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Model Documentation Report: Transportation Sector Module of the World Energy Projection System

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1. Introduction

Purpose of this Report

This report documents the objectives, analytical approach, and development of the World Energy Projection System (WEPS) Transportation Energy Model. The report catalogues and describes model assumptions, computational methodology, and parameter estimation approach.

This document serves three purposes. First, it is a reference document providing detailed descriptions of the WEPS Transportation Energy Model for energy analysts, model users, and the public. Second, this report meets the legal requirements of the Energy Information Administration (EIA) to provide adequate documentation in support of its models *(Public Law 94-3895, section 57.b2*). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements as future projects.

Model Summary

The WEPS Transportation Energy Model is a structural accounting model for road, rail, air, domestic shipping, international shipping, and pipeline energy use. Estimates of growth in total energy use for each mode are built up from estimates of growth in travel (miles per year) and growth in energy intensity (energy use per mile). Projections of the mix of fuels used at the modal level are based on historical trends informed by country-specific analysis of potential shifts in the fuel mix. The transportation model generates mid-term (up to 2020) forecasts of transportation sector energy use as a component of WEPS. Utilizing the same regional macroeconomic and demographic projections as other WEPS components, it passes back to WEPS regional transportation sector energy use.

The model is designed to provide a flexible and accessible platform for energy analysis. Toward these ends it has been developed as an Excel spreadsheet. Defining a "model run" (for a given set of regional macroeconomic and demographic forecasts) consists of a assigning values to key model parameters.

Archival Media

WEPS99

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Organization of this Report

Chapter 2 of this report discusses the purpose of the Transportation Energy Model, detailing its objective and listing input and output quantities and important intermediate results. Chapter 3 of the report describes the rationale behind the Transportation Energy Model design and provides a model overview. In addition, fundamental assumptions and important caveats are highlighted. Chapter 4 provides a description of the model logic and principal calculations for road transportation energy. Chapter 5 describes the calculations for all other transport modes.

The Appendixes to this report provide supporting documentation for the Transportation Energy Model. Appendix A is a bibliography of the data sources and background materials used in the model development process. Appendix B consists of a model abstract. Appendix C lists key variable (range name) definitions spreadsheet locations.

2. Model Purpose

Model Objectives

The Transportation Energy Model is designed to provide a framework for integrating knowledge of energy use trends in industrialized countries with analysis of potential energy demand growth in the developing world. Certainly much more is known about energy use in industrialized countries than in regions with only rudimentary transportation systems. Incorporating this knowledge within a framework capable of exploring alternative transportation system futures in the developing world was an important priority in the development of the Transportation Energy Model.

The mature transportation systems of the United States and Canada, Western Europe and industrialized Asia (industrialized countries) have been analyzed extensively—detailed data and forecasting systems have been developed and mid-range forecasts are routinely produced. These models often provide such structural details as the number and mix of road vehicles and the housing stock. In these regions, however, only modest growth in transportation energy is expected due to slower population growth and the beginnings of saturation for road vehicle services. In contrast, comparatively few studies have developed forecasting models for developing regions of Latin America, Asia, Africa, and the Middle East that include structural detail. These regions are expected to account for an increasing share of world transportation energy as economic development proceeds.

The Transportation Energy Model is an annual energy-forecasting model; as such, it does not project seasonal variations in fuel demand such as the increase in gasoline demand during the summer months. The model was designed primarily for use in applications such as the *International Energy Outlook* and other applications that examine mid-term energy-economy interactions.

The model can also be used to analyze the potential impact of alternative transportation policies. For example, vehicle efficiency in the industrialized nations has shown little improvement during the 1990's and, against a backdrop of stable oil prices, the reference case forecast in the *IEO* continues this trend into the forecast period. Analyzing the magnitude and timing of how higher energy prices affect consumer's vehicle purchasing decisions is beyond the scope of the Transportation Energy Model. This remains a very controversial subject. However, a time profile for average vehicle fuel economy in each region is a variable that the model user must make explicit assumptions about—one choice is to continue the recent trend; another is to specify the rate of change in vehicle energy efficiency for each forecast year. Consequently the impact of higher fuel economy on oil consumption and carbon emissions, whether in response to price signals or regulatory standards, can be evaluated.

Interaction with Other WEPS Modules

The Transportation Energy Model receives as inputs macroeconomic and demographic forecasts from WEPS. These forecasts are developed in the broader context of WEPS and are discussed in the documentation for WEPS. The Transportation Energy Model develops forecasts of transportation energy and oil consumption by mode of transport for each of the WEPS regions.

These forecasts are then utilized as input for developing regional oil consumption forecasts within the broader WEPS framework.

The Transportation Energy Model uses NEMS estimates of transportation energy use by mode for the United States as benchmarks. Internal model adjustments ensure that the Transportation Energy Model projections and the NEMS projections for the United States are identical.

3. Model Rationale

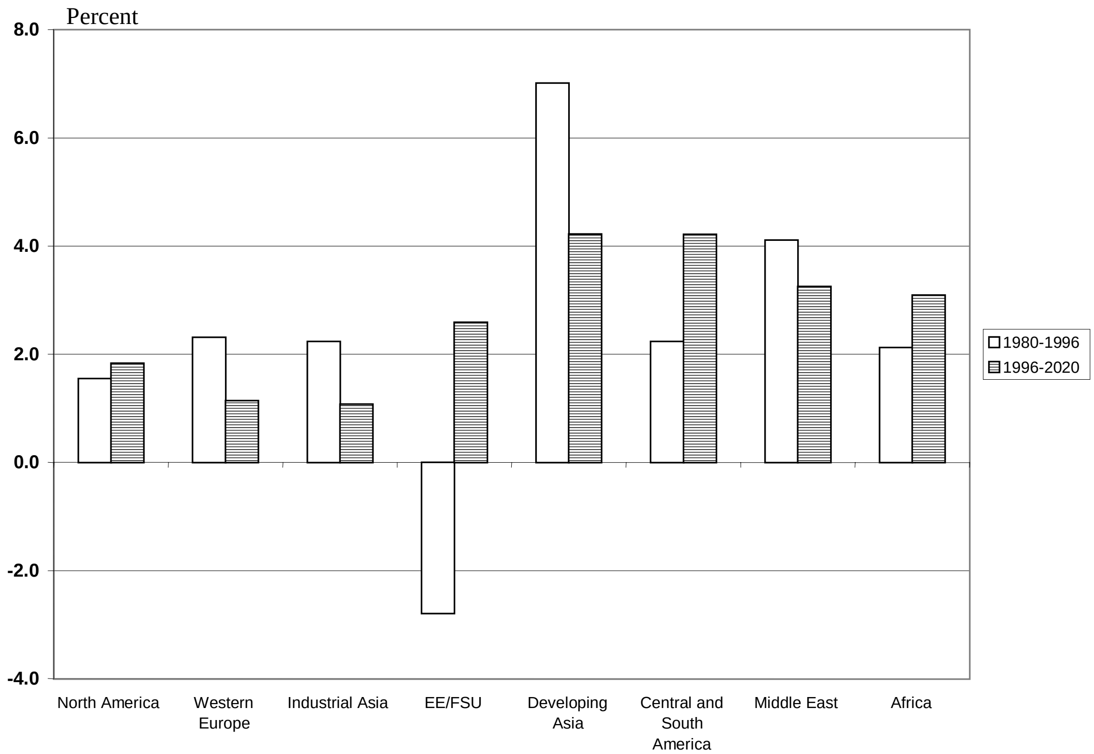
Analytical Approach and Model Overview

Introduction

The developing regions of Asia, Latin America, Africa and the Middle East accounted for less than one-third of world transportation energy use in 1995—and over three fourths of the world's population. This share is expected to increase rapidly in the future (contingent upon continued growth in per capita income) with forecast growth rates far higher than among industrialized countries (Figure 1). As a consequence of this expected increase in importance, particular attention has been paid to growth potential among the developing regions in the Transportation Energy Model.

Not surprisingly, however, far more data are available for analyzing emerging transportation energy trends in industrialized than developing nations. Often, for example, information on vehicle use characteristics and travel trends are not covered by routinely collected data in the developing world. It has been a major design principal of the Transportation Energy Model to make full use of the data that are available and to make explicit and transparent assumptions where data are not available. Analysts using the Transportation Energy Model, need, and should, not exclude information available for the industrialized nations because of limited data in some regions.

Figure 1. Historical and Forecast Growth in Transportation Energy by Region



Source: World Energy Projection System 1999

Regional Detail

The level of geographic detail in the Transportation Energy Model matches the WEPS. Countries that, by their size and potential economic growth, may impact aggregate energy use (and carbon emissions) in ways vastly different from historical trends are considered individual regions. For example, for purposes of developing annual transportation energy forecasts, China is considered a separate region within developing Asia.

In addition to economic and energy market importance, some countries are considered separate regions to allow aggregation to commonly used world subtotals such as OECD and Non-OECD Nations, Annex 1, Developing Nations, North America, and Latin America. The Kyoto Protocol defines Annex 1 (nations that have agreed to specific carbon emissions targets) to include Europe **LESS** Turkey; North America **LESS** Mexico; Industrialized Asia **LESS** South Korea, and the "Economies in Transition" (Countries of the Former Soviet Union and Eastern Europe). The regions listed below represent the current international modeling system that supports the *International Energy Outlook*.

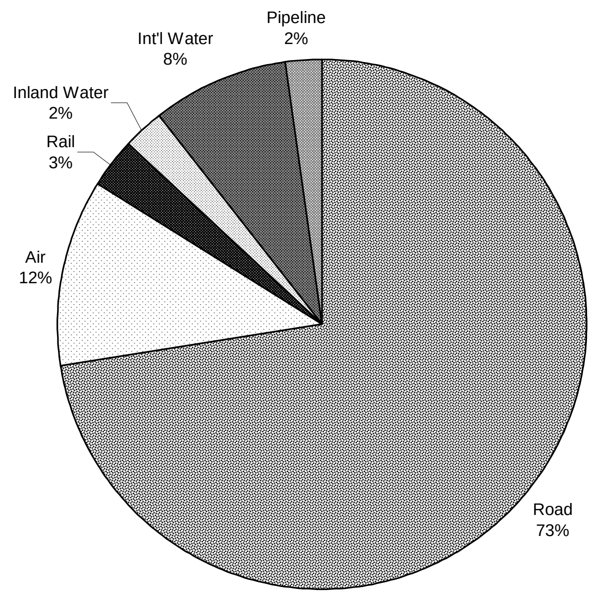
Table 1. Regional Detail in the Transportation Energy Model

United States	Former Soviet Union
Canada	Eastern Europe
Mexico	China
Japan	India
United Kingdom	South Korea
France	Other Developing Asia
Germany	Middle East
Italy	Africa
Netherlands	Brazil
Other Europe	Rest of Central and South America
Australasia (Australia and New Zealand)	Turkey

Modal Detail

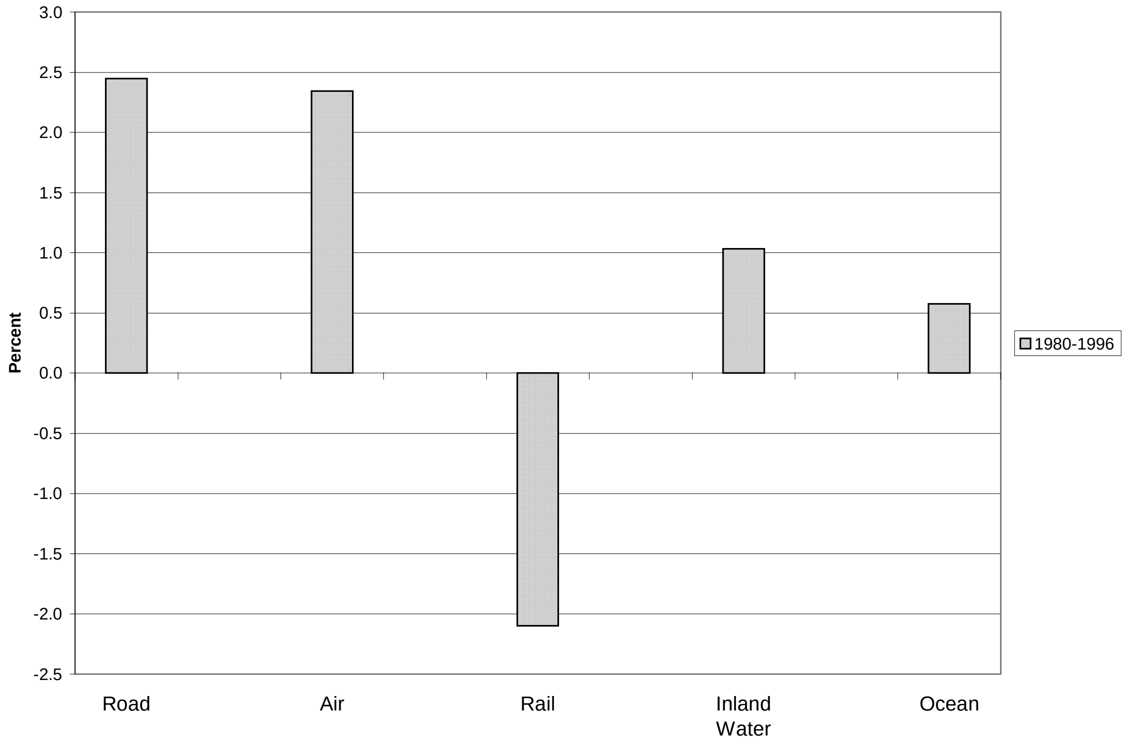
Data review and analysis have focused on two transport modes, road and air. Worldwide these modes accounted for 85 percent of transportation energy in 1996 and most of the growth on recent years (Figures 2. and 3.). This dominance is expected to continue in the future in both industrialized and developing economies.

Figure 2. Worldwide Transportation Energy Consumption in 1996, Percentage Share by Mode



Source: World Energy Projection System, 1999.

Figure 3. Growth in Worldwide Transportation Energy, by mode, 1980-1996



Source: World Energy Projection System, 1999.

Modeling Approach

The Transportation Energy Model provides a framework for systematically exploring the energy consumption implications of alternative sets of energy, economic and demographic assumptions. For a given set of assumptions (defining a scenario) the Transportation Energy Model forecasts energy use by transport mode, by fuel and by WEPS region. The transport modes are road; air; rail; domestic water; international water, and pipeline. Combined these modes account for all energy use typically categorized as transportation energy.[1]

For each transport mode and each region (modal and regional subscripts have been omitted for reading clarity):

$$\%\,\Delta\, Energy\ Use_{t,t+1} \quad = \quad \%\,\Delta\, Energy\ Intensity_{t,t+1} \quad + \quad \%\,\Delta\, Activity_{t,t+1} \qquad \textbf{(1)}$$

Where:

% Δ	Indicates percentage change
t,t+1	Between periods t and t+1. Note the Transportation Energy Model is an annual model.
Energy Use	Total energy use for a specific mode (i.e. road) and region
Activity	For air, rail, inland water, international water, and pipeline, growth in GDP is the metric of activity. For road energy, growth in the forecast number of vehicles is the activity metric. The number of vehicles forecast is driven by growth in per capita GDP.
Energy Intensity	Energy use per unit of activity per year (i.e. gallons per vehicle per year)

$$\%\,\Delta\, Energy\ Intensity_{t,t+1} \quad = \quad \%\,\Delta\, Travel_{t,t+1} \quad + \quad \%\,\Delta\, Energy\ Efficiency_{t,t+1} \qquad \textbf{(2)}$$

Where:

Energy Efficiency	Energy use per unit of travel service (e.g. gallons per vehicle-mile). **Note that improved vehicle efficiency means reduced energy per unit of travel (negative value for the term *%Δ Energy Efficiency*).** Year-to-year efficiency improvements are exogenous in the Transportation Energy Model (Appendix C, *Eff_[mode]_Gr_Value*).
Travel	Travel service per unit of activity (i.e., miles per vehicle per year or air travel per dollar GDP per year). Forecast year-to-year changes in travel per vehicle are based on forecast economic growth and region-specific travel elasticity assumptions *(*Appendix C, *Tr_[mode]_El_Value*).

In words, for road energy, equation 1 states that the percentage change in total road energy use from one year to the next equals the sum of percentage changes in a) fuel use per vehicle per year and b) the number of road vehicles. Thus, if the forecast average number of gallons of gasoline consumed per vehicle (energy intensity) remains unchanged between 2000 and 2001 while the vehicle count increases by 2.0 percent, total road energy use increases by 2.0 percent. Similarly for equation 2, the percentage change in gallons per vehicle per year (energy intensity) from one year to the next equals the difference between percentage changes in a) miles traveled per year,

[1] See, for example, the definition of the transportation sector used in the Energy Information Administration's *State Energy Data Report 1995*, (DOE/EIA-0214(95), page 5.

and b) gallons of fuel required per average vehicle-mile (energy efficiency measured as 1/mpg). Thus (all other things being equal), if forecast travel per vehicle increases by 2.0 percent between 2000 and 2001 while average vehicle energy efficiency remains unchanged, forecast total road energy use increases by 2.0 percent.

Energy use totals (by mode and region) are distributed to fuel types based on historical trends and recent energy market developments. Gasoline, diesel, LPG, electricity, residual fuel oil, and coal consumption are estimated as well as an "other" category which includes biofuels such as ethanol use in Brazil.

Fundamental Analysis Assumptions

The transportation energy forecasts in WEPS are not equilibrium solutions that minimize the expected cost of providing passenger-miles and ton-miles to an idealized economy in a far off year. These forecasts show incremental changes to current energy use patterns in specific countries and in specific transportation modes. Most importantly, each country's projected energy growth is contingent on exogenous forecasts of economic and population growth.

The potential for travel substitution among transportation modes is not evaluated in the Transportation Energy Model. Total transportation energy consumption sums projections made for six modes: road; air; rail; pipeline; inland water, and ocean (bunker). Each mode is evaluated independently based on economic growth assumptions and historical trends in regional transportation energy use. Direct substitution among road, rail and air is not considered. However, growth in energy use does vary by mode resulting in changing modal shares over time. This simplification is not judged to seriously affect the results over a forecast to 2020.

The Transportation Energy Model assumes that the future configuration of transportation services offered in developing regions follows examples from more advanced economies. Transportation services available in much of the developing world today remain rudimentary. China, in 1996, had fewer vehicles (including cars, trucks, and buses but not motor bikes) than Texas—less than 10 vehicles per 1000 people. Over the forecast, however, per capita income is expected to quadruple in China motivating increased demand for transportation services. As development proceeds, road and air modal shares are expected to increase while rail's share declines—this is the pattern seen among industrialized nations. China may choose a different course, emphasizing passenger rail over the personal automobile. To evaluate such a scenario, the elasticity of rail travel with respect to income would have to be increased and some adjustment to forecast growth in the number of road vehicles might be necessary.

Energy prices are noticeably absent from equations 1 and 2. This was not a judgement on the scale of the effect prices have on transportation energy and further work is planned in this area. Energy prices do count. Prices affect both the levels of transportation service demanded and the energy efficiency with which services are provided. However, the magnitude of price effects on transportation energy are expected to be modest compared to the effects of economic growth—particularly in the context of stable world oil prices.

4. Road

The end-use mode "Road" accounts for all road vehicle energy use in the Transportation Energy Model—cars as well as freight trucks, utility vehicles as well as buses. Correspondingly, projections linked with road energy such as vehicle count and vehicle energy intensity (energy use per vehicle per year) refer to an average or composite road vehicle representative of a region's road system. Each region's average vehicle energy intensity reflects its own particular vehicle mix, efficiency and usage (travel per vehicle) pattern. And changes in vehicle energy intensity over time mirror changes in these factors.

Limited data in the developing world was the key factor favoring a composite road vehicle approach. In industrialized nations, studies analyzing road energy by freight trucks separately from passenger vehicles are routinely done. But most growth is expected in developing nations where data are far more incomplete. Specifically, data distinguishing fuel use by cars from that of trucks were not used for this analysis. Nor were data on annual vehicle usage (miles per year) or energy efficiency (energy per mile) by vehicle type. What data were available on a consistent historical basis were total road energy consumption and the total number of registered vehicles. These data were used to develop base year estimates of the:

- Number of road vehicles in operation for each region, and
- Vehicle energy intensity (energy use per (composite) vehicle per year).

The Transportation Energy Model is a PC-based Excel spreadsheet model. The variable names used in this documentation report correspond to the range names defined within the model to ease navigation within and across model segments. Appendix C provides a cross-reference between the range names and spreadsheet locations.

The model user will note that the equations listed in this report explain the logic of the model in elemental form—actual model calculations sometimes combine several logical steps. Regional subscripts have been omitted from the equations, however, the range names encompass calculations for each of the Transportation Energy Model regions for all forecast years.

Number of Vehicles

For road energy, the number of road vehicles serves as the metric of activity referred to in Equation 1. The number of road vehicles in service in a region is estimated by multiplying the region's projected population by an estimate of the extent of its "motorization." Motorization in this context is the number of highway vehicles per 1000 population. The year-to-year change a region's vehicle stock is constrained to be non-negative following historical trends. In addition, to account for constraints in road infrastructure, the stock of highway vehicles is not allowed to increase by more than a user-defined percentage increase in any one-year.

Calculating the Number of Vehicles

On a percentage basis, the change in the number of highway vehicles is equal to the product of changes in motorization rates and population.

$$\%\Delta Hwy\_veh_{t,t+1} = \%\Delta Veh\_1000_{t,t+1} + \%\Delta Pop_{t,t+1} \qquad (3)$$

Subject to:

$$\Delta Hwy\_veh_{t,t+1} \geq 0 \qquad (4)$$

And:

$$Hwy\_veh_{t+1} \leq RSC * Hwy\_veh_{t} \qquad (5)$$

Where:

Hwy_veh_t	Total number of all highway vehicles in year t (regional subscript omitted)
Veh_1000_t	Motorization rate defined as the number of highway vehicles per 1000 population
Pop_t	Total forecast population in year t
RSC	Road structural constraint parameter. If *RSC* equals 1.1, a typical regional value, than the number of vehicles in t+1 cannot be more than 10 percent higher than the number of vehicles in t.

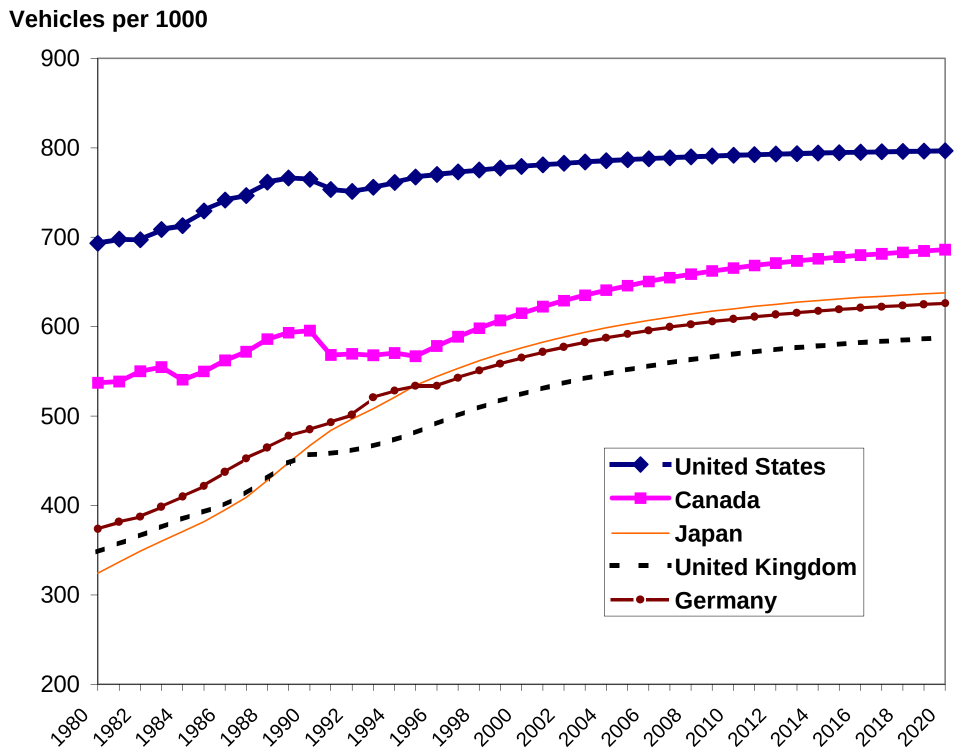
Motorization

Motorization levels by country and region fall into two broad categories. One consists of Western Europe, North America, and Industrial Asia. Nations in this category already have modern road and vehicle infrastructure systems. Among these nations motorization levels are already high and forecast annual growth averages only 0.5 percent between 1996 and 2020. At the other end of the spectrum, developing regions often have embryonic road systems and personal travel is fueled by “person power” (i.e. walking, biking). Motorization levels among these nations, while now low, are expected to grow rapidly.

In Industrialized Countries

Consistent with recent trends, motorization among the industrialized nations is assumed to increase slowly above current levels. The model user chooses 2020 target motorization levels and rates at which these targets are approached. By assumption in *IEO99*, 2020 motorization levels approach 800, 700, and 650, for the United States, Canada, and Japan, respectively. France and Germany reach 650 vehicles per 1000 population while motorization in the United Kingdom continues slightly lower. South Korea (included in the Developing Asia category) approaches a motorization level of 450 by 2020, up from 189 in 1995.

Figure 4. Motorization Trends for Selected Industrialized Countries



Source: *IEO99,* World Energy Projection System

The levels assumed for developing forecasts for the *International Energy Outlook* broadly follow historical trends in both a countries' own pace of incremental motorization and its level of motorization relative to that of other industrialized nations (Figure 4.). The historical experience, for example, supports choosing a 2020 motorization target for the United States that is significantly above the level assumed for European nations.

In Developing Countries

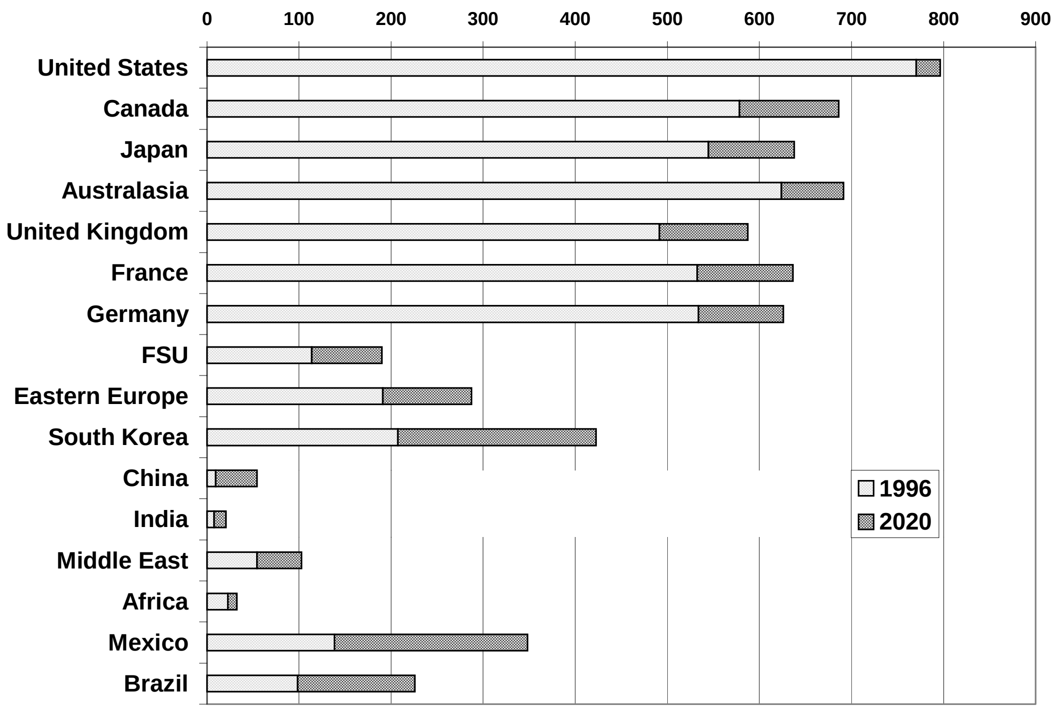
In Latin America many countries (e.g., Mexico, Brazil) have already achieved significant levels of motorization. For these nations their own experience in motorization growth relative to per capita income growth ("motorization elasticities") guides estimates of future motorization levels in the Transportation Energy Model. For example, a motorization elasticity of 1.2 indicates that a 10-percent increase in per capita income results in a 12-percent increase in motorization (vehicles per 1000 population).

For developing countries that had barely begun providing modern road transportation services by 1995 (China, India, and Other Developing Asia) utilizing "motorization elasticities" proved problematic. Instead, the South Korean level of motorization *in 1995* (189 vehicles per 1000 population) relative to its level of per capita income *in 1995* ($8,700 in 1997 dollars) was used as a template for developing 2020 motorization targets for these countries and regions. For example, to estimate the 2020 motorization level for China:

- Calculate the ratio of per capita income in China in 2020 to the level in South Korea in 1995 [2.6/8.7 = 0.3]
- Multiply the 1995 South Korean motorization level (189) by this ratio.

The result, a motorization target of 57 in 2020 (*IEO99)*, almost a 6-fold increase from China's 1996 level (Figure 5).

Figure 5. Motorization Levels for Selected Countries, 1996 and 2020



Source: *IEO99*, World Energy Projection System

Calculating Motorization Levels

The Transportation Energy Model provides three options for estimating 2020 motorization levels and the user must choose an option for each region (Appendix C, *Mot_Option)*. All assumptions made in developing a forecast for the *International Energy Outlook*, including those affecting motorization rate projections, are archived as part of the WEPS archival process.

Option 1

Option 1 utilizes assumed region specific, motorization elasticities (percentage change in Veh_1000 per unit percentage change in per capita income) to project year-to-year changes in levels of motorization. Motorization elasticities are inputs to the model. Again, regional subscripts have been omitted. Option 1 is well suited for regions that, while still classified as developing, have considerable experience in providing road transport services. This option has been used to develop forecasts of motorization for Latin America.

$$\%\Delta Veh\_1000_{t,t+1} = Mot\_el * \%\Delta GDP\_Pop_{t,t+1} \quad (6)$$

Where:

Mot_el	Motorization elasticity defined as the percentage change in vehicles per 1000 population per unit percentage change in per capita income.
GDP_Pop	Per capita gross domestic product

Option 2

In Option 2 year-to-year percentage increases in motorization rates are provided exogenously by the model user. This option provides a convenient means of incorporating results from other studies and developing alternative road energy use scenarios.

$$\%\Delta Veh\_1000_{t,t+1} = \%\Delta Veh\_1000_{t,t+1}(EXOG) \quad (7)$$

Where:

Veh_1000 (EXOG)	Exogenously specified, year-to-year, percentage growth in a region's motorization rate

Option 3

Option 3 assumes that a region's motorization rate will asymptotically approach a target value in 2020. A region's 2020 target value and the rate at which the target motorization level is approached are determined by user-specified parameter settings. The choice of a simple asymptotic relationship fits the historical data for industrialized countries reasonably well. These countries already have mature road systems and only modest increases in motorization rates are expected (Figure 7).

For countries where rapid increases are likely this functional form is more problematic because it is unclear how year-to-year changes in vehicles per 1000 population will be affected by the level of motorization already achieved. This issue is made somewhat moot by constraints limiting annual growth in the number of vehicles based on infrastructure limitations (*RSC* in Equation 5).

$$Veh\_1000_t = Veh\_1000_{2020} - [b \exp(-ct)] \quad (8)$$

Where:

Veh_1000_{2020}	The target assumed for the number of vehicles per 1000 population in 2020 in a region.
b	Veh_1000_{2020} - Veh_1000_{1995}
exp	The inverse of the natural logarithm. The expression exp (-ct) is read e raised to the power - ct.
c	A region specific parameter that controls the rate at which the motorization target is met (Appendix C, *c_Veh_1000)*.
t	*t* = 0 in 1995, *t* = 1 in 1996,....*t* = 25 in 2020.

And:

For Industrialized Nations:

(Veh_1000_{2020}) targets are set by choosing among 8 indexes (Appendix C, *Road_S_Index*), each corresponding to a different value (Appendix C, *Road_S_Index_Value)* for the number of vehicles per 1000 population in 2020. For example, in the version of the Transportation Energy Model archived for the *IEO99*, *Road_S_Index* = 1, corresponds to *Road_S_Index_Value* = 800.

For Developing Countries:

(Veh_1000_{2020}) targets are linked to forecast economic growth. This approach asks, what if motorization growth in region A follows the development pattern of region B? More specifically, what if increases in $Veh\_1000_{A,2020}$ are proportional to region A's per capita income *in 2020* relative to region B's per capita income *in 1995*. Using, South Korea as the development template:

$$Veh\_1000_{region,2020} = \frac{GDP\_Pop_{region,2020}}{GDP\_Pop_{SouthKorea,1995}} * Veh\_1000_{SouthKorea,1995} \qquad (9)$$

This method was especially useful for developing nations that have little experience in providing modern road services such as China and India. Use of Option 1 (motorization elasticity) for such nations can easily result in forecasts of motorization that are unrealistically high.

Vehicle Energy Intensity

The Transportation Energy Model bases projections of vehicle energy intensity (energy use per vehicle per year) on analysis of historical trends in both industrialized and developing countries. Three observations from this analysis shaped the methodology for forecasting vehicle energy intensity:

- Average vehicle energy intensity is consistently higher in developing regions than among industrialized nations.
- As the process of development continues average vehicle energy intensity declines.
- Although average vehicle energy intensity varies considerably among industrialized countries, it has shown remarkably little variation *within* industrialized countries over the last decade.

Energy intensity projections for a road vehicle that represents a composite of all highway vehicles implicitly include assumptions on the future mix of vehicles (e.g. passenger cars, buses, commercial trucks, freight trucks) and trends in each type vehicle's individual usage and efficiency characteristics. These implicit assumptions are critical to the energy forecast—freight trucks' may easily consume as much fuel as 30 passenger cars over a year. For developing countries major changes in the mix of highway vehicles mark the transformation of a nation's road system from one dominated by inefficient trucks driving long hours on poor roads to one increasingly focused on passenger vehicles. Needless to say, appropriate assumptions made to forecast vehicle energy intensity for developing nations differ from those made for industrialized nations. However, in each case, projected trends follow smoothly from historical data.

In Industrialized Countries

Figure 6 and 7 show historical, as well as illustrative forecast, vehicle energy intensities for many of the industrialized nations explicitly modeled in the Transportation Energy Model. Given these data refer to a composite representation of all road vehicles the near constancy of each industrialized nation's vehicle energy intensity over the last decade is striking—1995 values differ from those in 1985 by only a few percent and no trend is apparent. These mature economies appear to have each reached a stage where structural changes (i.e., changes in the mix, usage and age distribution of vehicles) no longer significantly influence changes in average vehicle energy intensity.

For these nations, vehicle energy intensity projections in the model weigh expected changes in vehicle efficiency against changes in vehicle travel. Thus, if average vehicle fuel efficiency (measured in gallons per mile) were forecast to increase by 3 percent between 2000 and 2001 while travel per vehicle (measured in miles) were forecast to increase by 2 percent, vehicle energy intensity would decrease by 1 percent.

Also noteworthy in the historical data are the major differences in vehicle energy intensities that have persisted between regions over the last decade. The United States and Canada have shared a vehicle energy intensity that is roughly 60- and 100-percent higher than rates in Western Europe and Japan, respectively. Higher average vehicle efficiency in Western Europe and Japan explains some of the difference. However, a large part of the difference is the result of factors that affect annual vehicle travel such as land area, population density, and the spatial distribution of employment and consumer services relative to residences. It is assumed that such differences are unlikely to change appreciably over the forecast period.

Figure 6. Vehicle Energy Intensity, United States, Canada and Japan

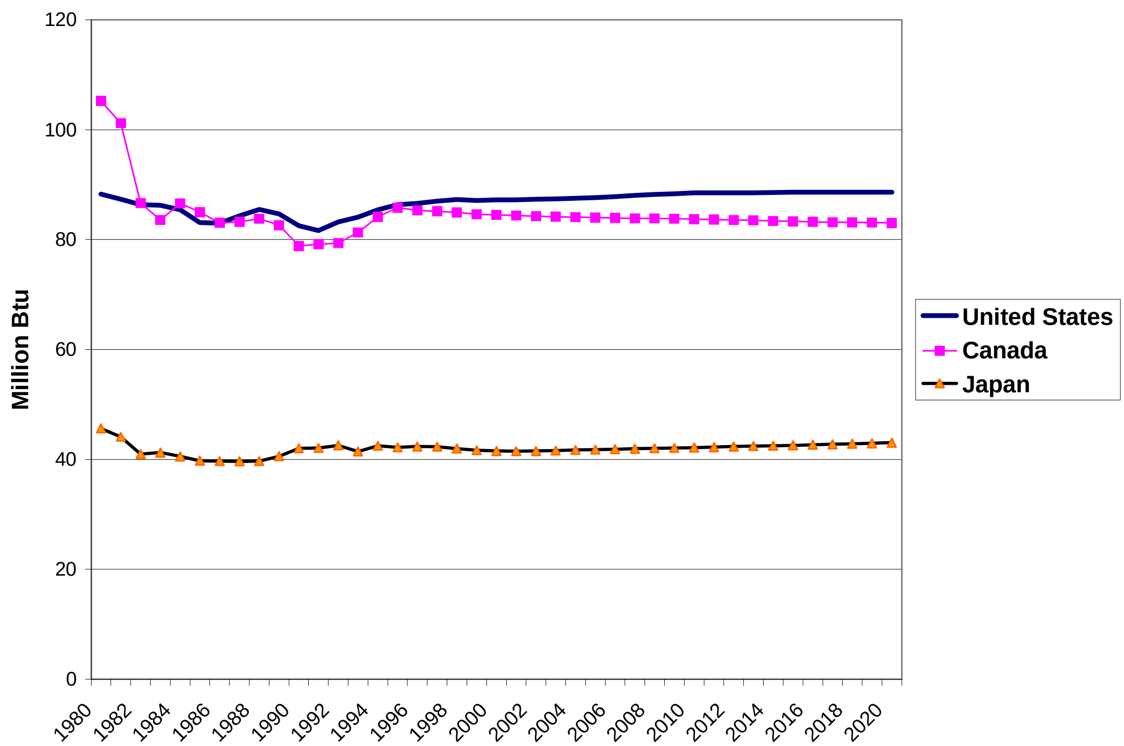
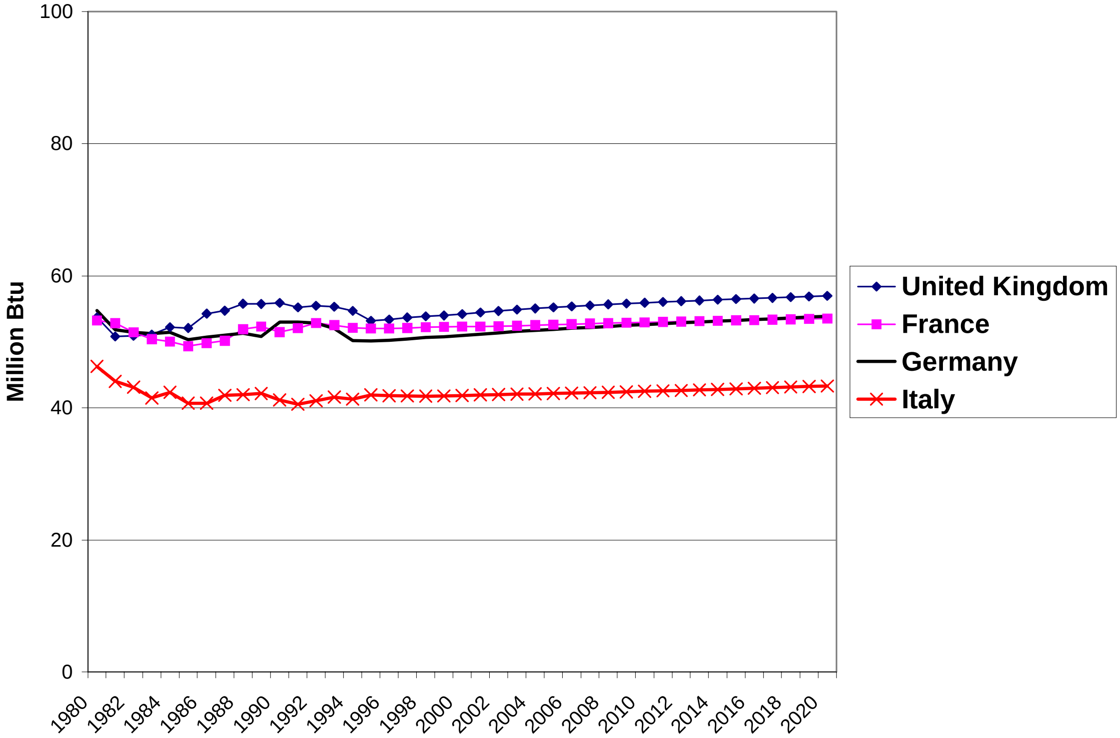


Figure 7. Vehicle Energy Intensity, Western Europe



In Developing Countries

Unlike industrialized nations, vehicle energy intensities in developing regions have generally declined significantly over the last decade (Figures 8 and 9). Declines are expected to continue over the forecast period, however, for the most part, annual fuel use per vehicle remains higher than in industrialized countries.

Figure 8. Vehicle Energy Intensity, Developing Regions

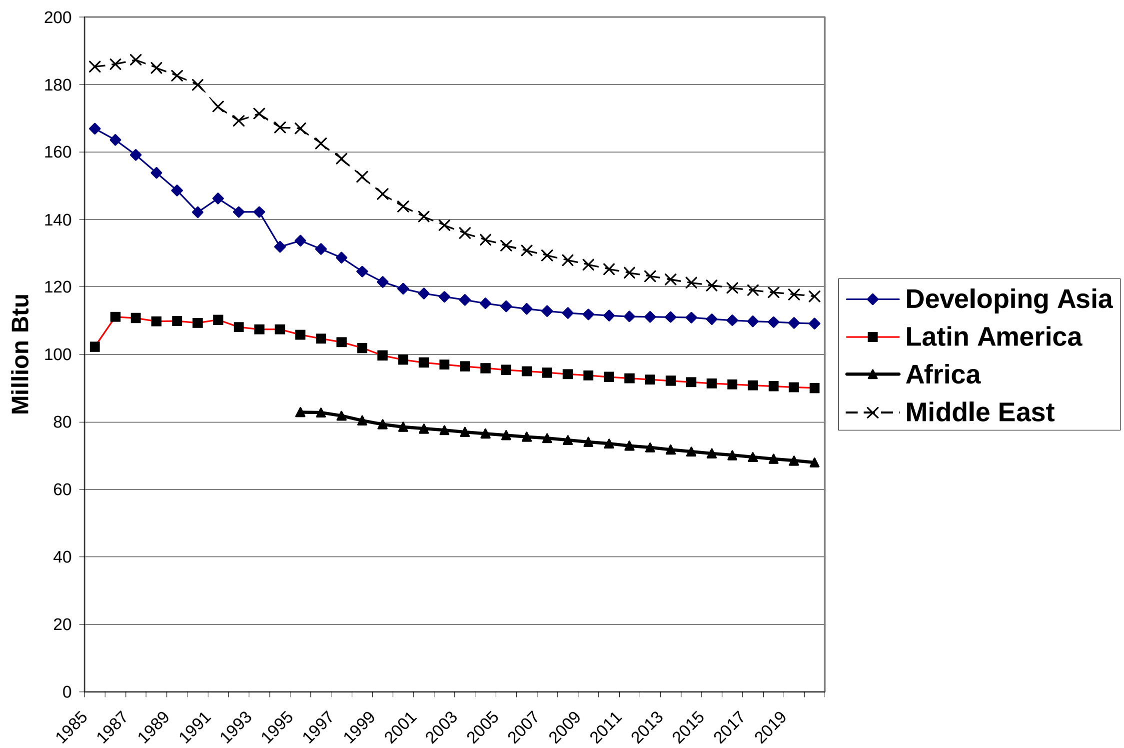
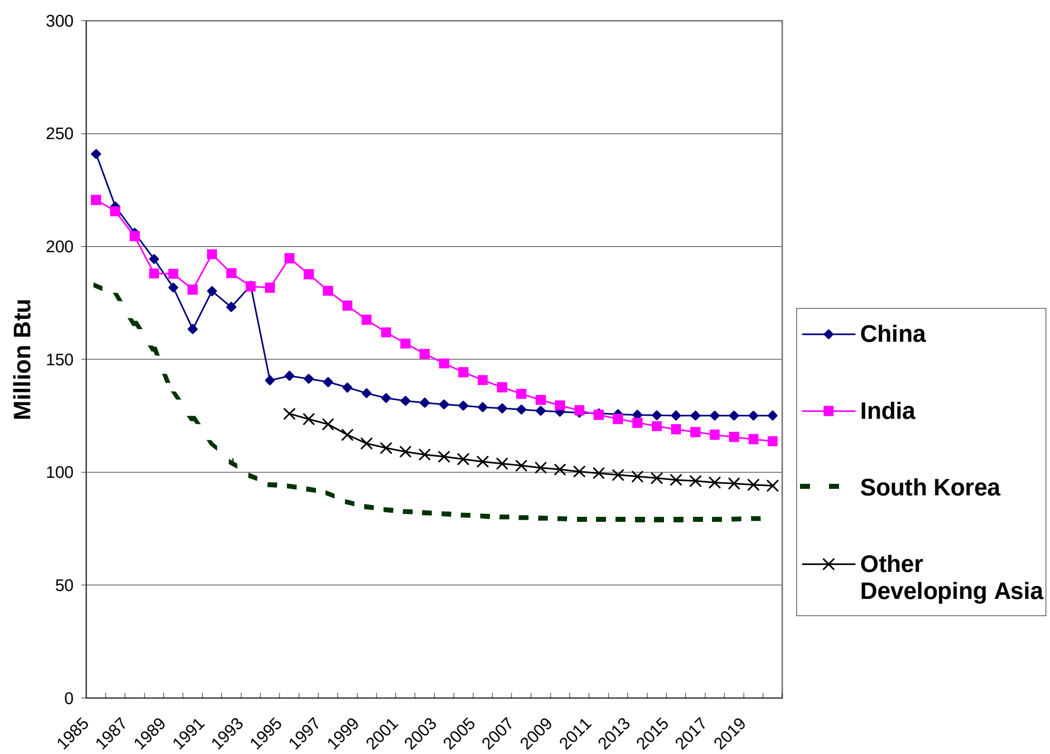


Figure 9. Vehicle Energy Intensity, Developing Asia



The Transportation Energy Model assumes that improved car and truck efficiencies played a relatively minor role in the declining vehicle energy intensity occurring between 1985 and 1995. Moreover, the model assumes that changes in the car-truck vehicle mix, in car and truck usage (miles per year) as well as changes in car and truck age and size distributions were, and will continue to be, the most important determinants of vehicle energy intensity in developing countries over the forecast period. How far developing regions' vehicle energy intensity is likely to fall over the forecast period due to changes in the structure of road transport is a matter for analysts' judgement. For developing forecasts for the *International Energy Outlook*, this judgement is guided by the development experience of nations that have undergone considerable motorization over the past decade such as South Korea, Mexico, and Brazil, is the basis for these assumptions.

Calculating Vehicle Energy Intensity

Energy use per vehicle per year for each region is calculated as the product of two factors; one relates to the maturity of a region's road transport system, the other captures year-to-year changes in average vehicle travel and efficiency. Again, the road vehicle referred to is a composite representation of all road vehicles. Regional subscripts have been omitted.

$$En\_Veh_t \quad = \quad St\_En\_Veh_t * \left[1 \quad + \quad \left(\frac{\%\Delta Tr\_Road \ + \%\Delta Eff\_Road}{100} \right) \right] \qquad (10)$$

Where:

En_Veh_t	Energy use per vehicle per year (vehicle energy intensity).
$St\_En\_Veh_t$	Estimate of vehicle energy intensity based solely on the assumed degree of structural change in a regions road transport system.
$\%\Delta$ *Tr_Road*	Cumulative percentage change in travel per vehicle between 1995 and forecast year t. Forecast year-to-year changes in travel per vehicle are based on forecast economic growth and region-specific travel elasticity assumptions (Appendix C, *Tr_Road_El_Value).*
$\%\Delta$ *Eff_Road*	Cumulative percentage change in vehicle efficiency (energy use per mile) between 1995 forecast year t. The model user (Appendix C, Eff_Veh_Gr_Value) specifies forecast year-to-year changes in average vehicle efficiency. **Note that improved vehicle efficiency means reduced energy per unit of travel (negative value for the term %Δ *Energy Efficiency*).**

$$St\_En\_Veh_t = St\_En\_Veh_{2020} - \left[b \exp\left(-ct\right)\right] \quad (11)$$

Where:

$St\_En\_Veh_{2020}$ — Vehicle energy intensity in 2020 based solely on structural change in road transport services.

<u>For Industrialized Nations</u>
Average vehicle energy intensity between 1990 and 1995.

<u>For Developing Countries</u>
Option 1
Menu of choices (Appendix C, *St_En_Veh_Value*) correspond to average vehicle intensities in the industrialized regions of the world (Figures 6 and 7).

Option 2
Use South Korean development experience as a template. The regions $St\_En\_Veh_{2020}$ is based on the regions 2020 motorization rate (vehicles per 1000 population) relative to the South Korean 1995 level and average vehicle intensity in South Korea in 1995.

b — St_Veh_{2020} - En_Veh_{1995}

exp — The inverse of the natural logarithm. The expression exp (-ct) is read e raised to the power - ct.

c — A region specific parameter that controls the rate at which the vehicle energy intensity target associated with structural change is met (Appendix C, *c_en_veh)*.

t — t = 0 in 1995, t = 1 in 1996,....t = 25 in 2020.

Calculating Road Energy by Fuel

A region's annual road energy is calculated as the product of the number of vehicles and the vehicle energy intensity (energy per vehicle per year). Fuel shares (i.e. gasoline, diesel, LPG) are based on historical values; however, the model user is free to alter fuel shares based on exogenous information. Appendix C lists range names and associated Row and Cell locations for modifying fuel share assumptions.

5. Other Transport Modes

Air, Rail, Inland Water, International Water

The Transportation Energy Model includes all modes of transport—road, air, rail, inland water, international water, and pipeline energy use. The non-road modes combined accounted for 27 percent of world transportation energy use in 1996 (Figure 2). With the exception of pipeline energy use, these modes share a common modeling approach. Appendix C lists modal specific range names and corresponding Row and Cell locations for modifying forecast assumptions. Modal and regional subscripts have been omitted for reading clarity.

$$\%\,\Delta\, Energy\ Use_{t,t+1} \quad = \quad \%\,\Delta\, Energy\ Intensity_{t,t+1} \quad + \quad \%\,\Delta\, GDP_{t,t+1} \qquad \textbf{(12)}$$

Where:

% Δ	Indicates percentage change
Energy Use	Total energy use for a specific mode and region
GDP	Gross Domestic Product (annual)
Energy Intensity	Energy use per dollar GDP

$$\%\,\Delta\, Energy\ Intensity_{t,t+1} \quad = \quad \%\,\Delta\, Travel_{t,t+1} \quad + \quad \%\,\Delta\, Energy\ Efficiency_{t,t+1} \qquad (13)$$

Where:

Energy Efficiency	Energy use per unit of travel (e.g. gallons per vehicle-mile). **Note that improved vehicle efficiency means reduced energy per unit of travel (negative value for the term *%Δ Energy Efficiency*).** Year-to-year efficiency improvements are exogenous in the Transportation Energy Model (Appendix C, *Eff_[mode]_Gr_Value*).
Travel	*Index of travel service.* Forecast year-to-year changes in travel per dollar GDP are based on forecast economic growth and region-specific travel elasticity assumptions (Appendix C, *Tr_[mode]_El_Value).*

In words, year-to-year percentage changes in energy use for air (rail, inland water, or international water) transport equals the sum of percentage changes in air energy use per dollar GDP (energy intensity) and GDP. And year-to-year percentage changes in energy intensity equals the sum of changes in air travel per dollar GDP and energy use per unit of air travel.

Pipeline

Only three regions reported appreciable pipeline energy use in 1995—the United States, Canada and the Former Soviet Union. The methodology implemented in the Transportation Energy Model assumes that only regions currently using pipeline energy consume pipeline energy in the future. However, only minor program changes would be required to model an alternative scenario.

For each region the model user sets annual growth in pipeline energy use—either at a constant rate for the entire forecast period or on a year-to-year basis. Setting growth rates on a year-to-year basis allows the modeler to include exogenous knowledge of planned major pipeline projects.

$$Pipeline_t = Pipeline_{t-1} * \left[1 + \left(\frac{Pipeline\_Gr\_Value_{t-1,t}}{100}\right)\right] \tag{14}$$

Where:

Pipeline	Total pipeline energy use (Appendix C, *Pipeline_Energy*).
Pipeline_Gr_Value	Growth rate for pipeline energy use. The modeler chooses a value by choosing a region specific *Pipeline_Gr_Index* or by specifying year-to-year growth in pipeline energy use *Pipeline_Gr_Exog* (Appendix C).

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Appendix A. Bibliography

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Appendix B. Model Abstract

Model Name:

Transportation Energy Model of the World Energy Projection System

Model Acronym:

None

Model Description and Purpose:

The WEPS Transportation Energy Model is a structural accounting model for road, rail, air, domestic shipping, international shipping, and pipeline energy use. Estimates of growth in total energy use for each mode are built up from estimates of growth in travel (miles per year) and growth in energy intensity (energy use per mile). Projections of the mix of fuels used at the modal level are based on historical trends informed by country-specific analysis of potential shifts in the fuel mix. The transportation model generates mid-term (up to 2020) forecasts of transportation sector energy use as a component of WEPS. Utilizing the same regional macroeconomic and demographic projections as other WEPS components, it passes back to WEPS regional transportation sector energy use.

The model is designed to provide a flexible and accessible platform for energy analysis. Toward these ends it has been developed as an Excel spreadsheet. Defining a "model run" (for a given set of regional macroeconomic and demographic forecasts) consists of assigning values to key model parameters. The parameter values used for developing forecasts for the *International Energy Outlook* are archived as part of the WEPS model archival process.

Most Recent Model Update:

August 1998

Part of Another Model?

World Energy Projection System (WEPS)

Model Interfaces:

Receives macroeconomic and demographic inputs from the World Energy Projection System.
Provides transportation energy consumption estimates by fuel and region to the WEPS system.

Official Model Representative:

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Documentation:

Model Documentaiton Report: Transportation Energy Model of the World Energy Projection System, July 1999.

Archive Information:

World Energy Projection System (1999)

Energy System Described:

World transportation energy consumption

Coverage:

- Geographic: 22 Regions (United States, Canada, Mexico, Japan, United Kingdom, France, Germany, Italy, Netherlands, Other Europe, Australasia, Former Soviet Union, Eastern Europe, China, India, South Korea, Other Developing Asia, Middle East, Africa, Brazil, Rest of Central and South America, Turkey)
- Mode: Road, air, rail, inland water, international water, pipeline
- Time Unit/Frequency: Annual 1996 through 2020

Modeling Features:

The model structure is an accounting framework of relationships concerning transportation energy consumption, economic and population growth, and structural changes in transport systems.

The model considers historical trends in travel and efficiency relative to population and economic growth as well as potential major changes in the transport systems of the developing regions of the world (which may account for a large portion of future increases in transportation energy).

Non-DOE Input Sources:

International Energy Agency, *Balances and Statistics of OECD [Non-OECD] Countries* (Paris).

Consumption of energy by fuel and transport mode.

DOE Input Sources:

None, beyond those utilized within WEPS.

Computing Environment:

Consists of Excel97 spreadsheet files run on an IBM compatible computer using Windows 95.

Appendix C. Cross-Reference Between Model Range Names and Spreadsheet Locations

The Transportation Energy Model is a PC-based Excel spreadsheet model. The variable names used in this documentation report correspond to range names defined within the model to ease navigation within and across model segments.   This appendix provides a cross-reference between the range names used in the descriptive equations provided in these report and spreadsheet locations.

Table 2. Summary Range Name Definitions

Range Name	Definition
Air_Energy	Total energy use for air transport
c_en_veh	Parameter controlling the rate of increase in vehicle energy intensity (Equation 11)
c_veh_1000	Parameter controlling the rate of increase in the rate of motorization (Equation 8)
Eff_Air_Gr_Value	Annual percentage change in energy use per unit of air travel (Equation 13)
Eff_Inlandwater_Gr_Value	Annual percentage change in energy use per unit of inland water travel (Equation 13)
Eff_Intlwater_Gr_Value	Annual percentage change in energy use per unit of international water travel (Equation 13)
Eff_Rail_Gr_Value	Annual percentage change in energy use per unit of rail travel (Equation 13)
Eff_Road	Cumulative percentage change in energy use per mile (Equation 10)
Eff_Veh_Gr_Value	Annual percentage change in energy use per mile (Equation 10)
En_Veh	Vehicle energy intensity (energy use per vehicle per year) (Equation 10)
GDP_Pop	Per capita gross domestic product
Hwy_veh	Total number of road vehicles (Equation 3)
Inlandwater_Energy	Total energy use for inland water transport
Intlwater_Energy	Total energy use for international water transport
Mot_el	Parameter defined as the percentage change in motorization (number of vehicles per 1000 population) per unit percentage change in per capita income
Pipeline_Energy	Total energy use in pipelines
Pipeline_Gr_Exog	Year-to-year exogenous growth in pipeline energy use (Equation 14)
Pipeline_Gr_Value	Constant rate of annual growth in pipeline energy use (Equation 14)
Pop	Total population
Rail_Energy	Total energy use for rail transport
Road_Energy	Total energy use for road transport
Road_Energy_Diesel_Share	Diesel share of total road energy
Road_Energy_Elec_Share	Electricity share of total road energy
Road_Energy_Gasoline_Share	Gasoline share of total road energy
Road_Energy_LPG_Share	LPG share of total road energy
Road_Energy_Other_Share	Other (including alcohol) share of total road energy
Road_Vehicle_Energy_Use_Per_Capita	Road energy use per capita
RSC	Parameter limiting annual growth in

	motorization based on limited infrastructure (Equation 5)
St_En_Veh	Vehicle energy intensity in each forecast year based on the maturity of a region's road system (Equation 11)
St_En_Veh_2020	Vehicle energy intensity in 2020 based on the maturity of a region's road system (Equation 11)
Tr_Air_El_Value	Parameter defined as the percentage change in air travel per unit percentage change in GDP (Equation 13)
Tr_Inlandwater_El_Value	Parameter defined as the percentage change in inland water travel per unit percentage change in GDP (Equation 13)
Tr_Intlwater_El_Value	Parameter defined as the percentage change in international water travel per unit percentage change in GDP (Equation 13)
Tr_Rail_El_Value	Parameter defined as the percentage change in rail travel per unit percentage change in GDP (Equation 13)
Tr_Road	Cumulative percentage change in composite road vehicle travel per year (Equation 10)
Tr_Road_El_Value	Parameter defined as the percentage change in travel per year (in a composite road vehicle) per unit percentage change in per capita GDP (Equation 10)
Veh_1000	Number of road vehicles per 1000 population (Equations 6,7,8)
Veh_1000_2020	Number of road vehicles per 1000 population expected in 2020 (Equation 8)
Veh_1000_EXOG	Exogenous specification of year-to-year levels of motorization (Equation 7)

Table 3. Cross-Reference Between Range Names and Spreadsheet Location

Range Name	Spreadsheet Location
Air_Energy	=Air!$A$10:$AV$37
c_en_veh	=Road!$A$417:$F$442
c_veh_1000	=Road!$A$169:$K$212
Eff_Air_Gr_Value	=Air!$A$162:$AV$188
Eff_Inlandwater_Gr_Value	=InlandWater!$A$162:$AV$188
Eff_Intlwater_Gr_Value	=Bunker!$A$162:$AV$188
Eff_Rail_Gr_Value	=Rail!$A$162:$AV$188
Eff_Road	=Road!$A$613:$AV$640
Eff_Veh_Gr_Value	=Road!$A$509:$D$543
En_Veh	=Road!$A$366:$AV$393
GDP_Pop	=ECONDEM_DATA!$A$149:$BH$174
Hwy_veh	=Road!$A$316:$AV$343
Inlandwater_Energy	=InlandWater!$A$10:$AV$37
Intlwater_Energy	=Bunker!$A$10:$AV$37
Mot_el	=Road!$A$97:$W$122
Pipeline_Energy	=Pipeline!$A$10:$AV$37
Pipeline_Gr_Exog	=Pipeline!$A$103:$AV$128
Pipeline_Gr_Value	=Pipeline!$H$2:$I$8
Pop	=ECONDEM_DATA!$A$107:$BH$132
Rail_Energy	=Rail!$A$10:$AV$37
Road_Energy	=Road!$A$657:$AV$682
Road_Energy_Diesel_Share	=Road!$A$781:$AV$806
Road_Energy_Elec_Share	=Road!A$847:AV$872
Road_Energy_Gasoline_Share	=Road!$A$748:$AV$773
Road_Energy_LPG_Share	=Road!$A$814:$AV$839
Road_Energy_Other_Share	=Road!A$880:AV$905
Road_Vehicle_Energy_Use_Per_Capita	=Road!$A561:$AV586
RSC	=Road!$A$274:$B$298
St_En_Veh	=Road!$A$409:$AV$442
St_En_Veh_2020	=Road!$A$417:$C$442
Tr_Air_El_Value	=Air!$A$105:$F$127
Tr_Inlandwater_El_Value	=InlandWater!$A$105:$F$127
Tr_Intlwater_El_Value	=Bunker!$A$105:$F$127
Tr_Rail_El_Value	=Rail!$A$105:$F$127
Tr_Road	=Road!$A$563:$AV$590
Tr_Road_El_Value	=Road!$A$456:$D$493
Veh_1000	=Road!$273:$298+Road!$A$273:$AV$298
Veh_1000_2020	=Road!$A$169:$K$212
Veh_1000_EXOG	=Road!$A$49:$AV$75