume diesel rail is 67% more expensive than electric rail based on the European Union funded TOSCA project (Andersson, Berg et al. 2011).

9.2.5 Energy intensity in the base year

Energy intensities (EI) of passenger and freight rail operations are available for the U.S., Canada, Western Europe, Eastern Europe, South Korea, India, China, and Australia. Based on a subset of these countries, we assume that diesel rail is 2.3x and 3x times more energy intensive than electric rail operations.

For the remaining regions, energy intensities are estimated based on three constraints: (i) total rail passenger and freight service must match estimates from the World Bank and other sources, (ii) total energy consumption must match IEA statistics, and (iii) diesel and electric rail intensities satisfy the above mentioned EI relationships.

The following graph gives our base year assumptions about EI in different countries (these are calculated as a weighted average of diesel and electric rail). The large variability in MJ/PKT is quite surprising – it ranges from 0.09 in India[8] to 2.33 MJ/PKT in the U.S. It may be partly explained by large differences in occupancy rates (load factors) and available amenities – as discussed in the prior section. Scholl et al. (Scholl, Schipper et al. 1996) had reviewed the passenger rail intensity of OECD countries in 1992 and estimated it to range from 0.42 MJ/PKT in Japan to 2.12 MJ/PKT in the U.S.

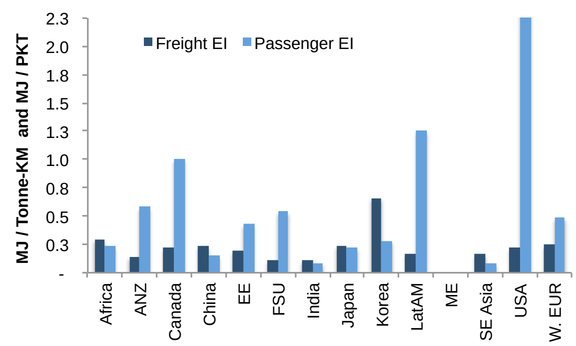

Figure 9.3: Freight and passenger rail energy intensity in 2005

9.2.6 Evolution of input parameters over time

In the current version of the model, we simplistically assume that $(P^{PR}_{OPEX-Fuel} + P^{PR}_{CAPEX})$ and $(P^{FR}_{OPEX-Fuel} + P^{FR}_{CAPEX})$ remain constant over time (constant dollar basis). Level of subsidies and fuel taxes are a policy tool, which are

[7] In Western Europe, where labor costs are likely to be similar to the U.S., labor productivity is quite low leading to large non-fuel costs. For example, in Sweden, the labor productivity is around 2,500 gross tonne-km / person-hour or around 2000 net tonne-km (based on personal communications with Professor Evert Andersson, Royal Institute of Technology, KTH, Sweden).

[8] Singh 2006 indicates that the EI of Indian Railways is 0.19 MJ/PKM compared to 0.09 MJ/PKM (authors' calculations using Indian Railways' Annual Reports). The reason for this difference is not clear. (Singh, S. K. (2006). "Future mobility in India: Implications for energy demand and CO2 emission." Transport Policy **13**(5): 398-412.

assumed constant in the Baseline Scenario – implying that P_{NF}^{PR} and P_{NF}^{FR} remain constant over time. Similarly, load factors are assumed to remain constant over time.[9]

As discussed in detail below, we adopt TOSCA's assumptions about advanced passenger and freight rail (Andersson, Berg et al. 2011; Andersson, Berg et al. 2011). These represent a combination of different technologies, which are in different stages of development and expected to be commercialized as a whole by 2025 or later.

For passenger rail, these technologies include (i) low drag trains which can potentially reduce energy use by 10% relative to reference trains due to better aerodynamics, (ii) low mass trains made of advanced light-weight materials that can potentially reduce energy use by 10%, (iii) further improvements in energy recovery and regeneration, (iv) space efficient trains that increase carrying capacity by using wide-bodied and/or double-decker rail cars, and finally (v) eco-driving aided by driver training, computerized support, and/or automatic train operation that can reduce energy use by 5-10%. A combination of these technologies is assumed to reduce energy intensities by around 40% relative to reference diesel as well as electric trains per the TOSCA study. Further, $(P_{OPEX-Fuel}^{PR} + P_{CAPEX}^{PR})$ is projected by TOSCA to reduce by 12% for electric and 22% for diesel. We assume that the trains will be commercially available in 2035 in the baseline scenario and in 2020 in the advanced technology scenario. A similar combination of technologies in the freight railroad industry will reduce energy intensity by greater than 50%, but $(P_{OPEX-Fuel}^{PR} + P_{CAPEX}^{PR})$ by around 6-10%. While TOSCA's analysis focused on Europe, we adopted their estimates globally.

[9] This implicitly assumes that the relative shares of inter-city and intra-city/suburban trains remain constant over time. Per BTS National Transportation Statistics, the share of inter-city Amtrak service in total rail passenger-kilometers dropped from 25% in 1990 to 19% in 2010. Based on statistics from Transport Canada, the share of inter-city VIA Canada service also dropped from 49% to 39% between 1999 and 2010. Since suburban rail has both lower EI and non-fuel costs, changes in EI and non-fuel costs should incorporate such dynamics. The current version of the model does not incorporate these dynamics – largely due to data constraints.

9.2.7 High Speed Rail[10]

High Speed Rail (HSR) systems are already operational in a few regions – Japan, Korea, West EUR, and most recently in China. To model HSR in other countries, we had to adopt a number of simplifying assumptions – especially those pertaining to energy intensity (MJ/PKT) and non-fuel costs (P_{NF}^{HSR}). To calculate region-specific values, we estimate the deviation of EI and non-fuel costs of HSR from that of conventional electric rail[11] in those countries.

There is substantial variability in values of these variables (absolute), as well as the percentage deviation of these values from those of conventional rail in those regions (relative). The absolute variability in operating and capital investment costs have been discussed by Campos and de Rus (2009).

- Energy intensity (MJ/PKT) relative to conventional rail

When measured on a MJ/Train-KM basis, *and standardizing for the carrying capacity of the train*, the energy intensity of HSR is around 15% to 22% higher than conventional electric rail ((EC 2010; Andersson, Berg et al. 2011; Hill and Morris 2012). Higher speeds are likely to result in lower energy efficiency. However, HSR cars have higher occupancy factors -- 60-80% occupancy versus 30-40% occupancy of conventional rail (Nakagawa and Hatoko 2007; Kosinski, Schipper et al. 2010; Mikhail and Arpad 2010; Nixon 2012).[12] As a result, on an

[10] UIC (International Union of Railways) and European Commission define HSR as trains that "generally" operate at speeds ranging from 200 to 250 km/hour (Campos and de Rus 2010). We have relaxed this definition to include trains like Amtrak's Acela Express, which has an average speed of 130 km/hour.

[11] We assume that High Speed Rail will be electric powered and not diesel powered. This may not be wholly accurate. Electric powered trains are necessary only for speeds beyond 200 km/hour (Peterman et al. 2009). The TREMOVE model accommodates diesel-power HSR. However, we only model electric HSR for sake of simplicity. Nearly all HSR trains running today are electric.

[12] For simplicity, we assumed that load factor of HSR trains is same as electric conventional rail. Given that occupancy factors are nearly double (60-80% instead of 30-40%), the implicit assumption is that capacity of HSR is 50% of conventional rail for developed regions. This does not affect any of our results.

MJ/Passenger-km basis, the EI of HSR is around 30% less than conventional electric rail per the TOSCA study. Similarly, in Japan, the Shinkansens are 30% more efficient than conventional rail (Kosinski, Schipper et al. 2010; Lipscy and Schipper 2012).[13]

For developed countries where there are no statistics available, we assume that HSR systems have the same EI (MJ/PKT) as conventional rail in those countries.

In developing countries, train occupancy rates are likely to be much higher than developed countries (i.e. with a 30-40% occupancy factor, as mentioned above). While there exist no specific statistics in this regard, the high load factor of trains in India and China may indicate that occupancy rates are high in these countries. A performance audit of Indian Railways by the Comptroller and Auditor General of India in 2008-09 (CAG India 2009), considered an occupancy rate below 50% in 30 of the 204 trains introduced since 2003 as a cause for concern – this suggests that average occupancy rates are much higher. As a result, we do not expect HSR in developing countries to enjoy superior occupancy rates compared to conventional rail. We assume that the EI of HSR (MJ/PKT) in developing countries is 25% higher than conventional rail.

- Non-fuel costs ($/PKT) and level of subsidy relative to conventional rail

The non-fuel costs of HSR are expected to be higher than conventional rail due to more technologically advanced, and hence more expensive, fixed and rolling stock – although higher occupancy factors are expected to mitigate some of the excess costs when considered on a passenger-kilometer basis.

The following table from a European Commission sponsored study (Steer Davies Gleave 2006) gives the operating and infrastructure costs (fixed and rolling) and "average" fares for a few HSR routes in Europe. The average non-fuel costs ($\boldsymbol{P^{HSR}_{OPEX-Fuel}} + \boldsymbol{P^{HSR}_{CAPEX}}$) for the routes is around $0.20 / passenger-km.

According to the TOSCA study, the HSR non-fuel costs ($\boldsymbol{P^{HSR}_{OPEX-Fuel}} + \boldsymbol{P^{HSR}_{CAPEX}}$) are 40% lower than conventional electric trains on a PKM basis (though they are 10-15% higher when measured on a $/Train-km basis, and after adjusting for capacity differences).

[13] Results confirmed by Dr. Evert Andersson, KTH via personal communications with the author.

Further, HSRs have higher fares (revenues) when measured on a $/PKM basis. For example, our review of the annual reports of JR Central and JR East indicates that Shinkansens have a revenue of 22-24 Yen/PKM versus 11-12 Yen/PKM for conventional rail. Similarly, the fares of Amtrak's Acela (U.S.) are more than twice those of the conventional North Eastern Corridor (NEC) running on the same route (Nixon 2012).

The above discussion points to a much better cost recovery ratio for well-established HSR routes compared to conventional routes. For example, Amtrak's Acela (U.S.) earned an "operating profit" of US $200 million on US $500 million of revenues (Nixon 2012); and the Lyon-Paris and Tokyo-Osaka HSRs are also estimated to be turning profits (Ryder 2012). However, establishing a level of subsidy that covers both operating and capital costs is difficult – capital costs are large and are typically paid by the government (Ryder 2012). Based on data on HSR in various European markets from (Steer Davies Gleave 2006), we calculated the simple average subsidy to be around 20% although the level of subsidy varies widely between routes – from 0% in the London-Paris route to almost 70% in the London-Manchester route. It should be noted that concept of "average" fares is very difficult. Railways usually have advanced yield management systems, and fares change over time based on ridership levels and competition from road and rail.

We make the following simplifying assumptions.

1. Fares in High Speed Rail are twice that of conventional (electric) rail. In other words, the non-time component of Generalized User Costs is twice the level of that for conventional trains.

2. The CAPEX and OPEX-FUEL components are 50% higher for a single period (15 years) on a $/Train-km basis than conventional electric trains in regions where HSR is well established – Japan, Korea and Western Europe. Subsequently, the costs are assumed to be only 25% higher. In all other markets, we assume that these costs (on a $/Train-km basis) are 50% higher for the initial phase (two-time periods or 30 years) to account for the huge initial capital investments such as planning expenses, land accusation, fixed and rolling infrastructure, and setting up of systems and processes. Subsequently, costs are expected to stabilize to a level similar to that

Non-fuel costs ($P^{HSR}_{OPEX-Fuel} + P^{HSR}_{CAPEX}$) and subsidies S^{PR} for a few HSR services in Europe ($/passenger-kilometer)

	Non-fuel OPEX	CAPEX	Total	Infrastructure Subsidy	Occupancy Factor	Fares	Calculated Total Subsidy
London - Paris	$ 0.08	$ 0.16	$ 0.23	$ -	75%	$ 0.25	0%
London - Manchester	$ 0.13	$ 0.15	$ 0.28	$ 0.09	60%	$ 0.08	70%
Frankfurt - Cologne	$ 0.08	$ 0.14	$ 0.22	$ 0.05	60%	$ 0.26	0%
Rome - Milan	$ 0.10	$ 0.10	$ 0.19	$ 0.08	65%	$ 0.12	35%
Paris - Marseille	$ 0.06	$ 0.08	$ 0.14	$ 0.03	75%	$ 0.12	15%
London - Edinburgh	$ 0.09	$ 0.09	$ 0.18	$ 0.05	50%	$ 0.20	0%
Madrid - Seville	$ 0.11	$ 0.05	$ 0.16	$ 0.02	70%	$ 0.14	12%
Madrid - Barcelona	$ 0.10	$ 0.06	$ 0.17	$ 0.02	75%	$ 0.14	18%
Average	**$ 0.09**	**$ 0.10**	**$ 0.20**	**$ 0.04**	**66%**	**$ 0.16**	**20%**

Notes: The above table is based on a European Commission sponsored study (Steer Davies Gleave 2006). Energy costs are a small percentage of total costs (3-5%) as given in Figure 3.5 of the above study. CAPEX includes rolling stock and fixed infrastructure costs.
The fares are based on review of actual fares in 2006 as reported in the cited study. Based on the reported fares and total expenses, we calculated the level of subsidy for individual routes.

in Japan and Western Europe.

3. The level of subsidy is calculated to ensure that #1 and #2 above are satisfied. In certain cases, like Japan, a negative subsidy results from the above steps. This may be consistent with observations by (Ryder 2012).

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10 AIR

This chapter describes the data and calculations of the GCAM air transportation module. This module includes five exogenously specified variables: load factor (number of passengers per aircraft), energy intensity (MJ of fuel used) (MJ/VKT), capital costs in $2005 ($/VKT), operating costs in $2005 ($/VKT), and fuel tax in $2005 ($/VKT), where all variables but the first are estimated on a per vehicle kilometer travelled basis. Each variable is estimated for the years 2005-2095 for each of the 14 GCAM regions. Additionally, for all variables except load factor, both reference technology and advanced technology cases are developed. The estimates here are only for commercial passenger airlines (i.e. air freight and private aircraft are not considered).

10.1 Structure of Data

Air passenger data in GCAM is broken into two categories: trips greater and less than 2000 km. This delineation differs from most major airline energy and travel databases which typically classify flights according to whether the flight crosses national boundaries (i.e. international versus domestic). Our reason for delineating based on distance is that the stage length (not whether a flight is domestic or international) is highly correlated with a flight's energy intensity measured in MJ per passenger-kilometer traveled (MJ/PKT), emissions in grams of CO_2 per MJ (gCO_2/MJ), and load factor in number of passengers per vehicle (pass). Our categorization of air travel is appropriate because many countries in the world (and in particular in Europe) have small land areas. In such regions, shorter flights compete with other modes (e.g. high speed rail, or even passenger cars), and the distinction between domestic and international trips makes little sense.

10.2 Load Factors

Load factors – defined here as the average number of passengers per aircraft for a given range category (e.g. < 2000 km) – are taken from (BTS 2012) for the United States and (ICAO 2005) for the rest of the world.

Load factors reflect the interaction of two separate variables: the average capacity of an aircraft and the average percent occupied.[1] In many regions, the two variables are inversely correlated. For example, even though the Middle East has a relatively low percent occupied rate for trips less than 2000 km as compared to other regions – AACO reports average load factors of 71% in 2009 (Arab Air Carriers Organization (AACO) 2010) – they tend to have larger capacity aircraft than other regions, and so have the highest load factor of all the GCAM regions.

Country	< 2000 km Load Factor (pass/veh)	> 2000 km Load Factor (pass/veh)
USA	125	233
Canada	125	233
Western Europe	121	224
Japan	122	224
Australia_NZ	122	224
FSU	121	224
China	122	224
Middle East	138	226
Africa	125	216
Latin America	114	204
Southeast Asia	114	204
Eastern Europe	121	224
Korea	122	224
India	122	224
WORLD (avg)	125	222

Table 9.1. Assumed load factors in the year 2005. Sources: (BTS 2005, ICAO 2005)

Data from (ICAO 2005) was available only for Africa, Latin America, Middle East, North America, Asia/Pacific, Europe/CIS, and for world averages. Since the GCAM regions are more highly disaggregated than these regions, we assumed that all GCAM regions within an ICAO region had the same load factor in 2005 (e.g. China and India are both assigned the Asia/Pacific load factor).

[1] In many airline industry reports and academic literature, the term "load factor" refers to the percent occupied (and is therefore reported as a percentage). Here, we define it as passengers per vehicle.

Operationally, airlines are becoming more efficient at scheduling flights and filling seats. There is good reason to believe that the percent occupied will continue to increase gradually for most regions of the world. However, we are less certain about how the total number of seats (i.e. capacity) of aircraft might change in the future. In the U.S. airline industry, turboprops and narrow-body aircraft are gaining a higher share within the fleet while wide-body aircraft are losing share. Between 2002 and 2011 in the U.S., the number of wide-body aircraft decreased from 614 to 463 aircraft ((IATA) 2011). Since we suspect that the percent occupied rates will continue to climb and aircraft capacities trends are uncertain, we base future growth rates of load factors on the historical growth rates of percent occupied ((IATA) 2011). The implicit assumption is that aircraft capacities will not change. Table 9.2 below shows the values used as load factor growth rates for developing and developed countries.

	Growth Rate (%/yr)	
Period	Developed	Developing
2005-2020	0.50%	0.50%
2020-2035	0.35%	0.35%
2035-2050	0.20%	0.20%
2050-2065	0.00%	0.00%
2065-2080	0.00%	0.00%
2080-2100	0.00%	0.00%

Table 9.2. Growth rates in load factors for developed and developing regions. Zero growth is assumed after the year 2050.

We assume that developing regions have slightly higher growth rates because those regions have slightly lower average load factors in the base year (2005). Using these growth rates and our assumption that all airlines have a 77% occupied rate in 2005 (IATA 2011), then annual growth rates will ensure a percent occupied of 82.9% in 2020, 87.4% in 2035, and 90.1% after 2050. Some (Lee 2000) suggest that 90% is the maximum feasible percent occupied.

As stated above, no distinction was made between the BAU and Advanced Technology scenarios for load factors.

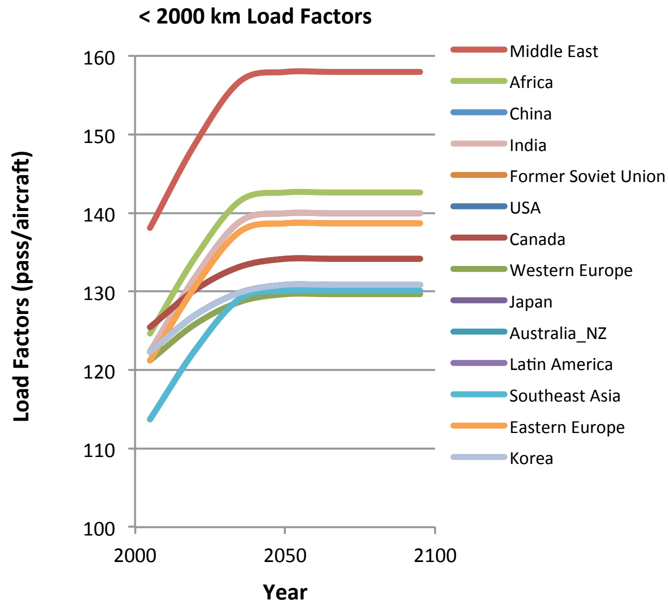

Figure 9.1. Load Factors for flights < 2000 km for 2005-2100 for the 14 GCAM regions

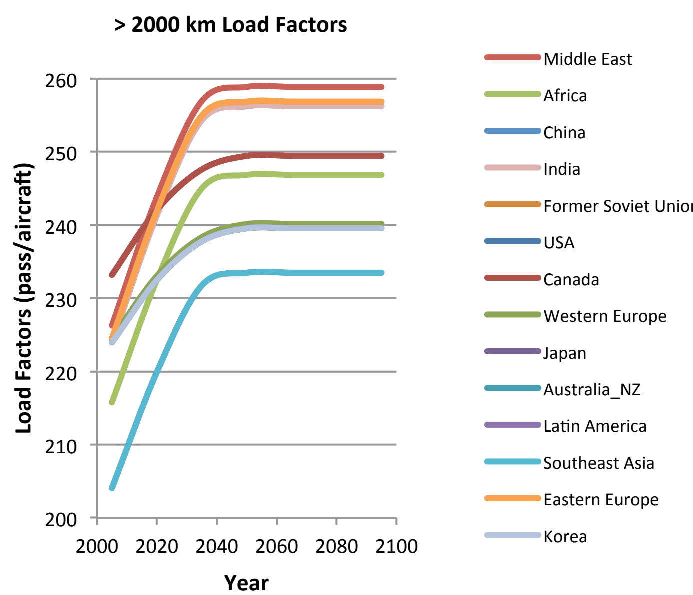

Figure 9.2. Load Factors for flights < 2000 km for 2005-2100 for the 14 GCAM regions

10.3 Energy Intensity (MJ/VKT)

Estimating air energy intensity (measured in MJ per vehicle kilometer traveled) is challenging because no data sources provide both energy use and passenger-km data. Additionally, it is unclear how many data sources account for fuel use or pass-km in international flights. For example, for a flight from the U.S. to Europe, will the energy use and pass-km be attributed to the U.S. or Europe or split 50/50? Furthermore, energy statistics in aviation typically aggregate both passenger travel and freight energy use together. Lastly, datasets on pass-km rarely count short trips or aircraft below a certain size while energy use statistics generally account for all aviation energy use.

As stated above, we delineate air travel by distance rather than by domestic vs. international. However, to give a sense of how wide the variability in the calculations of air energy intensity can be, we calculate MJ/PKT using a variety of datasets in Table 9.3. The data source(s) are given in the left-hand column (for example, IEA+ICAO means the energy intensity was estimated by taking the air energy use reported in (IEA 2005) and dividing by the pass-km reported in (ICAO 2005). Of these datasets, the most comprehensive for air pass-km travel is (ICAO 2005) while the most comprehensive for air passenger energy use is (IEA 2005).

World Passenger Energy Intensities (MJ/PKT)

Datasets	Domestic	International
IEA + ICAO	2.24	2.26
TREMOVE (Europe only)	various	various
SAGE + ICAO	2.73	1.51
IEA + Boeing	1.82	2.98
SAGE + Boeing	1.93	1.85
BTS (US only)	2.12	2.50
Japan + IEA (Japan only)	0.86	0.36
Japan + SAGE (Japan only)	0.80	3.53
Average (2005)	2.24	2.26

Table 9.3. Estimates of energy intensity (per passenger) using different combinations of data sources.

Using the IEA+ICAO model, the global average energy intensity for domestic flights is 2.24 MJ/Pass-km for domestic flights and 2.26 MJ/Pass-km for international flights. Multiplying these by the average global load factors of 125 and 222 we derive energy intensities of 280 MJ/vehicle-km and 501 MJ/vehicle-km for domestic and international flights, respectively.

Another potential source for energy intensity estimates is the TREMOVE dataset (EC 2010) which reports MJ/PKT for European Union flights and disaggregates by stage length (Table 9.4).

Stage Length (km)	Pass Energy Intensity (MJ/PKT)
<500	3.28
500-1000	2.46
1000-1500	1.85
1500-2000	1.78
>2000	1.85

Table 9.4. Passenger Energy Intensity (MJ/PKT) by stage length for flights originating in the European Commission (EC 2010).

Clearly long-haul flights are more energy efficient than shorter flights. This is due to the high relative proportion of fuel that is burned in the ascent and descent of the flight; the shorter the stage length, the greater is the time in ascent or descent (Babikian, Lukachko et al. 2002). However, long-haul, widebody jets often are larger and less aerodynamically efficient than medium range (1000-2000 km) regional jets (Babikian, Lukachko et al. 2002). This is likely the explanation for the 1500-2000 km stage length having the lowest energy intensity (Table 4).

Our approach to estimating energy intensity of aircraft is relatively simple. We take the total global aviation energy use in 2005 from the IEA and choose energy intensities in 2005 for developed and developing regions (Table 9.5) such that the sum of our estimated global pass-km matches the ICAO's global pass-km as shown in equation 9-1:

$$P_{<2000km} + P_{>2000km} = P_{ICAO} \quad (9\text{-}1)$$

$$P_{<2000km} = \sum_i \left(E_i * \left(\frac{1}{EI_i}\right) * LF_i\right) \quad (9\text{-}2)$$

$$P_{>2000km} = \sum_j (E_j * \left(\frac{1}{EI_j}\right) * LF_j) \qquad (9\text{-}3)$$

Where $P_{<2000km}$ is the estimated global pass-km for flights less than 2000 km in the base year, 2005, using equation (9-2), $P_{>2000km}$ is the estimated global pass-km for flights greater than 2000 km in the base year, 2005, using equation (9-3), E_i is the energy use (MJ) for region *i* in the base year for flights less than 2000 km (IEA 2005), EI_i is the energy intensity (MJ/VKT) of region *i* in the base year for flights less than 2000 km (which depends on whether the region is grouped among developed or developing countries), and LF_i is the load factor of region *i* for flights less than 2000 km. Variables have the same definition for subscripts *j* but are specific to >2000 km flights. Lastly, we choose these energy intensities so that developing regions are 90% as efficient as developed regions. This is largely due to the assumption that developed regions are operationally more efficient (e.g. less on-ground waiting time).

Vehicle Energy Intensity (MJ/VKT)

	< 2000 km	**> 2000 km**
Developed Regions	384	430
Developing Regions	426	478

Table 9.5. Energy Intensities (MJ/VKT) for the year 2005 used in the GCAM model.

The future improvement rates in energy intensities are similarly broken down by developed vs. developing region (Table 9.6). These growth rates take several factors into account. (Lee 2000) reports that fuel consumption decreased by 3.3% per year from 1959 to 1995 for U.S. airlines and that aircraft engines have become 40% more efficient over the same time period (he also notes that most of the improvement took place in the 1960s). Over the same time period, aircraft became more aerodynamically efficient (by 15%), most of which occurred after 1980. Finally, (Lee 2000) reports that the energy intensity of aircraft (measured in MJ/available seat kilometer, or essentially the same unit as our MJ/VKT) has decreased by 1.11% per year from 1980-2000.

(Babikian, Lukachko et al. 2002) report that for regional jets, engine efficiency improved by 40% (1.5% per year) between 1959-1989. (Vedantham 1999) estimate that aircraft fuel use per available seat decreased by 70% from 1960-2000. Based on the above estimates, we take a conservative approach and assume that growth rates in energy intensity will begin at -1.0% for 2005-2020 and approach zero by 2050 (Table 9.6).

	Growth Rate (%/yr)	
Period	**Developed Regions**	**Developing Regions**
2005-2020	-1.00%	-1.00%
2020-2035	-0.70%	-0.70%
2035-2050	-0.40%	-0.40%
2050-2065	0.00%	0.00%
2065-2080	0.00%	0.00%
2080-2100	0.00%	0.00%

Table 9.6. BAU scenario growth rates of energy intensity assumed in GCAM.

We then assume that the advanced technology growth rates are 1.5 times as high as the BAU growth rates, but similarly level off at zero after 2050 (Table 9.7).

	Growth Rate (%/yr)	
Period	**Developed Regions**	**Developing Regions**
2005-2020	-1.50%	-1.50%
2020-2035	-1.05%	-1.05%
2035-2050	-0.60%	-0.60%
2050-2065	0.00%	0.00%
2065-2080	0.00%	0.00%
2080-2100	0.00%	0.00%

Table 9.7. Advanced technology scenario growth rates of energy intensity assumed in GCAM.

10.4 Non-Fuel Costs ($2005/VKT)

As in the LDV passenger transport module, the non-fuel costs are given by:

$$P_{NF}^{Air} = (P_{CAPEX}^{Air} + P_{OPEX-Fuel}^{Air}) + P_{Fuel\,Tax}^{Air} \quad (9\text{-}4)$$

Total non-fuel vehicle ownership costs P_{NF}^{Air} (in terms of $/PKT) includes the aircraft purchase costs (P_{CAPEX}^{Air}), non-fuel operating costs ($P_{OPEX-Fuel}^{Air}$), and fuel taxes.

Cost estimates begin with data from the US DOT (U.S. DOT 2012) which gives quarterly average fares for the domestic U.S. cities for the year 2005. We convert these fares to $/PKT using the inter-city distance. Table 9.8 shows the share-weighted (by pass-km) average fares for flights less than and greater than 2000 km for 2005.

	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Avg
<2000 km	$0.12	$0.13	$0.13	$0.13	$0.13
>2000 km	$0.07	$0.07	$0.07	$0.06	$0.07

Table 9.8. Share-weighted U.S. airline fares ($/Pass-km) for 2005 between 9208 total origin-destinations.

These costs match cost estimates in the TREMOVE database (EC 2010) for European air travel of $0.12/PKT (assuming $1 = 1.2 Euro).

We then disaggregate average 2005 values of $0.13 and $0.07 into component costs and convert to $/VKT by using cost shares given by (Babikian, Lukachko et al. 2002) and shown in Table 9.9 and load factors discussed above. For example, for the capital cost ($/VKT) of region *i* for flights <2000 km, we use the following equation:

$$P_{CAPEX\_<2000km}^{Air} = \$0.13 * LF_i * 31\% \quad (9\text{-}5)$$

Where $0.013 is total average fare for flights of less than 2000 km (Table 9.8), LF_i is the load factor of flights (<2000 km) in region *i*; and 31% is the average Capital Cost share from (Babikian, Lukachko et al. 2002) (Table 9.9).

$P_{OPEX-Fuel}^{Air}$ is derived in the same manner.

The fuel tax cost is estimated using a slightly different method. First, international flights are not taxed. Thus, we only assume tax costs for flights <2000 km.

Next, we conducted a literature review for the value added tax (VAT) rates of domestic flights for various regions. A VAT is a tax on the final payment of a good, meaning that it is levied as a percentage of the cost of kerosene. The VAT on domestic flights ranged from 1% in the U.S. to 36.7% in Japan. In regions for which we could not determine the VAT rate, we assumed 1.0%. We multiply the $0.13/VKT by 17% (from the fuel share in Table 9.9) and by the tax rate to arrive at the estimated cost per VKT.

	Turboprops	Regional Jets	Large Jets	Average
Aircraft Fuels	13%	17%	22%	17%
Airframe	5%	2%	3%	3%
Amoritization	23%	17%	18%	19%
Depreciation	6%	11%	8%	8%
Engine Materials	1%	1%	3%	1%
Insurance	1%	0%	0%	0%
Labor for Airframes	5%	4%	3%	4%
Labor for Engines	1%	0%	1%	1%
Other Maintenance	21%	16%	8%	15%
Other Flying Ops	11%	13%	13%	12%
Pilot Salaries	15%	19%	22%	19%
Sum of Capital	34%	30%	29%	31%
Sum of Operating	53%	54%	49%	52%
Sum of Fuels	13%	17%	22%	17%

Table 9.9. Shares of airline costs. Line items in the upper left box are from (Babikian, Lukachko et al. 2002) while summary statistics were calculated offline. The average values of 31%, 52%, and 17% are used in our calculations.

We assume that these non-fuel costs of airline travel remain constant over time and between the Advanced Technology and BAU scenarios.

10.5 References

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ANNEXURE 1: AGGREGATED STATISTICS II

ANNEXURE 1: Aggregated Statistics

Passenger Transportation in 2005

Region	Travel Demand	Per Capita	Energy	EI	Monetary Costs	Time Cost	Generalized User Cost	Monetary Costs	Generalized User Cost
					Market Exchange Rate			*PPP*	*PPP*
	Billion PKT	PKT/year	PJ	MJ/PKT	$/PKT(a)	$/PKT(b)	$/PKT (b)	$/PKT (PPP)	$/PKT (PPP)
Africa	3,942	4,289	1,396	0.35	0.04	0.04	0.08	0.10	0.21
Australia & NZ	486	19,809	993	2.04	0.33	0.25	0.58	0.33	0.58
Canada	882	27,281	1,347	1.53	0.26	0.22	0.48	0.29	0.54
China	3,059	2,145	2,054	0.67	0.03	0.05	0.09	0.08	0.26
Eastern Europe	1,094	9,183	1,125	1.03	0.15	0.09	0.24	0.26	0.42
Former Soviet Union	1,997	7,023	2,481	1.24	0.13	0.06	0.19	0.24	0.36
India	3,552	3,246	616	0.17	0.02	0.03	0.05	0.07	0.17
Japan	1,513	11,894	2,309	1.53	0.31	0.54	0.85	0.25	0.69
Korea	736	15,296	875	1.19	0.21	0.19	0.40	0.22	0.42
Latin America	3,790	3,464	3,949	1.04	0.15	0.23	0.38	0.24	0.61
Middle East	2,848	15,148	3,057	1.07	0.10	0.09	0.19	0.14	0.27
South East Asia	7,843	8,957	2,996	0.38	0.04	0.05	0.08	0.07	0.17
U.S.A.	8,621	28,764	18,434	2.14	0.18	0.31	0.49	0.18	0.49
Western Europe	8,469	17,885	12,758	1.51	0.28	0.24	0.52	0.24	0.46
Global	**48,830**	**7,554**	**54,389**	**1.11**	**0.14**	**0.17**	**0.31**	**0.17**	**0.37**

India (Uncalibrated) (b)	5,015	4,584	1,049	0.21	0.03	0.03	0.06	0.08	0.11
China (Uncalibrated) (b)	9,933	6,965	3,653	0.37	0.03	0.05	0.08	0.08	0.26

(a) Costs are in 2005 Dollars and converted using Market Exchange Rate (MER)

(b) Estimate of travel demand and energy consumption in 2005 are based on literature;
Energy demand is not calibrated to IEA Energy Statistics

Passenger Transportation in 2005 – Share of Modes:

Share in total PKT and energy consumed by all passenger modes

Region		Car & LT	2W	3W	Bus	Rail	HSR	Air	Walk & Bike
Africa	PKT	17.0%	1.0%	0.0%	53.0%	1.0%		2.0%	25.0%
	Energy	62.0%	2.0%	1.0%	19.0%	1.0%		15.0%	0.0%
Australia & NZ	PKT	66.3%	0.4%		4.3%	4.2%		22.1%	2.7%
	Energy	72.0%	0.4%		2.3%	0.9%		24.3%	0.0%
Canada	PKT	80.2%	0.3%		8.2%	0.4%		10.1%	0.9%
	Energy	88.9%	0.3%		4.0%	0.3%		6.6%	0.0%
China	PKT	8.8%	10.4%	0.1%	52.4%	10.7%		1.3%	16.2%
	Energy	25.6%	19.5%	0.3%	39.7%	3.9%		11.0%	0.0%
Eastern Europe	PKT	63.8%	3.0%		18.3%	6.7%		1.9%	6.3%
	Energy	80.7%	2.8%		9.8%	2.7%		4.0%	0.0%
Former Soviet Union	PKT	42.5%	4.2%		16.4%	12.7%		8.9%	15.3%
	Energy	60.1%	4.1%		9.8%	5.6%		20.5%	0.0%
India	PKT	3.3%	9.8%	1.5%	33.8%	19.1%		0.9%	31.5%
	Energy	19.7%	30.2%	7.2%	20.6%	8.8%		13.5%	0.0%
Japan	PKT	53.5%	3.6%		5.9%	18.7%	5.0%	9.8%	3.7%
	Energy	70.8%	2.3%		8.4%	2.6%	0.5%	15.3%	0.0%
Korea	PKT	33.6%	1.8%		51.5%	6.6%	1.2%	2.8%	2.5%
	Energy	64.3%	1.9%		25.4%	1.3%	0.2%	7.1%	0.0%
Latin America	PKT	46.8%	3.7%		31.3%	0.3%		4.5%	13.5%
	Energy	70.1%	4.5%		13.5%	0.3%		11.6%	0.0%
Middle East	PKT	53.6%	4.0%		30.5%	0.0%		8.4%	3.6%
	Energy	70.1%	2.1%		9.0%	0.0%		18.8%	0.0%
South East Asia	PKT	11.5%	19.6%	1.5%	56.7%	1.0%		3.7%	6.0%
	Energy	30.0%	27.4%	3.2%	15.6%	0.9%		23.0%	0.0%
U.S.A.	PKT	76.9%	0.4%		6.4%	0.2%	0.0%	15.3%	0.7%
	Energy	78.6%	0.3%		1.7%	0.3%	0.0%	19.2%	0.0%
Western Europe	PKT	67.5%	1.4%		11.1%	5.9%	0.3%	11.2%	2.5%
	Energy	74.7%	1.0%		4.3%	1.9%	0.1%	18.0%	0.0%
Global	**PKT**	**41.4%**	**6.1%**	**0.4%**	**30.0%**	**5.2%**	**0.2%**	**7.1%**	**9.5%**
	Energy	**72.8%**	**4.0%**	**0.3%**	**8.1%**	**1.4%**	**0.0%**	**18.1%**	**0.0%**
India (Uncalibrated) (d)	PKT	4.6%	13.7%	1.8%	44.7%	12.3%		0.6%	22.3%
	Energy	22.3%	35.0%	7.1%	22.5%	5.1%		7.9%	0.0%
China (Uncalibrated) (d)	PKT	9.9%	10.7%	0.1%	61.6%	6.7%		0.8%	10.1%
	Energy	26.9%	20.1%	0.3%	43.9%	2.3%		6.5%	0.0%

Note: Energy refers to total energy consumed by passenger modes including aviation

Freight Transportation in 2005

Region	Travel Demand	Per Capita	Energy	EI	Monetary Costs	Time Cost	Generalized User Cost	Generalized User Cost
					Market Exchange Rate			*PPP*
	Billion Tonne-KM	Tonne-KM/year	PJ	MJ/Tonne-KM	$/Tonne-KM (b)		$/Tonne-KM (b)	$/Tonne-KM (PPP)
Africa	584	635	1,196	2.05	0.17	-	0.17	0.47
Australia & NZ	440	17,936	480	1.09	0.16	-	0.16	0.16
Canada	707	21,871	596	0.84	0.11	-	0.11	0.13
China	3,059	2,145	2,054	0.67	0.09	-	0.09	0.26
Eastern Europe	595	4,996	506	0.85	0.07	-	0.07	0.12
Former Soviet Union	2,742	9,644	847	0.31	0.03	-	0.03	0.05
India	835	763	871	1.04	0.04	-	0.04	0.14
Japan	373	2,932	1,318	3.53	0.76	-	0.76	0.62
Korea	158	3,290	327	2.07	1.48	-	1.48	1.58
Latin America	1,707	1,560	2,931	1.72	0.08	-	0.08	0.12
Middle East	558	2,966	1,366	2.45	0.15	-	0.15	0.21
South East Asia	616	703	1,482	2.41	0.11	-	0.11	0.23
U.S.A.	4,263	14,224	7,968	1.87	0.23	-	0.23	0.23
Western Europe	2,221	4,690	2,036	0.92	0.14	-	0.14	0.12
Global	**18,858**	**2,917**	**23,978**	**1.27**	**0.15**	**-**	**0.15**	**0.20**

India (Uncalibrated) (d)	1,073	981	1,596	1.49	0.05	-	0.05	0.17
China (Uncalibrated) (d)	3,727	2,614	3,351	0.90	0.13	-	0.13	0.37

(b) Costs are in 2005 Dollars and converted using Market Exchange Rate (MER)
(c) Time costs are not included for freight movement in the current version of GCAM
(d) Estimate of travel demand and energy consumption in 2005 is based on literature;
Energy demand is not calibrated to IEA Energy Statistics

Car and Light Truck Transportation in 2005

	Travel Demand		Monetary Costs (Fares)		Monetary cost as share of GUC	Average Load Factor	Energy Consumed	Energy Intensity
	PKT Billion	Share	¢/PKT (MER)	¢/PKT (PPP)			PJ	MJ/PKT
Africa	677	17%	10.17	27.69	91%	2.72	862	1.27
Australia_NZ	322	66%	43.87	43.87	70%	1.64	715	2.22
Canada	707	80%	29.92	33.51	59%	1.74	1,197	1.69
China	550	18%	7.44	20.15	82%	2.50	550	1.00
Eastern Europe	698	64%	19.39	33.51	77%	2.02	907	1.30
Former Soviet Union	849	43%	19.73	37.49	90%	1.85	1,490	1.76
India	119	3%	9.74	32.68	93%	2.71	121	1.02
Japan	835	55%	43.03	34.85	52%	1.54	1,636	1.96
Korea	248	34%	29.68	31.48	69%	1.46	562	2.27
Latin America	1,774	47%	23.44	37.98	74%	1.83	2,767	1.56
Middle East	1,525	54%	13.39	19.06	73%	2.50	2,144	1.41
Southeast Asia	901	11%	7.85	16.02	79%	2.66	898	1.00
USA	6,633	77%	20.61	20.61	40%	1.63	14,481	2.18
Western Europe	5,719	68%	36.21	31.86	65%	1.65	9,534	1.67
Uncalibrated to IEA								
India Uncalibrated	230	5%	9.74	32.68	93%	2.71	234	1.02
China Uncalibrated	983	10%	43.03	20.15	82%	2.50	984	1.00

- Share of car & light truck calculated with all passenger transportation including international aviation in the denominator.

Car and Light Truck Transportation in 2005 – Disaggregation by size class

Size Classes	**Mini**	**Sub Compact**	**Compact**	**Midsize**	**Large**	**Large Car & SUV**	**Light Truck & SUV**	**MPV / Van**
	< 1 litre	1-1.5 litre	1.5-2 litre	2-2.5 litre	> 2.5 litre			
Africa	26%	42%	11%					22%
Australia_NZ			25%	5%	32%		38%	
Canada				64%			14%	22%
China	18%	25%	40%			17%		
Eastern Europe		37%	47%			10%		6%
Former Soviet Union		8%	64%	17%		11%		
India	25%	43%	11%					21%
Japan	25%	24%	28%			23%		
Korea		22%	28%		13%	38%		
Latin America	24%	32%	31%			14%		
Middle East	30%	40%	25%			5%		
Southeast Asia	22%	58%	4%					16%
USA			34%	21%	10%		35%	
Western Europe		22%	59%			13%		5%
Uncalibrated to IEA								
India Uncalibrated	25%	43%	11%					21%
China Uncalibrated	18%	25%	40%			17%		

Notes: Shares of different size classes are for total PKT in 2005.

Two-wheeler Transportation in 2005

	Travel Demand		Monetary Costs (Fares)		Monetary cost as share	Average	Energy Consumed	Energy Intensity
	PKT Billion	Share	¢/PKT (MER)	¢/PKT (PPP)	of GUC	Load Factor	PJ	MJ/PKT
Africa	44	1%	2.68	7.29	70%	1.40	26	0.59
Australia_NZ	2	0%	71.27	71.27	74%	1.10	4	1.84
Canada	3	0%	59.42	66.55	74%	1.10	5	1.64
China	650	21%	3.35	9.09	65%	1.25	418	0.64
Eastern Europe	32	3%	7.90	13.66	54%	1.10	32	0.98
Former Soviet Union	84	4%	28.48	54.11	91%	1.10	101	1.20
India	349	10%	2.50	8.40	75%	1.40	186	0.53
Japan	56	4%	25.34	20.53	35%	1.10	53	0.94
Korea	13	2%	42.01	44.56	70%	1.10	17	1.26
Latin America	140	4%	21.94	35.55	70%	1.50	179	1.27
Middle East	113	4%	3.37	4.80	37%	1.50	64	0.57
Southeast Asia	1,539	20%	2.15	4.38	47%	1.40	822	0.53
USA	37	0%	69.11	69.11	69%	1.10	51	1.37
Western Europe	118	1%	29.44	25.91	57%	1.10	127	1.08
Uncalibrated to IEA								
India Uncalibrated	688	14%	2.50	8.40	75%	1.40	368	0.53
China Uncalibrated	1,062	11%	3.35	9.09	65%	1.25	683	0.64

Notes: Share of two-wheelers calculated with all passenger transportation including international aviation in the denominator.

Non-motorized Transportation in 2005

	Travel Demand		Per Capita Travel	
	PKT Billion	Share	Per Day	Per Year
Africa	999	25%	2.98	1,087
Australia_NZ	13	3%	1.46	531
Canada	8	1%	0.65	239
China	1,006	33%	1.93	705
Eastern Europe	69	6%	1.59	579
Former Soviet Union	305	15%	2.94	1,074
India	1,120	32%	2.80	1,023
Japan	57	4%	1.23	449
Korea	18	2%	1.03	375
Latin America	511	13%	2.54	929
Middle East	103	4%	1.51	550
Southeast Asia	474	6%	1.48	542
USA	61	1%	0.56	205
Western Europe	213	3%	1.23	450
Uncalibrated to IEA				
India Uncalibrated	1,120	22%	2.80	1,023
China Uncalibrated	1,006	10%	1.23	705

Notes: Share of walk and bike calculated with all passenger transportation including international aviation in the denominator.

Bus Transportation in 2005

	Travel Demand		Monetary Costs (Fares)		Fares as share of GUC	Subsidy		Energy Consumed	Energy Intensity
	PKT Billion	Share of Bus	¢/PKT (MER)	¢/PKT (PPP)		¢/PKT (MER)	¢/PKT (PPP)	PJ	MJ/PKT
Africa	2,075	53%	1.00	2.73	41%	0.71	1.92	13	0.01
Australia_NZ	21	4%	15.18	15.18	39%	1.73	1.73	23	1.07
Canada	72	8%	9.13	10.23	25%	4.57	5.12	53	0.74
China	3,263	107%	3.18	8.63	48%	0.32	0.85	853	0.26
Eastern Europe	200	18%	9.62	16.63	48%	11.37	19.66	110	0.55
Former Soviet Union	328	16%	9.39	17.83	67%	11.37	21.59	244	0.74
India	1,202	34%	3.38	11.32	70%	0.20	0.66	127	0.11
Japan	92	6%	12.22	9.90	20%	18.76	15.20	195	2.11
Korea	48	7%	5.64	5.98	30%	2.26	2.40	11	0.23
Latin America	1,184	31%	7.56	12.26	31%	0.81	1.32	532	0.45
Middle East	868	30%	5.69	8.09	35%	0.65	0.93	275	0.32
Southeast Asia	4,446	57%	3.20	6.52	43%	0.34	0.70	466	0.10
USA	550	6%	8.92	8.92	16%	0.50	0.50	308	0.56
Western Europe	943	11%	6.93	6.10	21%	4.51	3.97	544	0.58
Uncalibrated to IEA Energy Statistics									
India	2,240	34%	3.38	11.32	0.70	0.20	0.66	236	0.11
China	6,123	62%	3.18	8.63	0.48	0.32	0.85	1,603	0.26

Notes: Share of bus calculated with all passenger transportation including international aviation in the denominator.

Passenger Rail (Conventional Rail) in 2005

	Travel Demand		Monetary Costs (Fares)		Fares as share of GUC	Subsidy		Energy Consumed	Energy Intensity
	PKT Billion	Share of Rail	¢/PKT (MER)	¢/PKT (PPP)		¢/PKT (MER)	¢/PKT (PPP)	PJ	MJ/PKT
Africa	58	1%	1.00	2.73	41%	0.71	1.92	13	0.23
Australia_NZ	20	4%	13.17	13.17	35%	13.04	13.04	9	0.46
Canada	3	0%	11.47	12.84	36%	12.95	14.51	3	1.00
China	667	11%	0.90	2.43	34%	1.72	4.65	83	0.12
Eastern Europe	73	7%	4.92	8.50	48%	3.83	6.62	30	0.41
Former Soviet Union	253	13%	4.50	8.56	66%	8.24	15.65	139	0.55
India	677	19%	0.55	1.85	43%	1.14	3.83	54	0.08
Japan	292	19%	15.78	12.78	30%	3.08	2.50	61	0.21
Korea	48	7%	5.64	5.98	30%	2.26	2.40	11	0.23
Latin America	11	0%	40.26	65.24	82%	13.10	21.23	13	1.12
Middle East									
Southeast Asia	80	1%	1.07	2.19	33%	0.72	1.46	26	0.32
USA	20	0%	14.07	14.07	26%	12.15	12.15	48	2.33
Western Europe	500	6%	14.49	12.75	45%	12.58	11.07	245	0.49
Uncalibrated to IEA									
India Uncalibrated	616	12%	0.55	1.85	0.43	1.14	3.83	54	0.09
China Uncalibrated	667	7%	0.90	2.43	34%	1.72	4.65	83	0.12

High Speed Rail in 2005

	Travel Demand		Monetary Costs (Fares)		Fares as share	Subsidy		Energy Consumed	Energy Intensity
	PKT Billion	HSR as % of Total Rail	¢/PKT (MER)	¢/PKT (PPP)	of GUC	¢/PKT (MER)	¢/PKT (PPP)	PJ	MJ/PKT
Japan	77	21%	29.25	23.70	74%	-	-	12	0.15
Korea	9	15%	12.06	12.79	77%	-	-	1	0.16
USA	0	0%	46.41	46.41	77%	4.72	4.72	0	1.77
Western Europe	29	5%	25.54	22.48	83%	12.58	11.07	11	0.39

Passenger Air (Short & Medium Distance) in 2005

	Travel Demand		**Monetary Costs (Fares)**		**Fares as share**	Energy Consumed	Energy Intensity
	PKT Billion	Share of Air	¢/PKT (MER)	¢/PKT (PPP)	**of GUC**	PJ	MJ/PKT
Africa	28	1%	12.57	34.24	98%	96	3.42
Australia_NZ	29	6%	12.02	12.02	70%	92	3.14
Canada	69	0%	11.99	13.43	67%	69	1.00
China	52	11%	12.81	34.72	97%	182	3.48
Eastern Europe	1	0%	12.17	21.03	90%	3	3.52
Former Soviet Union	95	5%	12.17	23.11	95%	333	3.52
India	12	0%	12.81	42.98	99%	42	3.48
Japan	50	3%	12.81	10.38	59%	158	3.14
Korea	18	2%	12.02	12.75	79%	57	3.14
Latin America	46	1%	13.78	22.33	86%	171	3.75
Middle East	73	3%	12.81	18.23	90%	225	3.09
Southeast Asia	11	0%	13.78	28.12	96%	40	3.75
USA	919	11%	11.99	11.99	58%	2,811	3.06
Western Europe	388	5%	12.81	11.27	73%	1,226	3.16

Passenger Air (Long Distance) in 2005

	Travel Demand		Monetary Costs (Fares)		Fares as share	Energy Consumed	Energy Intensity
	PKT Billion	Share	¢/PKT (MER)	¢/PKT (PPP)	of GUC	PJ	MJ/PKT
Africa	54	1%	9.97	27.15	98%	119	2.21
Australia_NZ	78	16%	8.46	8.46	70%	150	1.92
Canada	20	0%	9.53	10.67	70%	20	1.00
China	26	11%	9.60	26.03	97%	55	2.13
Eastern Europe	20	2%	9.81	16.95	91%	43	2.13
Former Soviet Union	82	4%	9.81	18.63	96%	175	2.13
India	19	1%	9.60	32.22	99%	42	2.13
Japan	102	7%	9.60	7.78	60%	196	1.92
Korea	3	0%	9.60	10.19	81%	5	1.92
Latin America	123	3%	10.54	17.08	86%	289	2.34
Middle East	165	6%	9.60	13.67	90%	349	2.11
Southeast Asia	277	4%	10.54	21.50	96%	648	2.34
USA	399	5%	9.53	9.53	61%	736	1.84
Western Europe	559	7%	9.60	8.45	75%	1,070	1.92

Road Freight in 2005

	Transport Demand		Monetary Costs (Fares)		Energy Consumed	Energy Intensity
	Tonne-KM Billion	Share of Truck	¢/Tonne-KM (MER)	¢/Tonne-KM (PPP)	PJ	MJ/Tonne-KM
Africa	456	78%	20.87	56.84	1,172	2.57
Australia_NZ	194	44%	33.90	33.90	450	2.31
Canada	356	50%	19.82	22.20	523	1.47
China	904	30%	30.07	81.50	1,677	1.86
Eastern Europe	427	72%	7.44	12.86	475	1.11
Former Soviet Union	373	14%	15.79	30.00	623	1.67
India	329	39%	7.92	26.59	821	2.49
Japan	351	94%	81.02	65.62	1,312	3.74
Korea	146	92%	161.04	170.82	321	2.20
Latin America	1,373	80%	8.91	14.44	2,881	2.10
Middle East	558	100%	14.76	21.00	1,366	2.45
Southeast Asia	596	97%	11.53	23.53	1,460	2.45
USA	2,069	49%	46.22	46.22	7,475	3.61
Western Europe	1,802	81%	15.67	13.79	1,928	1.07
Uncalibrated to IEA						
India Uncalibrated	632	59%	7.92	26.59	1,548	2.45
China Uncalibrated	1,614	43%	30.07	81.50	2,996	1.86

Notes: Share of truck calculated with sum of road freight and rail freight in the denominator.

Freight Rail in 2005

	Travel Demand		Monetary Costs (Fares)		Energy Consumed	Energy Intensity
	Tonne-KM Billion	Share of Rail	¢/Tonne-KM (MER)	¢/Tonne-KM (PPP)	PJ	MJ/Tonne-KM
Africa	128	22%	1.56	4.25	24	0.19
Australia_NZ	246	56%	2.49	2.49	30	0.12
Canada	351	50%	2.41	2.69	73	0.21
China	2,156	70%	0.79	2.15	377	0.18
Eastern Europe	168	28%	6.20	10.72	31	0.19
Former Soviet Union	2,391	86%	0.94	1.78	260	0.11
India	506	61%	1.53	5.14	50	0.10
Japan	22	6%	4.22	3.42	5	0.24
Korea	12	8%	1.99	2.11	6	0.50
Latin America	334	20%	23.14	37.49	50	0.15
Middle East			-	-		
Southeast Asia	20	3%	1.98	4.03	22	1.10
USA	2,194	51%	1.21	1.21	494	0.22
Western Europe	419	19%	4.34	3.82	108	0.26
Uncalibrated to IEA						
India Uncalibrated	442	41%			49	0.11
China Uncalibrated	2,113	57%			356	0.17

Notes: Share of freight rail calculated with sum of road freight and rail freight in the denominator.

ANNEXURE 2: Country Specific Statistics in 2005

Notes:

(a) **Monetary costs ($/PKT or $/Ton-KM):** For cars & Light Trucks, 2W and 3W, monetary costs represent cost of owning and operating a conventional ICE propulsion technology. For public modes – bus, rail and air – the costs represent weighted average fares paid in 2005. Similarly, for trucks and freight rail, the costs represent average freight rates.

(b) **Costs ($/PKT and $/Ton-KM)** are in 2005 Dollars and converted using Market Exchange Rate (MER).

(c) Shipping transportation – Both domestic and international have not been included in this Appendix

(d) We have also included statistics for India and China where the energy estimates are not calibrated to IEA Energy Statistics. In case of India (un-calibrated), road and rail energy statistics are not calibrated. In case of China (un-calibrated), only road energy statistics have not been calibrated.

Africa in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI MJ/PKT or Ton-KM	Monetary Costs (Fares) $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Mini Car	174	2.50	176	1.01	0.06	0.01	0.07	
Subcompact Car	282	2.50	351	1.24	0.10	0.01	0.11	
Compact Car	72	2.50	113	1.57	0.15	0.01	0.17	
Multipurpose Vehic	148	3.50	222	1.49	0.14	0.01	0.15	
Two-Wheelers								
Motorcycle (50-250	44	1.40	26	0.59	0.03	0.01	0.04	
Three-Wheeler	8	1.88	8	1.05	0.05	0.01	0.06	
Bus	2,075	47.49	272	0.13	0.03	0.01	0.04	0.00
Passenger Rail								
Conventional Rail	58	1,152.01	13	0.23	0.01	0.01	0.02	0.01
Non-Motor								
Walk	749	1.00	-	-		0.15	0.15	
Bike	250	1.00	-	-		0.05	0.05	
Air								
Short (<2000 KM)	28	125	96	3.42	0.13	0.00	0.13	
Long (>2000 KM)	54	216	119	2.21	0.10	0.00	0.10	
Freight Trucking								
Truck (0-2t)	3	0.50	18	6.30	0.66		0.66	
Truck (2-5t)	14	1.13	72	5.08	0.52		0.52	
Truck (5-9t)	323	3.04	877	2.72	0.22		0.22	
Truck (9-16t)	116	6.00	205	1.77	0.12		0.12	
Freight Rail								
Conventional Rail	128	1,518.08	24	0.19	0.02		0.02	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	3,942	4,289	1,396	0.35	0.04	0.04	0.08
Freight	584	635	1,196	2.05	0.17		0.17

Australia and New Zealand in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI or Ton-KM	Monetary Costs (Fares) $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Compact Car	82	1.58	140	1.71	0.33	0.19	0.51	
Midsize Car	16	1.58	29	1.80	0.41	0.19	0.59	
Large Car	103	1.58	256	2.49	0.42	0.19	0.61	
Light Truck and SUV	121	1.75	290	2.39	0.53	0.19	0.72	
Two-Wheelers								
Motorcycle (>250cc)	2	1.10	4	1.84	0.71	0.25	0.96	
Bus	21	9.99	23	1.07	0.15	0.24	0.39	0.02
Passenger Rail								
Conventional Rail	20	29.86	9	0.46	0.13	0.24	0.37	0.13
High Speed Rail								
Non-Motor								
Walk	10	1.00	-	-		4.48	4.48	
Bike	3	1.00	-	-		1.49	1.49	
Air								
Short (<2000 KM)	29	122	92	3.14	0.12	0.05	0.17	
Long (>2000 KM)	78	224	150	1.92	0.08	0.04	0.12	
Freight Trucking								
Truck (0-1t)	9	0.21	191	22.42	5.04		5.04	
Truck (1-6t)	36	3.75	103	2.88	0.34		0.34	
Truck (6-30t)	150	20.30	156	1.04	0.07		0.07	
Freight Rail								
Conventional Rail	246	3,216.88	30	0.12	0.02		0.02	

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	486	19,809	993	2.04	0.33	0.25	0.58
Freight	440	17,936	480	1.09	0.16		0.16

Canada in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI or Ton-KM	Monetary Costs (Fares) $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Midsize Car	450	1.68	723	1.6	0.30	0.21	0.51	
Van	158	1.95	231	1.5	0.27	0.21	0.48	
Light Truck and SUV	99	1.68	243	2.5	0.34	0.21	0.55	
Two-Wheelers								
Motorcycle (>250cc)	3	1.10	5	1.6	0.59	0.21	0.81	
Bus	72	13.86	53	0.7	0.09	0.27	0.36	0.05
Passenger Rail								
Conventional Rail	3	29.86	3	1.0	0.11	0.21	0.32	0.13
Non-Motor								
Walk	6	1.00	-	-		3.04	3.04	
Bike	2	1.00	-	-		1.01	1.01	
Air								
Short (<2000 KM)	69	125	69	1.0	0.12	0.06	0.18	
Long (>2000 KM)	20	233	20	1.0	0.10	0.04	0.14	
Freight Trucking								
Truck (0-4.5t)	9	0.68	54	6.2	1.66		1.66	
Truck (4.5-15t)	67	4.88	137	2.0	0.27		0.27	
Truck (>15t)	280	10.00	332	1.2	0.14		0.14	
Freight Rail								
Conventional Rail	351	3,216.88	73	0.2	0.02		0.02	

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	882	27,281	1,347	1.53	0.26	0.22	0.48
Freight	707	21,871	596	0.84	0.11		0.11

China in 2005

	Travel Demand	Load Factor	Energy	EI	Monetary Costs	Time Cost	Generalized User Cost	Subsidy
	Billion PKT/TKT		PJ	MJ/PKT or TKT	$/PKT(a)(b)	$/PKT(b)	$/PKT (b)	$/PKT(b)
Cars & Trucks								
Mini Car	101	2.50	92	0.91	0.03	0.02	0.05	
Subcompact Car	136	2.50	131	0.96	0.05	0.02	0.06	
Compact Car	221	2.50	216	0.98	0.08	0.02	0.10	
Large Car and SUV	91	2.50	112	1.22	0.14	0.02	0.16	
Two-Wheelers								
Moped								
Scooter								
Motorcycle (50-250	650	1.25	418	0.64	0.03	0.02	0.05	
Three-Wheeler	7	1.75	6	0.82	0.04	0.02	0.05	
Bus	3,263	34.49	853	0.26	0.03	0.03	0.07	0.00
Passenger Rail								
Conventional Rail	667	944.89	83	0.12	0.01	0.02	0.03	0.02
Non-Motor								
Walk	755	1.00	-	-		0.24	0.24	
Bike	252	1.00	-	-		0.08	0.08	
Air								
Short (<2000 KM)	52	122	182	3.48	0.13	0.00	0.13	
Long (>2000 KM)	26	224	55	2.13	0.10	0.00	0.10	
Freight Trucking								
3W Rural	75	0.40	303	4.05	0.58		0.58	
Truck (0-6t)	229	0.53	611	2.66	0.79		0.79	
Truck (6-14t)	179	4.50	270	1.51	0.10		0.10	
Truck (>14t)	420	7.45	493	1.17	0.06		0.06	
Freight Rail								
Conventional Rail	2,156	2,108.95	377	0.18	0.01		0.01	-
	Travel Demand	**Annual PKT/Tonne - KM per capita**	**Energy**	**EI**	**Monetary Costs**	**Time Cost**	**Generalized User Cost**	
Passenger	6,221	4,363	2,148	0.35	0.03	0.05	0.08	
Freight	3,059	2,145	2,054	0.67	0.09		0.09	

China in 2005 – Un calibrated to IEA Statistics

	Travel Demand	Load Factor	Energy	EI MJ/PKT	Monetary Costs	Time Cost	Generalized User Cost	Subsidy
	Billion PKT/TKT		PJ	or Ton-KM	$/PKT or Ton-KM	$/PKT	$/PKT or Ton-KM	$/PKT
Cars & Trucks								
Mini Car	181	2.50	164	0.91	0.03	0.02	0.04	
Subcompact Car	244	2.50	234	0.96	0.04	0.02	0.06	
Compact Car	394	2.50	386	0.98	0.08	0.02	0.09	
Large Car and SUV	163	2.50	200	1.22	0.13	0.02	0.15	
Two-Wheelers								
Moped								
Scooter								
Motorcycle (50-25C	1,062	1.25	735	0.69	0.03	0.02	0.05	
Three-Wheeler	13	1.75	10	0.82	0.03	0.02	0.05	
Bus	6,123	34.49	1,603	0.26	0.03	0.03	0.06	0.00
Passenger Rail								
Conventional Rail	667	944.89	83	0.12	0.01	0.02	0.03	0.02
Non-Motor								
Walk	755	1.00	-	-		0.24	0.24	
Bike	252	1.00	-	-		0.08	0.08	
Air								
Short (<2000 KM)	52	122	182	3.48	0.13	0.00	0.13	
Long (>2000 KM)	26	224	55	2.13	0.10	0.00	0.10	
Freight Trucking								
3W Rural	134	0.40	541	4.05	0.58		0.58	
Truck (<6t)	410	0.53	1,092	2.66	0.79		0.79	
Truck (6-14 t)	319	4.50	482	1.51	0.10		0.10	
Truck (> 14t)	751	7.45	880	1.17	0.06		0.06	
Freight Rail								
Conventional Rail	2,113	2,108.95	356	0.17	0.01		0.01	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	9,933	6,965	3,653	0.37	0.03	0.05	0.08
Freight	3,727	2,614	3,351	0.90	0.13		0.13

Eastern Europe in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI MJ/PKT or Ton-KM	Monetary Costs $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Subcompact Car	257	2.02	321	1.25	0.16	0.05	0.21	
Compact Car	328	2.02	410	1.25	0.19	0.05	0.24	
Van	44	2.02	65	1.48	0.16	0.05	0.21	
Large Car and SUV	69	2.02	111	1.60	0.34	0.05	0.39	
Two-Wheelers								
Moped	19	1.10	14	0.73	0.02	0.08	0.10	
Motorcycle (50-250cc	8	1.10	10	1.25	0.13	0.06	0.18	
Motorcycle (>250cc)	5	1.10	8	1.48	0.23	0.06	0.29	
Bus	200	15.99	110	0.55	0.10	0.10	0.20	0.11
Passenger Rail								
Conventional Rail	73	59.08	30	0.41	0.05	0.05	0.10	0.04
Non-Motor								
Walk	52	1.00	-	-		0.73	0.73	
Bike	17	1.00	-	-		0.24	0.24	
Air								
Short (<2000 KM)	1	121	3	3.52	0.12	0.01	0.14	
Long (>2000 KM)	20	224	43	2.13	0.10	0.01	0.11	
Freight Trucking								
Truck (0-3.5t)	7	0.80	31	4.18	0.67		0.67	
Truck (3.5-16t)	36	2.14	94	2.59	0.28		0.28	
Truck (16-32t)	205	11.25	195	0.95	0.05		0.05	
Truck (>32t)	178	15.60	155	0.87	0.04		0.04	
Freight Rail								
Conventional Rail	168	355.92	31	0.19	0.06		0.06	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	1,094	9,183	1,125	1.03	0.15	0.09	0.24
Freight	595	4,996	506	0.85	0.07		0.07

Former Soviet Union in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI MJ/PKT or Ton-KM	Monetary Costs (Fares) $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Subcompact Car	70	1.85	109	1.57	0.14	0.02	0.16	
Compact Car	541	1.85	905	1.67	0.17	0.02	0.19	
Midsize Car	144	1.85	272	1.88	0.22	0.02	0.24	
Large Car and SUV	94	1.85	203	2.16	0.34	0.02	0.37	
Two-Wheelers								
Moped	20	1.10	15	0.74	0.04	0.03	0.08	
Motorcycle (50-250cc	56	1.10	74	1.32	0.34	0.02	0.37	
Motorcycle (>250cc)	8	1.10	12	1.49	0.49	0.02	0.52	
Bus	328	15.69	244	0.74	0.09	0.05	0.14	0.11
Passenger Rail								
Conventional Rail	253	263.00	139	0.55	0.05	0.02	0.07	0.08
Non-Motor								
Walk	229	1.00	-	-		0.32	0.32	
Bike	76	1.00	-	-		0.11	0.11	
Air								
Short (<2000 KM)	95	121	333	3.52	0.12	0.01	0.13	
Long (>2000 KM)	82	224	175	2.13	0.10	0.00	0.10	
Freight Trucking								
Truck (0-3.5t)	41	0.68	202	4.92	0.79		0.79	
Truck (3.5-16t)	41	1.91	108	2.63	0.31		0.31	
Truck (16-32t)	164	10.57	183	1.12	0.05		0.05	
Truck (>32t)	127	13.84	130	1.02	0.04		0.04	
Freight Rail								
Conventional Rail	2,391	3,716.00	260	0.11	0.01		0.01	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	1,997	7,023	2,481	1.24	0.13	0.06	0.19
Freight	2,764	9,722	883	0.32	0.03		0.03

India in 2005

	Travel Demand (Billion PKT/TKT)	Load Factor	Energy (PJ)	EI MJ/PKT or Ton-KM	Monetary Costs ($/PKT or Ton-KM)	Time Cost ($/PKT)	Generalized User Cost ($/PKT or Ton-KM)	Subsidy ($/PKT)
Cars & Trucks								
Mini Car	29	2.50	24	0.81	0.05	0.01	0.06	
Subcompact Car	51	2.50	51	0.99	0.09	0.01	0.10	
Compact Car	13	2.50	16	1.25	0.15	0.01	0.15	
Multipurpose Vehicl	25	3.50	30	1.20	0.14	0.01	0.15	
Two-Wheelers								
Moped	58	1.40	35	0.60	0.01	0.01	0.02	
Scooter	110	1.40	67	0.61	0.03	0.01	0.03	
Motorcycle (50-250	180	1.40	85	0.47	0.03	0.01	0.04	
Three-Wheeler	54	1.88	44	0.82	0.04	0.01	0.05	
Bus	1,202	47.49	127	0.11	0.03	0.01	0.05	0.00
Passenger Rail								
Conventional Rail	677	1,152.01	54	0.08	0.01	0.01	0.01	0.01
Non-Motor								
Walk	732	1.00	-	-		0.10	0.10	
Bike	388	1.00	-	-		0.03	0.03	
Air								
Short (<2000 KM)	12	122	42	3.48	0.13	0.00	0.13	
Long (>2000 KM)	19	224	42	2.13	0.10	0.00	0.10	
Freight Trucking								
Truck (0-2t)	6	0.50	37	6.00	0.25		0.25	
Truck (2-5t)	10	1.13	49	4.84	0.19		0.19	
Truck (5-9t)	230	3.04	596	2.59	0.08		0.08	
Truck (9-16t)	83	6.00	139	1.69	0.04		0.04	
Freight Rail								
Conventional Rail	506	1,518.08	50	0.10	0.02		0.02	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	3,552	3,246	616	0.17	0.02	0.03	0.05
Freight	835	763	871	1.04	0.04		0.04

India in 2005– Un calibrated to IEA Statistics

	Travel Demand	Load Factor	Energy	EI	Monetary Costs	Time Cost	Generalized User Cost	Subsidy
	Billion PKT/TKT		PJ	or Ton-KM	$/PKT or Ton-KM	$/PKT	$/PKT or Ton-KM	$/PKT
Cars & Trucks								
Mini Car	58.18	2.50	47.2	0.81	0.05	0.01	0.05	
Subcompact Car	97.05	2.50	96.5	0.99	0.08	0.01	0.08	
Compact Car	24.92	2.50	31.2	1.25	0.13	0.01	0.13	
Multipurpose Vehicl	49.67	3.50	59.4	1.20	0.12	0.01	0.13	
Two-Wheelers								
Moped	114.29	1.40	68.1	0.60	0.01	0.01	0.02	
Scooter	217.84	1.40	132.0	0.61	0.03	0.01	0.03	
Motorcycle (50-250	356.31	1.40	167.4	0.47	0.03	0.01	0.04	
Three-Wheeler	89.45	1.88	74.83	0.84	0.04	0.01	0.05	
Bus	2,240.37	47.49	235.8	0.11	0.03	0.01	0.05	0.00
Passenger Rail								
Conventional Rail	615.63	1,152.01	53.6	0.09	0.01	0.01	0.01	0.01
Non-Motor								
Walk	732.34	1.00	-	-		0.14	0.14	
Bike	387.71	1.00	-	-		0.05	0.05	
Air								
Short (<2000 KM)	11.93	122	41.6	3.48	0.13	0.00	0.13	
Long (>2000 KM)	19.48	224	41.6	2.13	0.10	0.00	0.10	
Freight Trucking								
Truck (0-2t)	4.04	0.50	24.3	6.00	0.25		0.25	
Truck (2-5t)	19.65	1.13	95.1	4.84	0.19		0.19	
Truck (5-9t)	447.50	3.04	1,158.1	2.59	0.08		0.08	
Truck (9-16t)	160.50	6.00	270.5	1.69	0.04		0.04	
Freight Rail								
Conventional Rail	441.76	1,518.08	48.5	0.11	0.01		0.01	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	5,015.18	4,584	1,049.2	0.21	0.02	0.03	0.06
Freight	1,073.45	981.21	1,596.4	1.49	0.05		0.05

Japan in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI or Ton-KM	Monetary Costs $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Mini Car	205	1.54	240	1.17	0.23	0.42	0.66	
Subcompact Car	202	1.54	393	1.94	0.37	0.38	0.75	
Compact Car	238	1.54	494	2.08	0.38	0.38	0.77	
Large Car and SUV	190	1.54	508	2.68	0.77	0.38	1.15	
Two-Wheelers								
Moped	36	1.10	27	0.75	0.13	0.51	0.64	
Motorcycle (50-250cc	14	1.10	17	1.26	0.42	0.38	0.80	
Motorcycle (>250cc)	6	1.10	8	1.38	0.61	0.38	0.99	
Bus	92	13.04	195	2.11	0.12	0.49	0.61	0.19
Passenger Rail								
Conventional Rail	292	320.71	61	0.21	0.16	0.37	0.53	0.03
High Speed Rail	77	768.09	12	0.15	0.29	0.10	0.40	-
Non-Motor								
Walk	44	1.00	-	-		5.84	5.84	
Bike	13	1.00	-	-		1.95	1.95	
Air								
Short (<2000 KM)	50	122	158	3.14	0.13	0.09	0.22	
Long (>2000 KM)	102	224	196	1.92	0.10	0.06	0.16	
Freight Trucking								
Truck (0-1t)	46	0.27	554	12.02	3.96		3.96	
Truck (1-6t)	305	3.82	759	2.49	0.33		0.33	
Freight Rail								
Conventional Rail	22	274.75	5	0.24	0.04		0.04	0.00

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	1,513	11,894	2,309	1.53	0.31	0.54	0.85
Freight	373	2,932	1,318	3.53	0.76		0.76

Korea (South) in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI or Ton-KM	Monetary Costs (Fares) $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Subcompact Car	54	1.46	95	1.77	0.16	0.13	0.30	
Compact Car	69	1.46	130	1.88	0.22	0.13	0.35	
Large Car	32	1.46	77	2.43	0.39	0.13	0.52	
Light Truck and SUV	93	1.46	260	2.79	0.40	0.13	0.54	
Two-Wheelers								
Motorcycle (50-250cc	13	1.10	17	1.26	0.42	0.18	0.60	
Bus	379	9.08	222	0.59	0.18	0.17	0.35	0.02
Passenger Rail								
Conventional Rail	48	320.71	11	0.23	0.06	0.13	0.19	0.02
High Speed Rail	9	578.00	1	0.16	0.12	0.04	0.16	-
Non-Motor								
Walk	14	1.00	-	-		2.06	2.06	
Bike	5	1.00	-	-		0.69	0.69	
Air								
Short (<2000 KM)	18	122	57	3.14	0.12	0.03	0.15	
Long (>2000 KM)	3	224	5	1.92	0.10	0.02	0.12	
Freight Trucking								
Truck	146	0.69	321	2.20	1.61		1.61	
Freight Rail								
Conventional Rail	12	274.75	6	0.50	0.02		0.02	

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	736	15,296	875	1.19	0.21	0.19	0.40
Freight	158	3,290	327	2.07	1.48		1.48

Latin America in 2005

	Travel Demand	Load Factor	Energy	EI	Monetary Costs	Time Cost	Generalized User Cost	Subsidy
	Billion PKT/TKT		PJ	or Ton-KM	$/PKT or Ton-KM	$/PKT	$/PKT or Ton-KM	$/PKT
Cars & Trucks								
Mini Car	418	1.83	463	1.11	0.10	0.08	0.18	
Subcompact Car	572	1.83	888	1.55	0.17	0.08	0.26	
Compact Car	545	1.83	902	1.66	0.32	0.08	0.40	
Large Car and SUV	240	1.83	513	2.14	0.43	0.08	0.51	
Two-Wheelers								
Moped	0	1.50	0	0.84	0.10	0.12	0.23	
Motorcycle (50-250cc	126	1.50	157	1.25	0.21	0.09	0.30	
Motorcycle (>250cc)	14	1.50	21	1.53	0.29	0.09	0.39	
Bus	1,184	20.65	532	0.45	0.08	0.17	0.25	0.01
Passenger Rail								
Conventional Rail	11	250.00	13	1.12	0.40	0.09	0.49	0.13
Non-Motor								
Walk	383	1.00	-	-		1.20	1.20	
Bike	128	1.00	-	-		0.40	0.40	
Air								
Short (<2000 KM)	46	114	171	3.75	0.14	0.02	0.16	
Long (>2000 KM)	123	204	289	2.34	0.11	0.02	0.12	
Freight Trucking								
Truck (0-1t)	96	1.23	640	6.70	0.36		0.36	
Truck (6-15t)	143	4.73	332	2.31	0.10		0.10	
Truck (>15t)	1,134	8.10	1,908	1.68	0.06		0.06	
Freight Rail								
Conventional Rail	334	2,000.00	50	0.15	0.02		0.02	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	3,790	3,464	3,949	1.04	0.15	0.23	0.38
Freight	1,707	1,560	2,931	1.72	0.08		0.08

Middle East in 2005

	Travel Demand	Load Factor	Energy	EI	Monetary Costs	Time Cost	Generalized User Cost	Subsidy
	Billion PKT/TKT		PJ	or Ton-KM	$/PKT or Ton-KM	$/PKT	$/PKT or Ton-KM	$/PKT
Cars & Trucks								
Mini Car	358	2.50	426	1.19	0.08	0.05	0.13	0.00
Subcompact Car	666	2.50	934	1.40	0.11	0.05	0.16	0.00
Compact Car	416	2.50	623	1.50	0.19	0.05	0.24	0.00
Large Car and SUV	85	2.50	161	1.89	0.28	0.05	0.33	0.00
Two-Wheelers								
Motorcycle (50-250	113	1.50	64	0.57	0.03	0.06	0.09	0.01
Bus	868	25.00	275	0.32	0.06	0.10	0.16	0.01
Passenger Rail								
Conventional Rail								
Non-Motor								
Walk	69	1.00	-	-		0.98	0.98	
Bike	34	1.00	-	-		0.33	0.33	
Air								
Short (<2000 KM)	73	122	225	3.09	0.13	0.01	0.14	
Long (>2000 KM)	165	224	349	2.11	0.10	0.01	0.11	
Freight Trucking								
Truck (0-2t)	4	0.50	21	6.00	0.48		0.48	
Truck (2-5t)	17	1.13	84	4.84	0.38		0.38	
Truck (5-9t)	395	3.04	1,022	2.59	0.16		0.16	
Truck (9-16t)	142	6.00	239	1.69	0.08		0.08	
Freight Rail								
Conventional Rail								

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	2,848	15,148	3,057	1.07	0.10	0.09	0.19
Freight	558	2,966	1,366	2.45	0.15		0.15

South East Asia in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI MJ/PKT or Ton-KM	Monetary Costs $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Mini Car	199	2.50	161	0.81	0.04	0.02	0.06	
Subcompact Car	523	2.50	520	0.99	0.08	0.02	0.10	
Compact Car	34	2.50	43	1.25	0.12	0.02	0.15	
Multipurpose Vehicl	145	3.50	173	1.20	0.12	0.02	0.14	
Two-Wheelers								
Moped	256	1.40	152	0.60	0.01	0.03	0.04	
Scooter	487	1.40	295	0.61	0.02	0.02	0.05	
Motorcycle (50-250	797	1.40	374	0.47	0.02	0.02	0.05	
Three-Wheeler	115	1.88	96	0.84	0.04	0.02	0.07	
Bus	4,446	47.49	466	0.10	0.03	0.04	0.07	0.00
Passenger Rail								
Conventional Rail	80	1,152.01	26	0.32	0.01	0.02	0.03	0.01
Non-Motor								
Walk	310	1.00	-	-		0.30	0.30	
Bike	164	1.00	-	-		0.10	0.10	
Air								
Short (<2000 KM)	11	114	40	3.75	0.14	0.01	0.14	
Long (>2000 KM)	277	204	648	2.34	0.11	0.00	0.11	
Freight Trucking								
Truck (0-2t)	4	0.50	23	6.00	0.36		0.36	
Truck (2-5t)	19	1.13	90	4.84	0.29		0.29	
Truck (5-9t)	422	3.04	1,092	2.59	0.12		0.12	
Truck (9-16t)	151	6.00	255	1.69	0.07		0.07	
Freight Rail								
Conventional Rail	20	1,518.08	22	1.10	0.02		0.02	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	7,843	8,957	2,996	0.38	0.04	0.05	0.08
Freight	616	703	1,482	2.41	0.11		0.11

U.S.A. in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI MJ/PKT or Ton-KM	Monetary Costs (Fares) $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Compact Car	2,245	1.58	4,138	1.84	0.15	0.31	0.46	
Midsize Car	1,383	1.58	3,262	2.36	0.20	0.31	0.51	
Large Car	668	1.58	1,636	2.45	0.24	0.31	0.55	
Light Truck and SUV	2,337	1.73	5,445	2.33	0.25	0.31	0.56	
Two-Wheelers								
Motorcycle (>250cc)	37	1.10	51	1.37	0.69	0.31	1.00	
Bus	550	18.39	308	0.56	0.09	0.40	0.49	0.00
Passenger Rail								
Conventional Rail	20	29.86	48	2.33	0.14	0.40	0.55	0.12
High Speed Rail	0	149.47	0	1.77	0.46	0.14	0.60	0.05
Non-Motor								
Walk	50	1.00	-	-		4.48	4.48	
Bike	11	1.00	-	-		1.49	1.49	
Air								
Short (<2000 KM)	919	125	2,811	3.06	0.12	0.09	0.21	
Long (>2000 KM)	399	233	736	1.84	0.10	0.06	0.16	
Freight Trucking								
Truck (0-2.7t)	52	0.27	920	17.55	3.92		3.92	
Truck (2.7-4.5t)	113	1.01	599	5.32	1.14		1.14	
Truck (4.5-12t)	686	3.60	2,057	3.00	0.35		0.35	
Truck (>12t)	1,218	4.16	3,898	3.20	0.31		0.31	
Freight Rail								
Conventional Rail	2,194	3,216.88	494	0.22	0.01		0.01	

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	8,621	28,764	18,434	2.14	0.18	0.31	0.49
Freight	4,263	14,224	7,968	1.87	0.23		0.23

Western Europe in 2005

	Travel Demand Billion PKT/TKT	Load Factor	Energy PJ	EI MJ/PKT or Ton-KM	Monetary Costs $/PKT or Ton-KM	Time Cost $/PKT	Generalized User Cost $/PKT or Ton-KM	Subsidy $/PKT
Cars & Trucks								
Subcompact Car	1,283	1.65	2,005	1.56	0.27	0.20	0.46	
Compact Car	3,400	1.66	5,376	1.58	0.32	0.20	0.52	
Van	302	1.65	565	1.87	0.49	0.20	0.69	
Large Car and SUV	734	1.64	1,588	2.16	0.67	0.20	0.87	
Two-Wheelers								
Moped	47	1.10	35	0.76	0.09	0.26	0.36	
Motorcycle (50-250cc	57	1.10	70	1.22	0.37	0.20	0.57	
Motorcycle (>250cc)	14	1.10	22	1.55	0.63	0.20	0.83	
Bus	943	16.48	544	0.58	0.07	0.26	0.33	0.05
Passenger Rail								
Conventional Rail	500	73.75	245	0.49	0.14	0.18	0.32	0.13
High Speed Rail	29	155.66	11	0.39	0.26	0.05	0.31	0.13
Non-Motor								
Walk	160	1.00	-	-		3.04	3.04	
Bike	53	1.00	-	-		1.01	1.01	
Air								
Short (<2000 KM)	388	122	1,226	3.16	0.13	0.05	0.17	
Long (>2000 KM)	559	224	1,070	1.92	0.10	0.03	0.13	
Freight Trucking								
Truck (0-3.5t)	49	0.80	203	4.18	1.41		1.41	
Truck (3.5-16t)	96	2.24	214	2.24	0.54		0.54	
Truck (16-32t)	895	12.43	849	0.95	0.11		0.11	
Truck (>32t)	762	16.29	662	0.87	0.08		0.08	
Freight Rail								
Conventional Rail	419	373.84	108	0.26	0.04		0.04	-

	Travel Demand	Annual PKT/Ton-KM per capita	Energy	EI	Monetary Costs (Fares)	Time Cost	Generalized User Cost
Passenger	8,469	17,885	12,758	1.51	0.28	0.24	0.52
Freight	2,221	4,690	2,036	0.92	0.14		0.14