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Comparison of global passenger transport models and available literature

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Abstract

Over the last decade transport has been strongest growing sector in terms of worldwide energy demand. As a result, proper modelling of transport has become more important in models describing global climate change. RIVM has developed the energy model TIMER as part of the global integrated assessment model, IMAGE (Integrated Model to Assess the Global Environment) to study long-term energy scenarios, related environmental problems and available options for mitigation (up to 2100). In the research project described, the aim was to find a modelling approach and identify determinants of transport energy demand to improve the projections of TIMER, focusing on passenger transport. Global transport models were compared by means of a literature study.

The literature that could be reviewed for this project focused mainly on passenger transport in OECD countries. In addition, four global transport models were studied – i.e. two models from the World Energy Council, one from the International Energy Agency, and a model described by Schafer and Victor. On the basis of this review, it became clear that the best improvements could be achieved in transport modelling in the context of TIMER by adopting an updated version of the transport model by Schafer and Victor. Such a model would take into account the determinants, technology, spatial organisation (population density), prices and possible demographic factors other than population size (e.g. age).

Contents

Samenvatting

In de afgelopen jaren is wereldwijd het energieverbruik in de transport sector zeer sterk gegroeid. Het goed modelleren van transport in "*integrated assessment*" modellen is daarom steeds belangrijker. Als onderdeel van het mondiaal milieumodel IMAGE (Integrated Model to Assess the Global Environment) heeft het RIVM het TIMER model ontwikkeld om lange termijn energie scenarios en gerelateerde milieuproblemen te verkennen. De huidige beschrijving van transport in het TIMER model is tamelijk geaggregeerd. In deze studie wordt een overzicht gegeven van de kennis in literatuur over de determinanten van de vraag naar energie van transport in het algemeen en van personenvervoer in het bijzonder. Bovendien is een overzicht gemaakt van enkele bestaande modellen die mondiaal transport beschrijven. Op basis van dit overzicht worden suggesties gedaan hoe de modellering van transport in TIMER eventueel kan worden verbeterd.

De literatuur die binnen het tijdstip van dit onderzoek beschikbaar kon worden gemaakt is met name gericht op OECD landen en personenautogebruik. In deze literatuur komen verschillende determinanten van transport activiteit en gerelateerd energiegebruik naar voren. De belangrijkste determinanten (met geoperationaliseerde variabelen) zijn economische ontwikkeling (bruto nationaal produkt), ruimtelijke indeling (urbane bevolkingsdichtheid), prijzen (brandstofprijzen, ticket prijzen), demografische factoren (bevolkingsomvang, leeftijd, geslacht) en technologische ontwikkeling (modale energie intensiteiten).

In de beschikbare literatuur kon van vier transport modellen een goede beschrijving gevonden worden. De twee modellen van de World Energy Council uit 1995 en 1998 zijn tamelijk simpele modellen waarin geen terugkoppelingen in de modelstructuur zijn opgenomen. In het 1995 model zijn de verwachtingen ten aanzien van economische, demografische en technologische ontwikkeling en transport activiteit exogeen in drie verschillende scenarios opgenomen. Het 1998 model heeft naar alle waarschijnlijkheid een gelijke modelstructuur als het 1995 model.

De structuur van het transport model van de International Energy Agency is gecompliceerder en incorporeert een personenauto stock-turnover model. Ook vormen regionale brandstofprijzen een belangrijke determinant.

Het transport model van Schafer en Victor richt zich alleen op personenvervoer. In dit model zijn de twee theorema van Zahavi opgenomen die poneren dat de mens een vast deel van zijn inkomen en een constante hoeveelheid tijd aan vervoer besteed. Ook gaat het model ervan uit dat bepaalde transport infrastructuren voor lange tijd de vervoerswijze in de toekomst bepalen. Daarnaast is ruimtelijke ontwikkeling expliciet opgenomen als determinant van de keuze voor een bepaald vervoersmiddel.

Op basis van de literatuurstudie en persoonlijke communicatie met Schafer lijkt de aanpak van Schafer and Victor in combinatie met een model om het energiegebruik van vrachtvervoer te beschrijven een goede methode voor de beschrijving van transport energiegebruik in TIMER.

Summary

Transport has developed into the strongest growing sector in terms of worldwide energy demand. As a result, proper modelling of transport is becoming more important in models describing global climate change. RIVM has developed the energy model TIMER as part of the global integrated assessment model, IMAGE (Integrated Model to Assess the Global Environment) to study long-term energy scenarios, related environmental problems and available options for mitigation (up to 2100). The description of the transport sector in this model is fairly aggregated. Within this research project, suggestions to improve the current formulation of transport in TIMER, have been made, focusing on passenger transport. These suggestions are based on an overview of transport-related literature (focusing mainly on OECD countries and car transport) and on the comparison and evaluation of global transport models.

Various determinants of transport activity and related energy consumption are identified in the existing literature. The most important determinants (with operationalised variables) are economic development (GDP), spatial organisation (urban population density), prices (fuel,ticket), demographic factors (population size, age, gender) and technological development (modal energy intensities, fuel economies).

Fairly detailed descriptions could be found of four global transport models in the available literature. Two of these, from the World Energy Council (1995, 1998), are relatively simple and do not contain any feedback relationships. In the 1995 model the expectations with respect to economic, demographic and technological development and transport activity were taken up exogenously in three different scenarios. The 1998 model probably has a similar model structure but does not adopt any scenarios.

The structure of the model of the International Energy Agency is more complicated and incorporates a private-car stock turnover model. Also regional fuel prices play an important role.

The transport model of Schafer and Victor only addresses passenger transport. In this model, two theorems of Zahavi state that on average people spend a fixed amount of their income and a constant amount of time on travelling. The Schafer and Victor model also assumes that certain transport infrastructures determine the use of specific modes of transport for the long term. Furthermore, spatial organisation has explicitly been taken up as a determinant of the choice for a certain transport mode.

On the basis of the literature study and personal communication with Schafer, we decided that the Schafer and Victor approach could provide the best opportunities to improve the description of future transport energy use in TIMER. The current model, however, needs to be extendend with a model describing freight transport energy use.

1. Introduction

In the 1990 – 1995 period, transport was the fastest growing sector in terms of its energy demand. Between 1971 and 1990, world transport energy demand grew by 2.8% per year, which is slightly faster than the growth rate of total energy demand (2.5%). Since 1990, the growth of transport energy demand declined to 1.7% per year – but the growth rate of total energy demand dropped even further to 0.7%. The share of transport in total world energy demand is around 20-25%. For the future it is expected that transport will continue to increase its share in the global energy demand. This is likely going to present serious problems with regard to congestion, safety and emission of environmental pollutants like greenhouse gasses (GHG). Proper modelling of transport becomes thus more and more important in models describing global climate change.

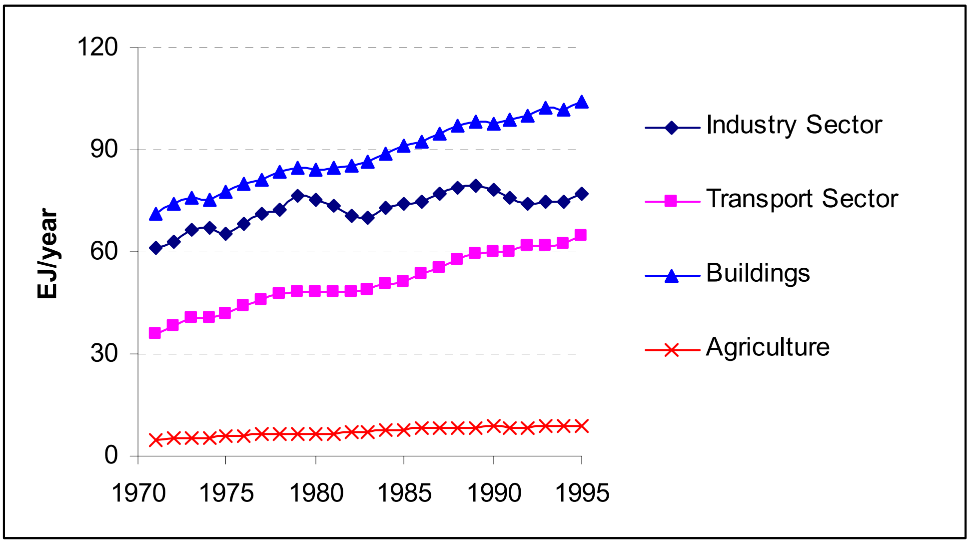

Figure 1-1 Global energy consumption from 1971 to 1995 (Based on IEA, 1998)

As part of the global climate change model IMAGE, the TIMER energy model was developed by the RIVM (Netherlands Institute for Public Health and the Environment) to study long-term energy scenarios, related environmental problems and available options for mitigation (up to 2100). This model is gradually being extended to include more detailed information on the physical realities behind the different scenarios[1]. Currently, the description of transport energy demand in TIMER is rather simple, just like other energy demand sectors in the model. In this research project, an attempt would be made to find a modelling approach and identify determinants of transport energy demand to improve the projections of TIMER, focusing on passenger transport.

Transport activity is generally divided between passenger transport and freight transport. For this study, we chose to address passenger transport only. In 1995, passenger transport contributed to 57% of total transport energy consumption World Energy Council (1998). In Figure 1- presents the position of the system examined (global passenger transport energy consumption) within the total energy system. The division of global energy consumption over

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[1] A description of the TIMER model can be found in De Vries et al. (2001).

the different sectors is taken from TIMER (year 1990). The modal split in 1990 is derived from Schafer (1998). The split between freight and passenger transport is based on passenger transport data from Schafer (1998) and total transport energy demand from TIMER.

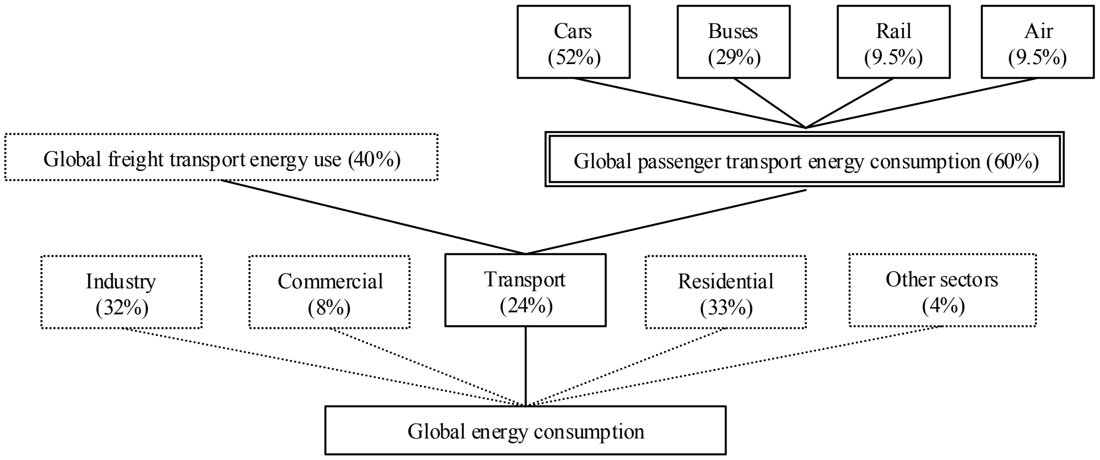

Figure 1-2 System boundaries and share in energy consumption, 1990.

Chapter 2 outlines the methodology of this study. In fact, the study starts with a literature study to obtain insight into the relationships of transport activity and energy consumption with several determinants. The results of this literature search are presented in Chapter 3[2]. Chapter 4 presents four largely independent global transport models and one model, partly derived from one of the previous four. In Chapter 5, the first four models are compared and evaluated. Next, in Chapter 6 a very brief overview is given of several energy demand scenarios of different models (mostly very aggregated models), in particular to give an indication of how the current TIMER performs in comparison with other global energy models. Chapter 7 discusses the models in relation to three important determinants. Finally, in Chapter 8, an idea is presented that could serve as a framework for the implementation of the identified improvements in TIMER.

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[2] Please note that Chapter 3 is not intended to give a full summary of the reviewed articles and reports but that it identifies determinants of transport activity or energy consumption.

2. Methodology

One can identify five general steps in the development of a conceptual model to an operational model. The first step comprises the development of a conceptual model. In the second step, the variables are identified that reflect the content of the determinants of the conceptual model. In the third step, the relationships between the variables are determined. In step 4, the values of the various parameters are determined (calibrated) on the basis of historical data sets and in step 5, projections of autonomous (independent) variables are made to feed the model. Although the intention of this study is not to build a new transport energy model, but to review a set selected existing models, nevertheless these steps can more-or-less connected to our activities.

First, we will discuss some of the available transport literature to develop an idea of how the conceptual model of a good transport model should look like. Chapter 3 shows the results of this review of mainly car transport-related literature on OECD countries. Although it was not our intention to focus on car transport only, most of the available literature focussed on car transport. This can be explained by the large share of car transport in the modal split. We noticed that the literature addressing the complete overview of passenger transport was fairly limited. More literature was found on detailed topics like vehicle ownership or CO_2 emissions as a result of global transport. Chapter 3 focuses on identifying determinants of the three variables in Figure 2-1, which according to Schipper (1997) determine passenger transport energy consumption. “A” denotes total travel expressed as passenger kilometres, “S” denotes the modal split (relative participation of the various transport modes in total transport) and “I” is the specific modal energy intensity (the energy which a specific transport mode consumes per km).

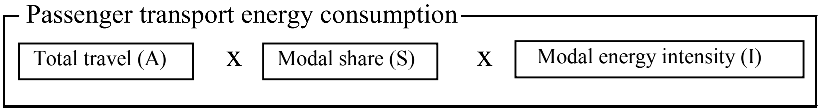

Figure 2-1 Passenger transport energy consumption.

The modal energy intensity term itself is composed of several components based on Schipper, 1997):

$$I_i = E_i * C_i * U_i \tag{1}$$

where E is technical efficiency, C vehicle characteristics, and U the inverse of capacity utilisation for each mode i. $E_i * C_i$ is the energy use per vehicle kilometre and is called vehicle fuel intensity. The technical efficiency is the energy required to propel a vehicle of a given set of characteristics a given distance, and is affected by the motor, drive train, frictional terms (including drag) etc. For cars, characteristics could be represented by vehicle power (or gross weight) and technical efficiency by energy use per km per unit of power (or gross weight). People/vehicle or tonnes per vehicle could measure capacity utilisation U.

In Chapter 4 an inventory of global transport models is made. These models are described and compared. In addition we have looked at whether the models include the determinants found in Chapter 3.

Next, attention is paid to strengths/weaknesses of these models. In particular attention is paid to the question, how, based on these models possible improvements can be implemented in TIMER.

The determinants that turned out to affect passenger mobility are tested for their applicability in the TIMER model. The constraints that limit applicability are the operationalbility of the determinants, data availability and the specific TIMER requirements (degree of detail, etc). The first constraint refers to the ability to identify one or more variables that are able to reflect the meaning of a determinant. An example is whether aviation fuel price is a good representation of the costs of flying. The second constraint is the data availability of the selected variable. Some modelling approaches can not be adopted since data availability is limited. The last constraint refers to requirements imposed by TIMER, like compatibility with the applied level of detail. Is it useful to describe/model transport energy consumption with a high level of detail while other sectors contributing (approximately) equally to total energy consumption (e.g. industry) are modelled with only moderate detail?

Figure 2-2 presents a graphical visualisation of the above-mentioned methodology.

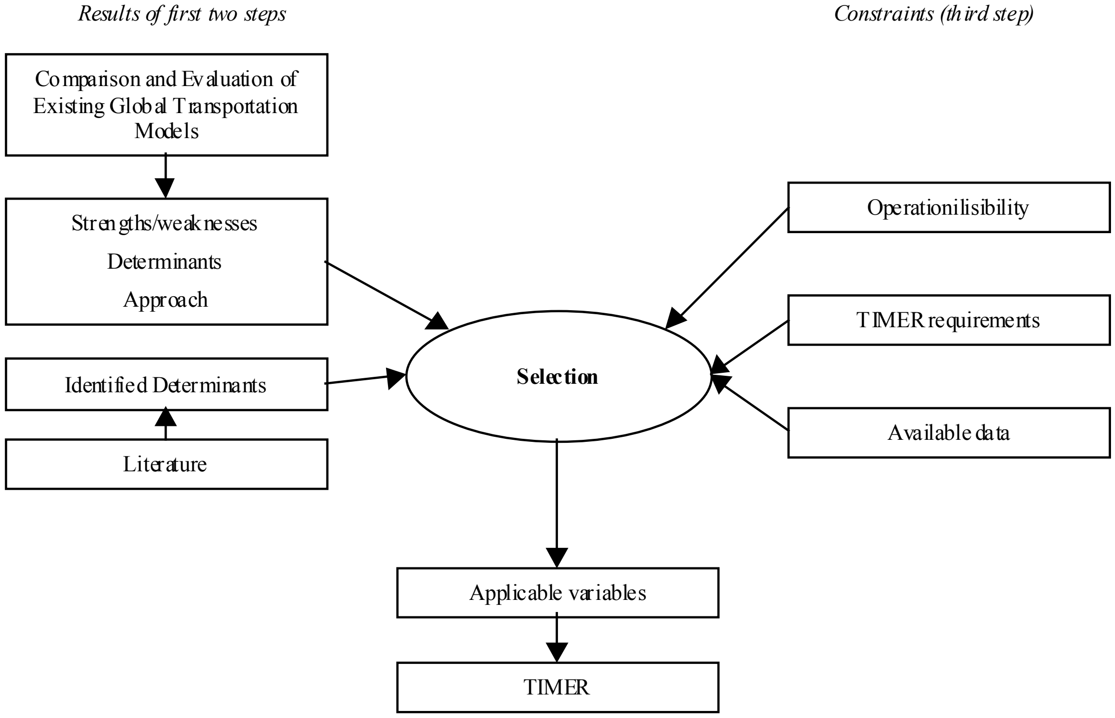

Figure 2-2 Methodological approach of project.

3. Identifying determinants of passenger mobility energy demand

Breaking down energy use into different variables as presented in Chapter 2 can give us some grip, while searching for determinants affecting passenger mobility, as many literature sources discuss developments and projections of the variables shown in Figure 2-1 or equation (1). An overview at the end of this chapter gives the topics emphasised in the literature reviewed in the chapter. Note that this chapter, unless otherwise clearly stated, only represents the content of the articles and the reports.

3.1 Schipper (1997)

In Schipper (1997) an indication is given of how the World Bank could use its policy influence, and lending and analytical capabilities, to contribute to mitigation of CO_2 emissions in the transport sector. With examples of OECD countries, important relationships are illustrated, which are often difficult to identify in non-OECD countries due to lack of data and measurement problems. Schipper discusses among other things the theses important for the World Bank's policy: involvement of local authorities, transportation policies of OECD countries, pricing strategies, urban planning, lending and the World Bank's analytical capabilities.

The summary here will focus on the determinants of transport energy consumption. In Figure 2-1 and equation (1) it is shown which variables could be influenced to decrease transport energy demand and CO_2 emissions. Some of these variables show interdependency. For example, total travel, A, depends on speed, so a shift in the modal split, S, from car to air is associated with greater travel. Secondly, I determines the marginal fuel costs of using vehicles. Transportation variable costs decrease to the same extent as I decreases and, as a result, transport demand might increase.

The author argues that the variables mentioned are generally affected by income, prices, technology, policy and behaviour. The number of passenger kilometres A and modal split S are dependent on income and prices. Personal travel depends in part on the distance between work, home, leisure and services, all depending on the spatial organisation of these destinations. In societies with lower incomes and little motorised travel, or in societies with higher incomes, where congestion or other factors make travel expensive or slow, facilities are close together or individual radii of action are small. Where travel is cheap or rapid, markets cover much wider areas, and so do people. All of these dimensions are expanded with higher incomes. Price strategies are also expected to induce technological advances. Higher variable costs will stimulate development of energy efficient vehicles.

The vehicle intensity ($E * C$) is affected by both technological development and vehicle characteristics. Old and heavy cars have higher vehicle intensities than new and lightweight vehicles. In the last years people tend to drive more comfortable and heavier cars, partly offsetting the improved motor efficiency. Closer examination of trends in OECD countries has confirmed this development. While the average tested fuel use per kilometre driven and per kilogram of new cars fell dramatically in all countries, the weight (and performance) of new cars increased in all countries, absorbing much of the effect of improved technology.

Worsening driving conditions also proved to have significant impact on the vehicle efficiency. Both more high-speed vacation driving and driving in congested areas raised fuel use per km above what tests would predict. Actual fuel use per km fell dramatically in the U.S. and Canada but barely changed in Japan and most European countries.

The variable U[3] turns vehicle intensities into modal intensities. Increasing income causes people to value luxury and comfort more, lowering the occupancy degree of the vehicle and increasing the vehicle intensity by buying larger and heavier cars, overall increasing the modal intensity.

Schipper (1997) also shows that geographical organisation has influence on mobility and travel behaviour. A comparative study between San Francisco and Stockholm proved significant differences in mobility and modal split due to the difference in urban forms and physical layout of cities. Stockholm residents travel only a quarter of the distance San Franciscans do, the large difference partly explained by the fact that, in general, the Swedish travel only half the distance Americans do. Still, according to Schipper (1997), it could be said that urban structure – represented by population density – affects travel.

The relationships as described above are graphically shown in Figure 3-1.

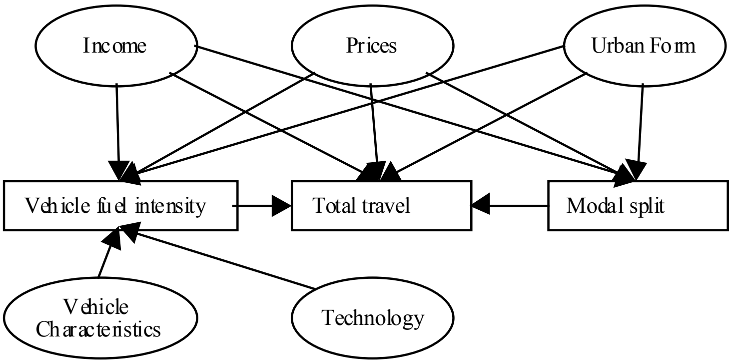

Figure 3-1 Relationship between equation variables and determinants as presented in Schipper (1997).

Table 3-1 represents a summary of a larger interaction matrix shown in Schipper (1997). It shows to what extent policies affect the variables in Figure 2-1.

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[3] The vehicle occupancy U has been used in many U.S. cities as an important policy element. By reserving lanes for highly occupied vehicles, the effective lane capacity for that particular lane is increased.

Table 3-1 Interaction between policy and mobility, and modal share and intensity

Component/Option	*A (Mobility)*	*S (Modal share)*	*I (Intensity) (veh. intensity, characteristics, load factor)*
Vehicle Fuel Economy Technology	None except through rebound	Slightly encourages modes with lower running costs	All
Overall fuel taxation	Slight restraint, elasticity low	Favours modes with low fuel intensities	Encourages improvements in all factors
Kilometer pricing (including congestion pricing)	Significant restraint.	Favours modes with small footprints per passenger (ie. Bus, train)	Little effect unless small vehicles selectively permitted
Alternative fuels: development, pricing	Little effect unless price of fuel forced up	Little unless "clean fuel" modes given priority	Little, unless clean fuel more efficient
Land-use planning	Supposedly would reduce total mobility	Could increase transit share	Little

3.2 Blijenberg and Van Swigchem (1997)

This paper discusses, among other things, trends in transport activity, associated energy use and some driving forces. Attention is also given to ways achieve a sustainable passenger transport system. In this perspective, the zero-emission vehicle, land use and policy implications are discussed.

In this summary, these driving forces are briefly mentioned and the effect of technological development, and the theory of constant travel time budget, are more closely examined.

According to Blijenberg and Van Swigchem (1997), the main driving forces of travel mileage (or mobility) are time and money. The increasing travel mileage must be due to faster transport modes and/or longer travelling time. Many economic and statistical sources show that faster transport is the dominant factor.

Some authors claim that something like a Constant Travelling Time Budget exists, valid throughout history and for all cultures. This is supported by some historical data indicating an average travelling time per person per day of around one hour and 5 to 20 minutes. Others indicate that travelling time depends partly on the amount of time spent on other activities, especially on the number of working hours Kraan (1996). As the average number of working hours is diminishing somewhat, the time available for other activities – including transport – may increase. If, in such a situation a faster mode of transport is introduced, this will reduce the total travelling time in the short term. In the longer term spatial patterns will change, resulting in greater travel mileage and longer travelling time. The opposite may occur as well: increased congestion will result in more time being spent on travel in the short term, but in the long term, mileage will be reduced and thus travelling time will decrease again.

The effect of technological development on the fuel intensity of vehicles is partly offset by the induced mobility. If, for example, motor efficiency is improved, the use of that vehicle becomes cheaper due to a decrease in fuel use and will thus probably be used more intensively, increasing mobility, with a consequent partial offset of the fuel-use reduction gained. This situation supports the theory of the Constant Travelling Money Budget, more elaborately described in Schafer and Victor (2000) and Schafer and Victor (1999). In the Netherlands, the share of total income spent on transport from 1950 to 1988 increased only slightly (from 5.0% to 7.2%), but total expenditure on transport rose substantially. More money was spent on travel, resulting in both greater mobility and upgrading of cars Blijenberg and Van Swigchem (1997).

3.3 Banister (1996)

In Banister (1996) the emphasis is placed on the relationship of urban form and the energy consumption of transportation. Results from research in several cities in the U.K. proved that physical factors do have a significant effect on energy consumption, particularly gross density, measured in persons per hectare. In order to obtain still better results, the author's advice was to develop a more sophisticated measure.

Open space within metropolitan areas also emerged as a significant factor in this study. From the perspective of the local authorities, there needs to be a balance between making cities more compact to limit transport needs, and maintaining and increasing the amount of open space, since this affects the attractiveness of the city.

Other factors, physical and socio-economic, turned out to be significant in some, but not all, examined cities (e.g. size of urban area, household size and car ownership). Other relationships were found to have a variable sign (e.g. employment).

Finally, the author concludes that no definitive set of factors has been produced to determine the links between urban structure and energy use in transport. There seems to be consistency in the physical factors, but the socio-economic factors are also important taken individually. Furthermore, he states that it is still extremely difficult to obtain consistent data sets, either within towns (linking transport data with census, employment and other data sets) or between towns (different types of travel surveys).

3.4 Dargay and Gately (2001)

In this paper, the authors present the results of a model projecting the growth of vehicle stock over the next two decades for 82 countries at different levels of economic development. This paper extends their earlier work in three ways. Firstly, the data set is extended in time and is more comprehensive. In this study 86% of the world population and 96% of vehicle stock is represented. Secondly, the assumption of a common saturation level for all countries is relaxed. In earlier work, the estimated saturation level was constrained to be equal for all countries. Differences in vehicle ownership between countries at the same income level were accounted for by allowing saturation to be reached at different income levels. Differences among countries in the quality of the transportation infrastructure and alternative transport modes are reasons why saturation levels may differ. In this study the saturation level is described as a function of population density. Since the saturation level varies over time as well as across countries, the saturation level γ for country i at time t is specified as:

$$\gamma_{it} = \gamma_{\text{mean}} + \lambda PD_{it}$$

where the population density (population per square km), PD, is normalised, so that γ_{mean} is the mean of the saturation level of the data sample.

The third extension concerns the assumption of symmetry in the response of the vehicle stock to rising and falling income. Traditional demand modelling is based on the implicit assumption that demand responds symmetrically to rising and falling incomes, as well as to all other explanatory variables. Although there is little doubt that increasing income leads to a higher vehicle ownership, less is understood about the effect of declining income. Given the longevity of vehicle stock, habit persistence etc, one might expect that reductions in income would not necessarily lead to changes in vehicle ownership of the same magnitude as those resulting from increasing income. This study allows for a possible asymmetry; the demand function is specified in such a manner that adjustment to falling income is allowed to be different from that to rising income.

Car ownership is described as a Gompertz function, depending on saturation level γ, a factor taking into account lags in the adjustment of vehicle ownership to per-capita income and the a-symmetry factor, resulting in:

$$V_t = \gamma(\Theta_R D_R + \Theta_F D_F)e^{\alpha e^{\beta GDP_t}} + (1 - \Theta_R D_R - \Theta_F D_F)V_{t-1}$$

where V_t is vehicle ownership,
$D_R = 1$ if $GDP_t - GDP_{t-1} > 0$ and $=0$ otherwise,
and $D_F = 1$ if $GDP_t - GDP_{t-1} < 0$ and 0 otherwise,
α and β are parameters derived from the elasticity function (below) determining the curvature, and θ denotes the speed of adjustment in the other direction, depending on D.

Values for θ, α and β have been estimated with cross-section time series data for 82 countries. The adjustment factors θ and α are constrained to be equal for all countries. β is estimated for each country separately. The long-run income elasticity for various levels of the Gompertz function is a function of income:

$$\eta_t^{LR} = \alpha\beta GDP_t e^{\beta GDP_t}$$

This function strongly increases at lower incomes and, after a maximum, continuously declines to zero for higher incomes. The θ for rising income turned out to be 0.12 and for declining income, 0.07.

3.5 Schrijnen (1986)

In Schrijnen (1986) inventories of factors linked to or having influence on vehicle ownership are presented, along with the use of cars in the Netherlands. Their conclusions also comprise suggestions to reduce both car ownership and car use.

Car ownership

The study observes that income is the main important factor influencing car ownership. The variable costs of car use barely affect the level of ownership. Only extraordinary high fuel costs would be able to reduce car ownership. In Schrijnen (1986) it is also suggested that car costs compensations from companies might have considerable influence on the level of car ownership. Furthermore, they conclude that a significant relationship exists between age and mobility (longest journeys and the highest level of car ownership can be attributed to people between 30 and 50 years).

The order of cause and consequence remains unclear in the relationship between ownership and use. It is still the question whether mobility is a result of a high level of ownership or that the need to travel long distances causes people to purchase cars?

It was found that the possession of a driver’s license and a car also have a strong relationship with employment status. Moreover, there are indications that distance from dwelling to job has an influence on the level of car ownership. People with the higher incomes live, on average, a greater distance from their jobs than people with the lower incomes. Among households in urbanised areas, the level of car ownership is lower than among households with similar household characteristics (income, household composition, age, etc.) outside these areas. In urbanised areas, bicycle and walking play a larger role in travelling, as the distance to many destinations is shorter than in rural areas. However, there were indications that in urban areas the availability of public transit is more important for car ownership than distances to work, shops, services etc.

Car use

The level of car use proved to show great coherence with car ownership. The author tries to explain this by indicating that there is a need to travel. Income and general welfare influence, in turn, the spending on mobility. The level of car use highly increases with increasing income. People with higher incomes not only have a larger car ownership but also use their cars more than people from lower income groups. Mobility is also strongly dependent on gender and age. Most movements are made between 25 and 45. However, men make more than twice as many car movements than women do. The average journey is more than four times as large. These results can be explained by the lower degree of participation of women in the labour market and lower average salaries.

From this study it becomes clear that increases in fuel price have only a small effect on car use. Moderate increases in fuel price will cause a slight decrease in car use on the long term. The authors also note that with improving motor efficiencies and a constant budget for travelling, car use will not necessarily have to decline with higher fuel prices. Furthermore, people tend to stick to their travelling pattern, so they will try to compensate increasing fuel costs by economising on other costs (e.g. fixed costs: delaying the purchase of a new car). This study finally concludes that with a geographical organisational policy, the distance covered by the movements and the level of car use can be reduced on the long term.

3.6 Pronk (1991)

To analyse the factors determining car ownership, this study examined the developments between car owners in the Netherlands and car owners in foreign countries, and between car owners in the Netherlands and non-car owners in the Netherlands. The study was performed to be able to formulate policy measures to reduce car ownership and use. The main conclusion drawn is that a strong relationship exists between income and car ownership. It was also found that the higher the income, the newer the car. Finally, it turned out that total income strongly determines the presence of a second car. Also, gender, the function/position within households, occupancy and education turned out to affect car ownership.

The author argues that policy measures should be divided in measures affecting the *possibility* to buy a car and the *wish* to have car. She notes that it becomes harder to influence the possibility to buy a car as nowadays many car types are available so that anyone can find a car (new/second hand, large/small, diesel/gasoline, business/private) most suitable for him, given his financial possibilities. She also notes that the measures should focus on the uncoupling of ownership and use. This is based on the assumption that in the current situation there always are movements that one would like to make by car and that ownership stimulates use. By offering sufficient alternative transport possibilities, the necessity to have a car to travel is reduced.

3.7 Blaas *et al.* (1992)

This report provides a comprehensive overview of the relationships between car ownership, car use and driving behaviour. Figure 3.2 gives an overview of the research field of Blaas *et al.* (1992). In this scheme four types of behaviour determining energy consumption are discerned. These types of behaviour are, in turn, affected by eight behaviour determinants as listed below:

1. Finances
2. Personal characteristics
3. Household situation
4. Geographical spread of living
5. Services and employment
6. Quality and quantity of car infrastructure
7. Quality of services for alternative means of transport
8. Quality of information on the car, and its alternatives and intrinsic motivators (attitudes).

The focus of this study has been placed on the relationship between the eight behaviour determinants and the behaviour types, B, T, R and M. Most conclusions with respect to relationships between costs and ownership, and costs and use, have been mentioned already in Pronk (1991) and Schrijnen (1986). The added value of this study is the more elaborate examination of the relationship between personal characteristics and household composition, and ownership and use. Furthermore, the addition - the examination of the relationship between information, and ownership and use, signify added value. A chapter in which driving behaviour is studied is also included (as this strongly affects the vehicle energy intensity).

The impact of the behaviour types on energy consumption has only received limited attention.

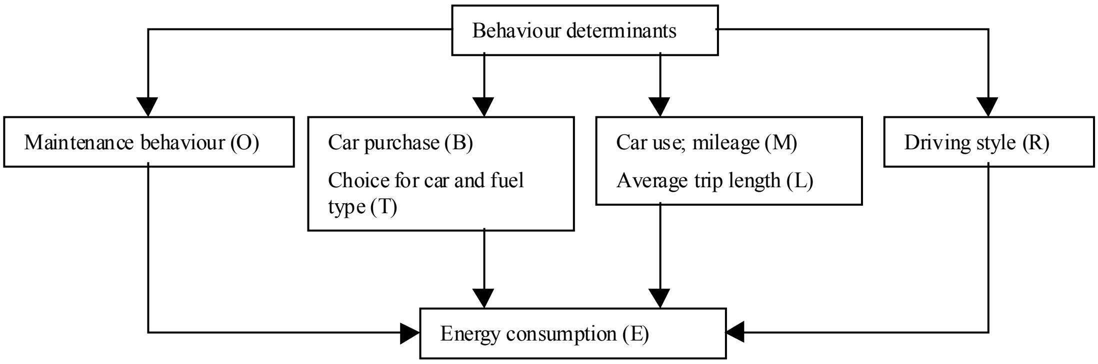

Figure 3-2 Research field passenger mobility and energy use.

Presentation of the conclusions of this study in matrix form could have given good insight into the relationships if there had not been so many different types of conclusions. The conclusion with respect to one relationship (e.g. between car use and personal characteristics) contains many remarks, since inclusion of only one remark might give too narrow a view on the considered relationship. Furthermore, the conclusions drawn focus on the intrinsic aspects of the examined relationship to reveal how policy can influence one of the behaviour types. The household situation, for example, turned out to have a significant relationship with car use and ownership. However, this result only becomes interesting if it is known in what way and degree. The authors then argue that men and people from a certain age category show higher car ownership and use since their need to travel (work) is generally greater than for people not belonging to these categories. Another example is the relationship between the quality and the quantity of the public transport network. The author observes a significant relationship. A closer look reveals that especially the competing travel time of alternative modes is an important factor. Public transport often scores poor on this factor because of its organisational fragmentation (connections, waiting times), lower average speed and low network density.

3.8 Johansson and Schipper (1997)

In Johansson and Schipper (1997) the effect of income, price, taxation and population changes on car stock, mean fuel intensity, mean driving distance, car fuel demand and car travel demand is studied. The data used encompasses 12 OECD countries for the 1973-1992 period .

The total demand for car fuel per capita (Q) was defined as the product of car stock per capita (S), fuel intensity (fuel consumption per kilometre driven) (I), and mean driving distance per car per year (D):

$$Q \equiv S \cdot I \cdot D$$

The three equation variables are modelled separately, which giving the obvious advantage of studying how large a fraction of a long-run change in fuel demand (caused by a change in fuel price) is the result of a decrease in the size of the vehicle stock, a decrease in mean fuel intensity and a decrease in mean driving distance per car. However, a disaggregation is much more demanding regarding data. The limited data set has been used as efficiently as possible by focusing on pooled cross-section time-series models. With respect to interdependency of the equation variables, only mean driving distance per year (D) has been estimated as a function of *S* and *I* (and other variables: fuel price, income, taxation and national population density). *S* and *I* are only dependent on other variables, providing the possibility to use a recursive system instead of a simultaneous equation approach. The results of this study are presented in Table 3-2.

Table 3-2 Approximate range of the rstimated long-run parameters from regressions, including indirect effects ["best guess" in parentheses][4]

Estimated component	Fuel Price[5]	Income	Taxation (other than fuel)[6]	Population density[7]
Car stock	-0.20 to 0.0 [-0.1]	0.75 to 1.25 [1.0]	-0.08 to –0.04 [-0.06]	-0.7 to –0.2 [-0.4]
Mean fuel intensity	-0.45 to –0.35 [-0.40]	-0.6 to 0.0 [0.0]	-0.12 to –0.10 [-0.11]	-0.3 to –0.1 [-0.2]
Mean driving distance (per car per year)	-0.35 to –0.05 [-0.2]	-0.1 to 0.35 [0.2]	0.04 to 0.12 [0.06]	-0.75 to 0.0 [-0.4]
Car fuel demand	-1.0 to –0.40 [-0.7]	0.05 to 1.6 [1.2]	-0.16 to –0.02 [-0.11]	-1.75 to –0.3 [-1.0]
Car travel demand	-0.55 to –0.05 [-0.3]	0.65 to 1.25 [1.2]	-0.04 to 0.08 [0.0]	-1.45 to –0.2 [-0.8]

3.9 Kenworthy and Laube (1999)/Dudson (2000)

In Kenworthy and Laube (1999) arguments are introduced for the strong relationship between car use in urban regions/cities and urban density. On the basis of data from 47 cities throughout the U.S., Europe and Asia, the authors show that 85% of the variance in transport energy use in cities can be explained by urban density, and that there is no evidence to determine a city's wealth as an explanatory value[8]. The authors conclude that to enhance the role of public transport in transport energy conservation and to reduce overall transport energy use, cities need to strategically increase their densities of development and improve their degree of centralisation.

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[4] What Johansson and Schipper consider as most reasonable on the basis of regressions, knowledge of data limitations and statistical methods, and experience

[5] The average price of petrol and diesel fuel, weighted with the actual quantities used by cars and light trucks, from IEA (1978-1992) and an unpublished survey by the USA Department of Energy (1973-1978). Prices have been converted to real local 1985 currency using the domestic consumer-price indices. OECD purchasing power parities (PPP) exchange rates have been used to convert all different currencies to 1985 U.S. dollars.

[6] Defined as the sum of different kinds of purchase taxes and import fees plus the present value (on the basis of 15 years and a real interest rate of 6 per cent) of the annual tax for a specific car, a medium-sized standard car of Volkswagen Golf type.

[7] National population density (citizens per km^2).

[8] The relation derived from this study is consequently only able to say something about the expected transport activity or transport energy use on a given moment at a given urban density. To examine the effect of a rising (or falling) GDP on the energy consumption of urban passenger transport (or on transport activity), cities with similar densities but with different GDP should be analysed.

Dudson (2000) rejects the recommendations of Kenworthy and Laube (1999) on how urban form policy should contribute to reducing urban transport energy use. The author argues that in order to achieve substantial transport energy reduction, efforts must not be placed on improving public transport or redeveloping cities, but that attention should be paid to new technologies (fuel injection, hybrids) and alternative fuels (fuel cells) with which energy consumption reductions can be achieved of 20% to 75% by the year 2005. Dudson (2000) argues that, under two “extreme” assumptions, the decrease in energy use due to geographical planning is only marginal. If public transit consumes 40% less energy per passenger per km than cars and if, “beyond reasonable expectations”, the use of public transit doubles from 3% to 6% of motorised urban transport, the energy reduction potentially possible in U.S. cities will be no more than 1.5%. On the basis of these findings the author concludes (re)developing urban form to be ineffective “within the timeframe of a potential new oil crisis” (since substantial city growth will take several decades) and emphasis should be placed on the implementation of new technologies.

3.10 Literature – subjects overview

Table 3-3 Literature sources and topics discussed in relation to transport activity/energy consumption

Source/ Determinant	Technology	Policy	Urban Form / Planning	Car ownership	Car use	CO_2 emission	Elasticities	Time/money constraint
Schipper (1997)	X	XX				X		
Blijenberg and Van Swigchem (1997)	X	XX				X		X
Banister (1996)			XX					
Dargay and Gately (2001)				XX				
Schrijnen (1986)		X		XX	XX			
Blaas *et al.* (1992)		X		XX	XX			
Pronk (1991)		X		XX	XX			
Johansson and Schipper (1997)							XX	
Kenworthy and Laube (1999)		X	XX					

XX: Focus of considered source
X: Receiving attention in combination with focus

4. Global transport models

In this chapter, five global transport models are presented on the basis of available information about these models. Except if explicitly mentioned, this chapter does not represent the view of the author.

4.1 IEA Model and income & price elasticities - Wohlgemuth (1998)

4.1.1. Methodology

This paper presents the IEA's approach of modelling transport energy demand. Fuel demand, which is not a demand *per se,* is derived, whenever possible, from the economic activity in the transport sector and not estimated directly, i.e. using one equation or a (simultaneous) equation system. In general, the transport models employ a "two-step approach". In the first step, transport activity, the sector's relevant energy service, is estimated econometrically. In the second step, the transport activity projections are then combined with estimates of efficiency improvements, car turnover rates and diesel/gasoline penetration assumptions to arrive at projections of fuel demand. The effectiveness of economic instruments is a function of the reaction of consumers (and businesses) to income and price changes. An in-depth understanding of income and price elasticities of transport demand and transport energy demand is important to be able to assess the effectiveness of policies considered.

4.1.2 Determinants of transport energy demand

GDP alone proved insufficient to explain variations in transport energy demand. In addition to income other factors like cost of driving, availability and ticket prices for public transit, prices of motor vehicles, quality of the transport infrastructure, settlement structure, social patterns, climatic, physical and geographical conditions and policy measures can play an important role too. Wohlgemuth (1998) emphasises that it is essential to model demand for the various fuel types individually, since the demand is driven by different factors. The demand for diesel fuel is usually closely linked to general economic development, whereas demand for petrol/gasoline and, to a lesser extent, aviation fuels depends much more on available income, demography, weather, fuel prices and taxation. The IEA model applied in this study projects global transport energy demand (passenger and freight) by region and fuel type. Figure 4-1[9] presents the model as presented by Wohlgemuth (1998).

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[9] In section 4.1.4 a more recent version of the IEA model structure is presented. Though, the results of the study described in Wohlgemuth (1998) are based on the model presented in Figure 4.1.

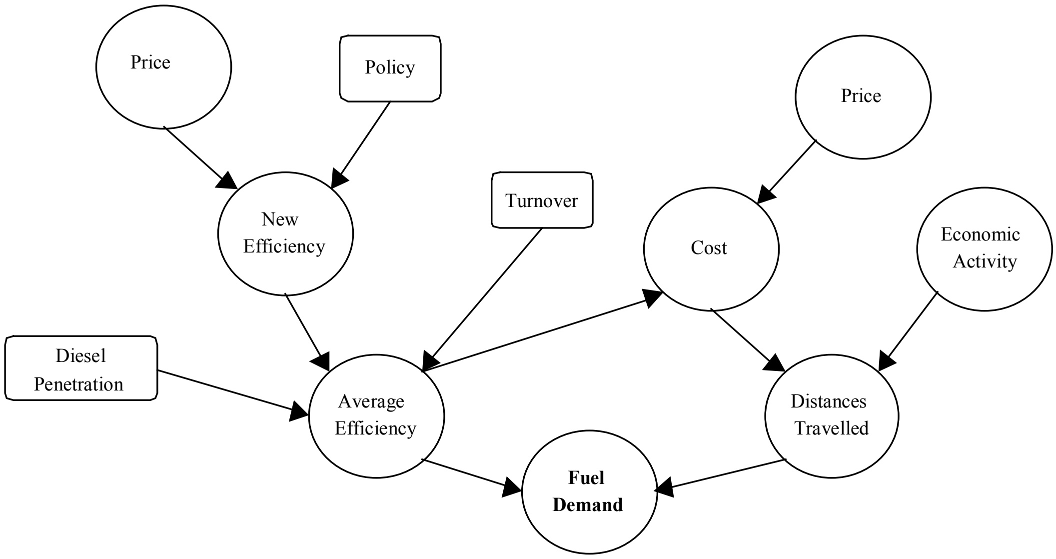

Figure 4-1 Overview of the IEA transport model.

The weakness of this model is that it has not endogenised the choice of mode of transport (car, bus, rail or aircraft) or the purpose of travel (recreation, work or shopping). The model only projects fuel demand for road transport. It is argued that a more detailed model would require the projection of a larger number of exogenous variables, a requirement that is not compatible with the overall design of the World Energy Model (WEM).

Whenever possible the IEA's transport model employs the two-step approach. Fuel demand is not directly estimated but if reliable data are available for the region considered, it is derived from the economic activity in the transport sector. The elasticities obtained are a reflection not of the demand for fuels but of the relevant energy services, which are a combination of energy-related capital equipment (vehicles) and fuel efficiency. The principal advantage of this approach is that the relevant energy services are modelled and that, for model simulation, efficiency improvements, gasoline penetration and car turnover rate can be dealt with explicitly.

4.1.2.1 Importance of income

Income is both in absolute and in per capita terms the most important determinant of transport demand. However, the related energy consumption can vary considerably among countries with equal per capita GDP. Therefore it is expected that the structure of GDP is also important. If the structure of GDP shifts away from heavy towards a lighter industry (dematerialization), the number of tonne kilometres is expected to decline. However, a contradictory trend might offset the reduced energy consumption induced by dematerialization, since freight transport energy intensity may increase through a shift to more energy intensive modes of transport (i.e. rail to road). The overall effect on energy consumption is ambiguous.

The share of (incremental) transport energy demand within total final energy demand is also closely linked to the stage of development: the higher the per-capita GDP, the more prominent the role of transportation.

4.1.2.2 Fuel prices and cost of travel

Fuel also has a great effect on transport energy consumption. Gasoline/petrol and diesel prices vary substantially among countries and account for part of the difference in per-capita fuel consumption between regions. In the U.S. people drove farther on cleaner fuels for less money in 1995 than ever before. Real average prices were lower than they were in the entire 80-year period before.

Taxation on vehicle purchases is usually designed to raise governmental revenues instead of improving energy efficiencies. Too high taxes can even have a negative impact on the fleet efficiency because people tend to keep their old (low-fuel efficiency) car as long as possible. Fuel costs are only part of total costs of travel (around 25%), which means that elasticity to total costs is larger than to fuel costs alone. The elasticity will depend on the time period, trip purpose, method of charging the absolute level of price changes and the income level. It is found that the elasticity is lowest for business trips, higher for commuting to work and highest for shopping and leisure activities.

4.1.2.3 Fuel economy

Energy consumption is not only dependent on transport mode but also on the way the mode is managed. In general, lifestyle and car driver behaviour have great influence on fuel economy. Short trips in the city usually consume more energy per kilometre than longer non-urban trips due to the lower level of congestion and less frequent acceleration and braking. The last few years a trend has been seen of consumers tending to prefer heavier, more comfortable and more powerful cars, which partly offsets fuel savings by technological progress. The average fuel economy (i.e. use of fuel) has also been increasing due to the declining vehicle occupancy. Possible policy measures could involve higher fuel taxes or higher minimum standards of average fuel economy.

4.1.3 Elasticity estimates

Many researchers have been doing studies on transport fuel demand elasticities. However, the common feature is that there is little consistency in methodology and assumptions among the various studies. The study pesents a few price elasticities. A comprehensive summary of price elasticities from Goodwin (1992) suggests that traffic volume elasticities with respect to fuel prices are –0.16 in the short term and –0.33 in the long term. The short-term elasticity on fuel consumption is probably around –0.27 and, in the long term around –0.71 when using time-series estimates. Elasticities derived from cross-section data tend to be higher on average: -0.28 in the short term and –0.84 in the long term.

Fuel consumption elasticities can be expected to be greater than traffic demand elasticities because, in the long term, changes in the fuel economy and vehicle characteristics (motor power, weight) can be expected to have an effect on fuel consumption while preserving mobility. A price increase may thus cause lower fuel consumption while the distance travelled does not decline.

4.1.4 Demand elasticities in the OECD transportation sector

4.1.4.1 Road passenger transportation

Distances travelled by passenger cars and light trucks have been estimated for the United States, OECD Europe and Japan. Determinants for estimates of road passenger transportation activity are income, cost of travel and population. Income is approximated by consumer expenditures (per capita in U.S case); fuel prices and fuel efficiencies are used as proxies for costs of travel. The estimated distances travelled, together with assumptions and estimates of efficiency improvements, penetration of diesel cars and average life of cars give the projected fuel demand (see Figure 4-1 Overview of the IEA transport model).

Appendix 2 Table A-15 shows the long-term OECD transportation demand elasticities. The lower elasticity in the U.S. could be explained by the higher saturation of road transport. Also, the estimation is on a per capita basis. When estimating the levels, the implied long-term income elasticity increases to 0.93. Price elasticity remains almost unchanged at -0.14 [10]. It is notable that the large fuel efficiency improvements in the U.S. have had a big influence on income elasticity. If the fuel efficiency variable was omitted, the income elasticity increased from 0.88 to 1.06 in the per-capita case and from 0.93 to 1.04 when estimating levels. The increases of the elasticities correspond well with estimates of Greene of the rebound effect (0.15). The higher elasticities for Europe are explained by the better public transport system in Europe, allowing for more substitution. Price increases force people more quickly into using public transport. It should be noted that in the model the cost of travel is determined by the price of gasoline only. If the diesel price is used instead of the gasoline price, the long-term price elasticity falls to –0.56, still much higher than either in the U.S. or Japan.

Appendix 2 Table A-16 shows elasticities obtained from estimations based on a consistent database. In this case, the level of distances travelled for distances travelled in all three regions is estimated using consumer expenditures, the gasoline price and omitting the fuel efficiency variable. In Appendix 2 Table A-17, the short-run (first year, 1967) OECD transport demand elasticities are presented. The difference between the values for Europe and the U.S. is remarkable.

4.1.4.2 Freight transportation

The dependent variable in freight transportation is tonne kilometres for Europe and Japan and tonne miles for the U.S. In case of Europe and U.S., truck freight kilometres have been estimated indirectly via total estimated freight volume and the share of truck-moved freight. In the case of Japan, truck tonne kilometres have been modelled directly.

GDP reflects economic activity and the relative costs of travel are reflected by the real price of diesel. The resulting income elasticities are close to 1 for U.S. and Europe, while 1.4 for Japan. If elasticities are modelled directly for U.S. and Europe, elasticities rise respectively to 1.13 and 1.37. The reason for this difference probably lies in the fact that road transportation grows faster than rail transport. The modal split is affected by the value-to-weight ratio. Generally, an increasing ratio means a shift from rail to road transportation. In all three regions the long-term price effect is approximately – 0.2.

4.1.4.3 Air transportation

Due to lack of reliable data, only fuel consumption of U.S. air travel has been estimated with the underlying variables of passenger air miles and costs of travel (broader than fuel costs only). The fuel consumption of air travel in Japan and Europe has been estimated directly (cross-sectional or time-series). The underlying income variables are consumer expenditures for Japan and Europe, and GDP in the case of the U.S.. The resulting long-term elasticities of 1.35 for Europe and 1.8 for Japan and the U.S. probably reflect the luxury nature of air travel.

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[10] Note by the author: however, the relative change is only 5.3% for the income elasticity and 12.5% for price elasticity

The fuel price elasticities, based on the costs of crude oil, are -0.03 and –0.09 for Japan and Europe, respectively. The price elasticity of the U.S., reflecting total costs of travel, is much larger than the elasticities of Japan and Europe at -0.34. One can expect price elasticities based on primary price series to be less sensitive than those based on end-use prices because of the often weak links between these two prices. However, even end-use prices of fuels usually do not properly reflect the cost of travel since the fuel-cost component of the different modes of transportation can be very low compared to total cost of travel. In the model, the fuel price of air transportation in the U.S. in 1993 amounted to less than 20% of total cost of air travel. In cases where crude oil prices in the U.S. case are used, U.S. price elasticity falls to –0.055, much closer to the values of Japan and Europe.

4.1.5 Travel/fuel demand elasticities in non-OECD regions

Estimation of fuel demand elasticities in non-OECD countries has been performed with simpler methodologies since data availability is low. A cross-sectional approach has been used to analyse the income and price elasticities for numerous non-OECD countries due to lack of consistent time-series. Another reason for using cross-section techniques lies in the fact that it is intended to reveal long-term equilibrium relationships. Many of the problems related to obtaining good estimates for income and price elasticities arise because of lags between changes in the dependent variable and the corresponding exogenous model variables (i.e. slow vehicle turnover rates). When employing a time-series approach, a feasible dynamic specification, which is reflected in a specific lag-structure, has to be imposed. Use of a cross-sectional approach can avoid this by assuming that the estimates immediately reflect long-term relationships.

Appendix 2 Table A-18 show the long term non-OECD transportation (fuel) demand elasticities. The type of methodology and the underlying dependent variables are also presented. In the regions for which no time-series data are available, the elasticities have been derived using cross-section analysis. The elasticities and the underlying assumptions are shown in Appendix 2 Table A-19.

4.1.6 Projections

The model projects a rapid increase in passenger and freight traffic and the corresponding transport energy demand, which is likely to lead to pressures on transport policies. In many regions of the world it is recognised that demand management tools such as road pricing and telematics will have to play a prominent role in the future to control transport volumes.
The largest concerns/weaknesses of this model are the non-endogenised variables “choice of mode”, “purpose of travel” and non-incorporation of the costs of potential substitutes, although the effects of the latter probably are only moderate since a large proportion of driving is non-discretionary. However, estimating the cost of travel presents a major problem, at least in the long term, since it should include the lifetime costs of owning and operating a car. Even the short-term cost of travel is not only determined by the costs of fuel but should take into account the fuel efficiency of the car and other variable costs as well. The above-mentioned model restrictions and weaknesses may have led to uncertain results.

The projections of the IEA model for the increase in transport and the fuel demand are presented per region in Table A-20 Appendix 2. This IEA model projects an average annual growth rate in the transport energy consumption of 2.6% per year (over 1993-2010).

4.1.7 IEA model

Figure 4-2 presents the renewed transport model structure of the IEA. The old econometric approach is combined with a recently developed bottom-up approach because the policies described in chapter 11 of IEA (2000) require a more disaggregated framework than provided by the standard World Energy Model. The structure presented is thus not obtained from Wohlgemuth (1998) but from Appendix 1 of the World Energy Outlook 2000 IEA (2000). For every region, activity levels for each mode of transport are a function of population, GDP and price. The elasticity of transport activity to the fuel costs per km is applied to all modes except passenger and freight rail, and inland waterways. In the case of passenger vehicles, this elasticity is also used to determine the rebound effect of increased transport demand resulting from improved fuel intensity. Other assumptions to reflect passenger vehicle ownership are also made.

Modal energy intensity is projected by taking into account changes in energy efficiency and fuel prices. Explicitly, stock turnover for cars and light duty vehicles is modelled in order to allow for the effects of fuel efficiency regulation of new cars on fleet energy intensity. Fuel efficiency regulation and additional fuel taxation can be directly modelled.

This model projects that in 2020, 120 EJ will be used in the transport sector, which corresponds with an average annual growth rate of 2.4% (1997-2020).

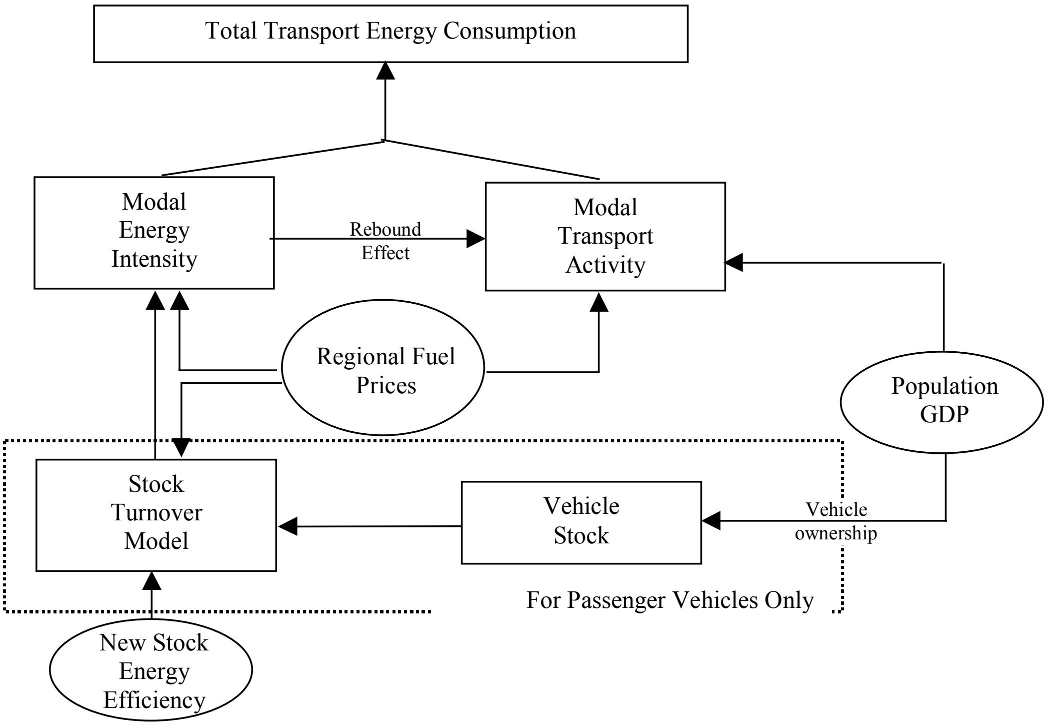

Figure 4-2 IEA transport model structure.

4.2 Model: World Energy Council (1995)

Over the past years, the World Energy Council (WEC) has developed a global transportation model. The initial model, covering car, road/rail freight, and aircraft transport, is used to project the transport activities through 2020 (World Energy Council, (1995). Explicit scenarios were developed to examine how the world's total energy use might be radically altered either by more robust economic growth or by a radical change in priorities favouring increased environmental protection.

4.2.1 Introduction

The global transport model used in the World Energy Council (1995) has been developed within Statoil Corporate Planning for the primary purpose of producing the quantitative scenario assessments for the WEC transportation project. This model actually emphasises passenger road transport; due to lack of data for other sectors, it was not considered meaningful to construct a detailed model for freight and air transport. Results from this model are generated with scenario analysis through the year 2020. Three different scenarios have been designed, each attributed with a different projection of economic and technological development, oil supply, environmental awareness, government/market involvement (regulation) and lifestyle changes.

4.2.2 Determinants

The WEC report determines economic growth as the most important determinant of transport energy demand but suggest that this apparent stable link between GDP and transport demand might be broken by "dematerialisation" (ever-growing importance of the service sector) and the global trend towards economic liberalisation and internationalisation of trade[11]. Notable is the impact of liberalisation of the oil market, since it can have a great effect on the incentive to develop energy-efficient or alternative technologies for vehicle propulsion. Due increasing competition the oil price will fall and still the demand of oil will be met. The incentive for technological development will decline.

Secondly, the report mentions demographic trends as another vital factor affecting future transport demand. Not only population growth, but also age structure, urbanisation and household size and composition have been examined. The most important demographic factor is the declining fertility affecting household size. The most important social factor is the decline in the three-generation families and the reduction in the proportion of married couples in the population. The most important economic factor is the increased affluence and the growing economic independence of women and young people. The fragmentation of families and the associated loosening of family bonds will result in a growing demand for mobility.

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[11] The suggested possible decoupling of GDP and transport has so far not been seen. This is explained in the same reference: Already in the early 1980s, it was generally expected that freight transport in the industrialised countries would grow only very slowly because of the relative decline of heavy industry. The assumption was, of course, that growth in the service sector would require less freight transport than growth in the industrial sector. So far, however, the forecasts have been wrong. Actually, the fact that ECMT freight volumes grew rapidly from the mid-1980s can largely be explained by economic liberalisation. This compensatory factor has lead to a spatial redistribution of the economic activities of production and distribution, built on national and international specialisation, which in turn has resulted in longer distances for freight transport.

Environmental concerns[12] are the driving force behind many of the transport sector regulations. The most efficient way of abating these environmental problems is through measures constraining the demand for transport or by developing new fuel-efficient technologies, although alternative fuels and reformulated gasoline will also play a role. Side-effects of measures taken will, however, redistribute the costs in society. Policy-makers will not only have to look at the merits of transport regulation but also take into account the interest of various stakeholders.

Changes in lifestyle could have a fundamental impact on future transportation demand. Today, the car serves as an important transportation device but also as a symbol of welfare. In the future, lifestyle changes could be linked to increased environmental awareness or continued dramatic progress in the field of advanced telecommunication. However, the impact is likely to vary substantially among different regions in the world. The introduction of telecommuting, for instance, has been relatively faster in the U.S. than in other industrialised countries.

Fuel efficiency and alternative fuels are determinants related to the more exogenous factor “technology”. With time, technology improvements will enable introduction of more fuel-efficient motors or motors using alternative fuels like ethanol at a competitive price. The car industry is in this respect easier to adjust than the aircraft industry. Potential alternative fuels for gasoline in the car industry are ethanol, hydrogen, LPG, rape-seed oil, electricity and methanol (of which natural gas (LPG) has the best odds within the given time framework: year 2020). The practical possibilities of the implementation of the possible alternative fuels (natural gas and liquid hydrogen) in the aircraft industry is low. This is due to a lack of technology, as well as to the gigantic investments in aircraft and infrastructure for the refuelling at the airports.

4.2.3 The model

The model configured for the description of passenger road transport is as indicated in Figure 4.3.

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[12] Author’s note: In the report, environmental concerns are also taken up in the same chapter. However, the negative impact of environmental pollution due to increased transport, will probably not affect transport demand autonomously (in contrast to GDP, for example). Since the effects of environmental pollution (read emissions) are long-term ones, the gravity of the resulting problems (e.g. lung diseases, reduced learning ability) for the population is often unclear. If the impact of a certain event is apparent, the awareness among people will be greater and also their response. An example mentioned in World Energy Council (1995), was the increased death rate, probably due to increased NO_2 levels in London in 1991. Statistics showed a 10% increase, though it is doubtful whether the London population was really aware of the cause of it. In this way, environmental pollution will probably not have a great mitigating effect on transport demand. Pollution merely figures as an incentive for governments to search for solutions.

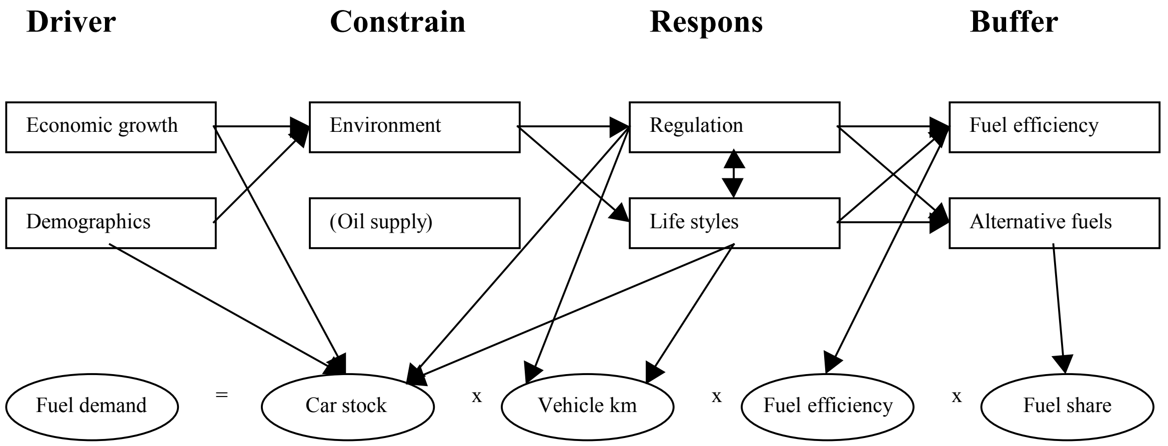

Figure 4-3: Links between mega trends and the Car Fuel Demand Model.

4.2.4 Scenarios

The three scenarios applied are Markets Rule, Muddling Through and Green Shock. The first scenario is one that envisages a world dominated by market regulation worldwide; the second is dominated by regionalism and economic growth is therefore less than in the Markets Rule scenario; the last scenario is a scenario in which environment is the central issue.

A common trend among all three scenarios is the decreasing share in energy demand of car transport, compared to trucks and air transport. It is expected that the share of automobile transport in total transport energy demand will drop from 50% in 1995 to around 30% (even lower in the Green scenario) in 2020. This trend will cause a shift in the fuel-demand ratio, with less emphasis placed on car fuels (gasoline) and more on truck fuel (diesel). The reason for this shift is that freight transport is linearly related to GDP while car use is logarithmic in OECD countries and exponential in developing countries. Since OECD account for more than 75% of private car transport, the effect of diminishing growth rates will override the increasing growth rates of the developing countries. Furthermore, the volume effect of the shift in market share of road freight transport at the expense of rail causes the demand for diesel to increase.

Also visible is the increasing relative importance of non-OECD countries in total transport energy demand. The predictions of high economic growth rates in these regions naturally affect the demand for both personal mobility and freight transport.

The effect of initial input data proved to be predominant in the determination of all the results, even for the Markets Rule scenario, where the rapidly growing, low volume, developing countries experience average car growth rates of 10% per year. Table A-14 presents the scenario assumptions that form the intrinsic base of the three scenarios. In Table 4-1 the scenario results are presented[13].

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[13] The figures are visually extracted from graphs in the concerning report. The accuracy is thus doubtful.

Table 4-1 World transport energy demand in the year 2020

	Green Shock	Muddling Through	Markets Rule
Global Transport Sector Energy Demand (in EJ per year)	63.9 (AAGR 0.1%)	122 (AAGR 2.7%)	166 (AAGR 4.0%)

AAGR = Average annual growth rate (1995-2020 period)

4.2.5 Model variable values

The quantitative model is composed of passenger transport, freight (road/rail) transport and an air (passenger and freight transport) submodel. Buses/light rail, water/seaborne transport, pipelines and motorcycles are not included. The most important model variables and relationships are presented in Appendix 1.

4.3 Model: World Energy Council (1998)

Between 1995 and 1998, the model of the World Energy Council (1995) was extended with other modes of transport: domestic waterborne transportation and international waterborne transportation. The focus of the report on the 1998 model differs as well from the focus of the WEC 1995 report. In the 1998 report, the reader gains a better perspective about current and future patterns of transportation energy use. Consecutively, the adopted approach and the scope of the study are elaborated. The results are presented in Table 4-2.

The approach is just like in the earlier project - simple, transparent and intuitive – staying in between econometrics and simple extrapolation. It does not incorporate explicit feedback relationships and there is no explicit consideration of certain variables known to be important in determining energy demand – the most significant of these being energy prices. The model consists, just like the earlier version, of a set of linked computer spreadsheets. Each of the eleven different geographic regions and each of the five transportation modes is analysed independently. Unlike the approach used in World Energy Council (1998) no explicit scenarios are formulated.

This study covers the transport modes that consume the bulk of the world’s transportation energy and contribute to the bulk of the world’s transportation-related environmental emissions. These include light-duty passenger vehicles, passenger-carrying aircraft, freight haulage lorries/trucks, railways, domestic waterborne transportation, and international waterborne transportation. Regional definitions are as far as possible based on the WEC/IIASA long-term energy model (see Appendix 6).

In this study, GDP was adjusted to reflect purchasing power parity (PPP). To increase comparability among other WEC reports, the GDP and population projections contained in the WEC/IIASA long-term energy demand model have been adopted.

Energy prices do not appear in this study although it is recognised that they probably cause the differences in energy consumption throughout the various regions and modes. Exclusion of energy prices is defended by the authors’ intention not to have the report getting side-tracked into a debate over energy price elasticities. The sensitivity analyses are constructed to be one step removed from energy price changes – or any other causal factor. What is analysed is how a specific change in an important variable, however generated, is likely to impact transportation energy demand.

A 25- year time horizon has been chosen in this study. Infrastructure is not believed to change dramatically and new types of vehicles (hybrids) are not expected to gain a substantial market share within this period. While no revolutionary changes occur in transportation systems over the space of 25 years, a quarter of a century is believed long enough to observe fundamental changes in direction in transportation trends.

In Table 4-2 the global energy demand of transportation is presented as projected by the WEC-1998 model World Energy Council (1998).

Table 4-2: Energy demand by mode (EJ/y)

	Light-duty vehicles	Air passenger	Trucking	Rail	Maritime	Total
1995	39.1	6.3	24.4	5.0	5.4	80.3
2020	55.0	16.2	40.9	5.4	7.9	125.5
Change	15.9	9.9	16.5	0.4	2.5	45.1
	Average annual rate of growth. 1995-2020 (%)					
	1.40%	3.80%	2.10%	0.30%	1.50%	1.80%
	Modal share					
1995	49%	8%	30%	6%	7%	100%
2020	44%	13%	33%	4%	6%	100%

4.4 Schafer and Victor’s Passenger motorised mobility model: Schafer (1998), Schafer and Victor (2000), Schafer and Victor (1999)

The model applied here projects motorised passenger mobility for 11 world regions (definition according to WEC/IIASA) up to the year 2020/2050. The one article puts more emphasis on the implications of the growing demand for passenger mobility (CO_2), the other on the more intrinsic aspects of the model. The transport modes included in this model are cars, buses, railways and aircraft (including high-speed trains, for both aircraft and high-speed train provide the same service level). The model differs from other models in that it takes into account the competition between transport modes. Scenarios are generally based on independent projections of traffic volume per mode of transport over time. Typically, each modal projection builds on a different method, and the total traffic volume becomes simply an aggregate of the independent estimates for the various modes. The lack of dynamics, and the absence of causal relationships between the various transport modes, limits the model to predict inter-modal competition.

This model avoids that problem by approaching the problem from the Zahavi constraints *Constant Travel Time Budget* and *Constant Travel Money Budget* that state that an average person spends a constant amount of time and a constant percentage of his/her GDP on travelling. In addition to these two constraints, the model is based on two additional characteristics. One is *path dependence.* Transport infrastructures, like many massive technologies and infrastructures, do not rise and fall rapidly. Initial choices become locked in, constraining possible future developments and limiting the rate at which one mode can substitute for another. Thus the future for some modes of transport may be determined by the development of their current infrastructure (i.e. low speed conventional railroads heavily depend on dedicated infrastructure). The final characteristic is that *population density* and *land-use* partially determine modal split. In regions with approximately equal traffic volume per capita, car-saturation levels reached different values as a result of different population densities. In general, slower means of transport are used in higher density regions.

The TTB and the TMB constraints are used to argue that increasing GDP leads to the use of faster and more flexible transport modes. According to TMB the average amount of money spent on travelling increases if GDP increases. One will have to travel farther in order to spent the increased budget on travelling. If the time spent on travelling is also to be constant, transport modes with higher average travel speed will have to be used. It is shown that regions with a lower per capita GDP make use of the slower and inflexible transport modes of bus and rail. The PAS region illustrates that developing regions with increasing GDP, the share of bus travel is saturated due to a more rapidly increasing traffic volume of higher-speed vehicles, i.e. passenger cars and aircraft. A more extreme region is NAM, in which the declining automobile share is being translated into an absolute decline in favour of aircraft. Buses and railway only play a marginal role in the total mobility in this region.

The calculations start with projecting total motorised mobility, the aggregate of traffic volume of cars, buses, railways and aircraft; secondly, the related modal shares are projected. On basis of a unique historical data set (1960 to 1990) and the above-mentioned constraints, the (aggregated) relationship between GDP, population and mobility has been derived for the 11 world regions. In the light of a world population increasing by 50% from 1990 to 2020 (both projected by UN “medium population” projection and the World Bank), absolute motorised mobility will increase by a factor of three.

Any change in world passenger energy use is determined by four factors:
(a) a rise in per capita traffic volume,
(b) population growth,
(c) change in modal split and
(d) alterations in energy intensity of the four modes.

Ad (a) and ad (b): the expected impact of a rising per capita traffic volume (double through 2020 at the given GDP growth rate of 2% per year) in combination with a 50% growth in world population will lead to a rise in passenger transport energy use by a factor of three. In Schafer and Victor (2000), the total global motorised mobility in 2020 is estimated at 53,747 billion. pkms.

Ad (c): the change in modal split is likely to increase the overall modal energy intensity (with 2020 modal energy intensities similar to 1990 modal energy intensities). The energy intensity is expected to rise by 11-20% from 1.61 MJ.pkm^{-1} in 1990 to 1.79-1.93 MJ.pkm^{-1} in 2020, depending on projected modal shares. In combination with the threefold increase in aggregate travel demand, passenger transport energy use is expected to rise by a factor of 3.3-3.6.

Ad (c): the 2020 energy intensities of all ground transport modes are assumed to remain at 1990 levels – an optimistic assumption in the light of historical development. The energy intensity of high speed transport (essentially aircraft) is expected to decline by 2% per year (in line with historical development). Based on the modal split in 2020, the projected energy intensities reduce the mean energy intensity by about 15%. Combined with the growth in aggregate transport demand and the projected modal split change, overall world transport sector energy use is projected to rise by a factor of 2.8-3.1 over the 1990 level.

The results are summarised in Table 4-3.

Table 4-3: World modal shares and final energy intensities of vehicle fleets in 1990 and projections for 2020

	1990		2020	
	Modal Share (%)	FEI (MJ.pkm^{-1})	Modal Share (%)	FEI (MJ.pkm^{-1})
Cars	52	2.10	45-55	2.10
Buses	29	0.65	29-19	0.65
Ordinary railways	9.5	0.40	5	0.40
High speed transport	9.5	3.00	21	1.65
Total/weighted average	100	1.61	100	1.50-1.65

4.5 Azar *et al.* (2001)

In this study, the authors have been looking at three alternative fuels to the conservative fuels gasoline/diesel in the transportation sector: hydrogen, methanol and natural gas. Methanol is used as a proxy for all liquid biofuels, disregarding the advantages and disadvantages compared to ethanol.

The purpose of this study is to analyse the transition towards lower CO_2 emissions on a global scale. In particular, the transition towards CO_2 neutral energy technologies in the transportation sector, the relative competitiveness of hydrogen and methanol in the transportation sector and the potential for bioenergy, in the form of hydrogen or methanol, in the transportation sector are analysed.

These issues are studied using a global energy model developed specifically for this project. The model is a linear programming model that is globally aggregated and has three end-use sectors (transport energy demand, heat and electricity). It is set up to meet exogenously given energy demands while meeting a specific atmospheric concentration target at the lowest system cost.

This study actually provides two interesting topics conforming to our modelling intention for TIMER. The first one is how transportation energy demand is modelled, and the second is how the various fuels are divided over total transport energy demand. This last topic has not been explicitly mentioned in the introduction, but it might be a subject that should receive more attention after more insight has been obtained on how to model transport energy demand. Therefore, it is shortly discussed in this section.

The transport model applied in this study projects both passenger and freight transport for the year 2100. The passenger transport model is based on a model developed by Schafer and Victor (see section 4.4). Because this model only projects passenger transport activity (and energy consumption) until 2050, the model had to be extended. This implicated among other things different calibration on the basis of other input data (GDP projections from WEC/IIASA C1 scenario), aggregation to one region (from 11 applied in Schafer and Victor (2000)) and an additional constraint regarding high-speed transport.

An important part of Schafer and Victor's model, is the projection of the modal split. Schafer and Victor do not differentiate between different high-speed modes. Since high-speed modes grasp a growing share of total transportation during the modelled time period such a differentiation needs to be made. Currently, the share of high-speed trains is only significant in Japan, where they account for 30% of high-speed personal transportation. On a global scale, Azar *et al.* (2001) have assumed that high-speed trains will increase its share from 4% in 1990 to 30% in 2100 (the fifth constraint in addition to the four mentioned in section 4.4). In this model, other energy intensity values for the various transport modes are adopted than by Schafer and Victor (2000). In this study, the initial values (1990) are generally lower than in Schafer and Victor (2000) and also the development over time is different (continuously decreasing for all but the high-speed transport mode) (see Table 4-4).

Table 4-4: Energy intensity transport modes (MJ pkm^{-1})

	Schafer and Victor (2000) (see **Error! Reference source not found.**)		Azar *et al.* (2001)	
	1990	2020	1990	2100
Car	2.10	2.10	2.1	1.2
Buses	0.65	0.65	0.63	0.28
Ordinary Railways	0.40	0.40	0.32	0.16
Air	3.00	1.65	2.7	1.1
High speed-trains	(in Air)		0.47	0.47
Overall (weighted according to modal share)	1.61	1.50-1.65	1.6	0.97

See Appendix 5 for a short elaboration on freight transport modelling in Azar *et al.* (2001). Since the composition of the fuel mix of the transport sector is not really the topic of this paper, the projection approach adopted in Azar *et al.* (2001) is only shortly explained.
In Azar *et al.* (2001), the costs are calculated of setting up infra-structures for distribution and refuelling of natural gas, methanol and hydrogen. Also, the costs of production of the fuels and the driving costs for vehicles are calculated and projected. Using different scenarios, it is analysed what the contribution of the three fuels will become in 2100. The various scenarios take into account different price developments and different CO_2 constraints. Under the condition of no carbon constraints, methanol becomes the dominant transport fuel in 2100. If the atmospheric CO_2 concentration is not allowed to exceed 400 ppm, hydrogen becomes dominant in 2100. The implications for the other two end-use sectors, “heat” and “electricity”, will not be discussed here since it falls outside this paper’s scope.

5. Evaluation of the literature and model comparison

In this chapter, the literature discussed in Chapter 3 is evaluated and the global transportation models described in Chapter 4 compared. The Azar *et al.* (2001) model is not elaborately discussed here. The passenger transport part of that model is largely taken from Schafer and Victor (2000), so that most remarks about Schafer and Victor's model are also valid for Azar.

5.1 Literature evaluation

In the previous chapters a series of transport-related documents were summarised. Since most documents have their own focus, comparison is hampered. Therefore we will attempt here to present the most important relationships gleaned from the reviewed literature. Some sources (Schrijnen, 1986), Blaas *et al.*, 1992) were so elaborate that one cannot claim to cover all the relationships in this section. For all studies, the independent variables are presented in parentheses.

Schipper (1997)
- Total travel (Income, Prices, Urban form, Modal split, Vehicle fuel intensity, Sum of vehicle fuels j in mode i)
- Modal Split (Income, Price, Urban form)
- Vehicle Fuel Intensity (Income, Technology, Vehicle characteristics)
- Sum of vehicle fuels j in mode i (Modal split)

Blijenberg and Van Swigchem (1997)
- Long term: Travel time (Time spent on other activities)
- Long term: Spatial organisation (Transport modes)
- Travel mileage (Technology)

Banister (1996)
- Energy demand (Urban form)

Dargay and Gately (2001)
Vehicle projection with new methodology:
- Saturation level of car ownership (Population density)
- Change in vehicle stock different for falling and increasing income

Schrijnen (1986)
- Car ownership (Income, Age, Gender, <Costs, Geographical organisation, Alternative transport modes)
- Car use (Ownership, Income, Age, Gender, <Fuel price)
- Relation between employment and car ownership/possession of driver's license
- Higher level of ownership in urbanised regions than in rural areas
- Indication that car ownership is more strongly related to (Quality and quantity of public transit) than to (Spatial organisation of services, home, work, etc)

Pronk (1991)
- Car ownership (Income, Gender, Occupation and education, Position in household)
- The higher the income, the newer the car

- Ownership of second car (Income)

Blaas *et al.* (1992)

- Costs
  - Strong autonomous development in car ownership
  - The increase in real income of past years made ownership possible for greater public
  - Absolute costs of ownership and use barely increased over past years
- Low cost awareness
  - Financial determinants do not play an important role in the decision to own or use a car
  - Price sensitivity (trip distance, trip motive)
  - Variable costs have much larger influence than fixed costs on car use
- Personal Characteristics
  - Car ownership (age, gender)
  - Possession leads almost automatically to use
  - Car use (income, gender, distance between home and work)
  - Car ownership (income)
  - Car use barely increases with increasing income in higher income groups, whereas it does increase in lower income groups
- Household characteristics
  -Car use is higher in a multi-person household composition
- Infrastructure
  -Car ownership and use (quality/quantity road infrastructure)
- Information
  -Relationships are unclear; however, there is a matter of a one-sided information supply from the car branch
- Driving behaviour
  -Driving style (age, gender, purpose of trip, road infrastructure)

Johansson and Schipper (1997)

- Vehicle stock per capita (Vehicle stock$_{t-1}$, Fuel price, Income, Taxation, Population Density)
- Mean fuel intensity (Mean fuel intensity$_{t-1}$, Fuel price, Income, Taxation, Population Density)
- Mean annual driving distance (Mean annual driving distance$_{t-1}$, Fuel price · Mean fuel intensity, Income, Taxation, Population density, Vehicle stock per capita)

The literature presented focuses mainly on road transport. Only a bit of literature is found that copes with projections of the energy consumption of air transport. The cause of underexposure probably lies in the fact that many studies regard near-future time intervals of 1990-2020 - World Energy Council (1995), World Energy Council (1998), 1995-2025 Dargay and Gately (2001) - for which it is expected that road transport will play an important role. Another reason could be the national policy focus of many studies. For example, Schrijnen (1986) and Pronk (1991) address car ownership, use and mitigation-related issues for the Dutch situation. Banister (1996) studied the possibilities of urban area design to reduce the need for transportation executed in the U.K. On the whole, these documents provide insight into a specific niche of global transportation, namely, road transport. Especially the importance of various determinants of car ownership and use has been stressed. Also, the direct relationship between Car use and Transport energy consumption has not really received much attention. Blijenberg and Van Swigchem (1997) and Schipper (1997) addressed this relationship in combination with technological improvements. Blaas *et al.* (1992) made note of this relationship by mentioning that driving style and driving behaviour have a large impact on the fuel economy.

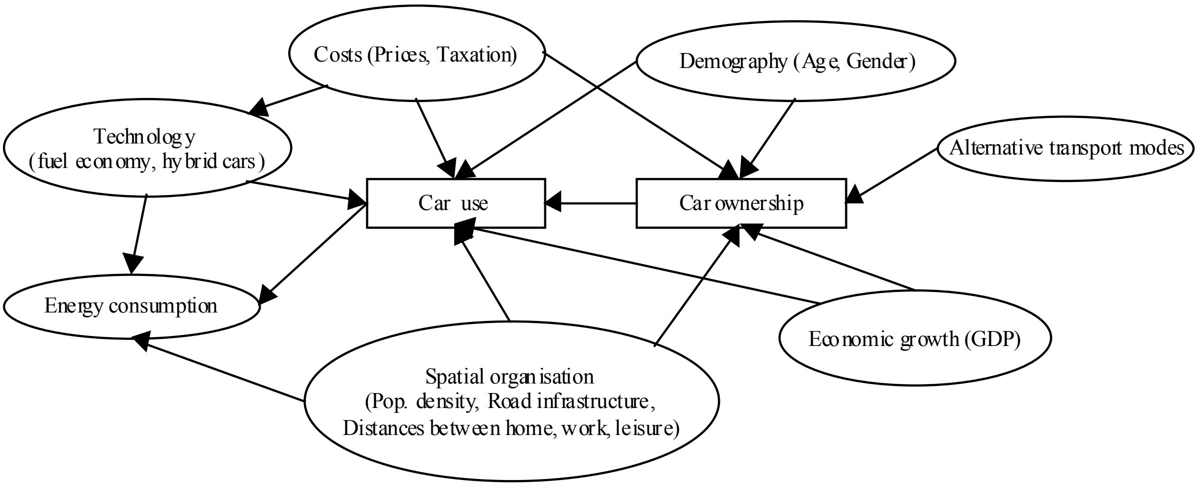

Figure 5-1: The most important determinants of car ownership and use, and associated energy consumption.

The most relevant relationships extracted from these references are presented graphically below. Note that the operational variables, examined in the studies, are classified in five more general descriptions (Costs, Economic growth, Demography, Spatial organisation and Technology).

5.2 Overview of Global Transportation Models

In Table 5-1 and Table 5-2 the significant model characteristics of the four global transportation models are presented.

Table 5-1 Model comparison

Name	1) IEA model (Wohlgemuth (1998), IEA (2000)	2) Model World Energy Council (1995)
General description	Long-run income and price elasticities	Global transport sector energy demand
Region	Global OECD regions (U.S., Europe and Japan) 11 non-OECD world regions	Global Results for 8 world regions classified according to IIASA/WEC.
Projection period	1990-2020	1990-2020
Goal variables	Road passenger, road freight and air transportation activity elasticities (OECD countries, see Table A-15 – A-17) Fuel demand elasticities (gsl, dsl, avg) (non-OECD regions, see Table A-18 and Table A-19)	Projection for activity and energy use of cars, road/rail freight and aircraft.
Model relationships and determinants	See Relationships 1 IEA ***model*** (below table)	See Relationships 2 and Figure 4-3
Remarks	Regional fuel prices included	
Results	See Table A-15 to Table A-19	See Table 4-1 and Appendix 1

Table 5-2 Model comparison (2)

Name	3) Model World Energy Council (1998)	4) Schafer and Victor (2000), Schafer and Victor (1999), Schafer (1998), Azar *et al.* (2001)
General description	Development of Global transport and related Energy demand	Motorised passenger mobility / Carbon emissions due to global passenger travel
Region	Global 11 world regions (classified according to IIASA/WEC)	Global 11 world regions (classified according to IIASA/WEC)
Projection period	1995-2020	1990-2050
Goal variables	Total transport energy consumption per mode (light-duty vehicles, air [pass.], trucks [freight], rail, maritime) Modal shares Carbon emissions	Passenger transport activity (pkm) (car, bus, rail, air) (Modal energy intensities) (CO_2 emissions)
Model relationships and determinants	Not specifically mentioned but assumed to be almost equal to WEC 1995 model	See Relationships 3 Schafer and Victor (under table)
Remarks		Travel time and travel budget as percentage of GDP are constant, inter-modal competition
Results	See Table 4-2	See Table 4-3

5.2.1 Model relationships

Relationships 1 IEA model

Road transport OECD (Figure 4-1):

- Fuel demand (Distances travelled, Average efficiency)
- Distances travelled (Economic activity, Cost)
- Cost (Price, Average efficiency)
- Average efficiency (Diesel penetration, Turnover, New efficiency)
- New efficiency (Price, Policy)

Air transport OECD:

Europe and Japan

- Fuel demand (Consumer expenditures, Price of crude oil) [directly estimated]

U.S.

- Fuel demand (Passenger air miles)
- Passenger air miles (GDP, Cost series)

Travel fuel demand non-OECD:

- See Table A-18 for underlying variables and approaches applied for estimation of income and price elasticities of non-OECD regions

Model as presented in IEA (2000) (Figure 4-2)

- Total transport energy consumption (Modal energy intensity, Modal transport activity)
- Modal energy intensity (Stock turnover model, Regional fuel prices)
- Modal transport activity (Population, GDP, Regional fuel prices, Modal energy intensity [rebound effect])
- Stock turnover model (Regional fuel prices, Vehicle stock, New stock energy efficiency)
- Vehicle Stock (Population, GDP)

Relationships 2 WEC 1995 model

- Car Fuel Demand (Car stock, Vehicle km, Fuel efficiency, Fuel shares)
- Car Stock (GDP, Scenario) [S-curve] [Table A-2]
- Average annual vehicle km (Scenario) [Table A-3]
- Fuel efficiency (Scenario) [Table A-4]
- Freight transport fuel demand (Total freight transport, Modal share road, Fuel efficiency road, Total freight transport, Modal share rail, Fuel efficiency rail)
- Demand for freight (GDP, Freight intensity) [linear + temporary uncoupling] [Table A-7]
- Freight intensity (Scenario) [Table A-6]
- Modal share rail (Scenario) [Table A-8]
- Fuel efficiency road (Scenario) [Table A-9]
- Fuel efficiency rail (Scenario) [Table A-10]

- Air transport energy demand (Passenger transport volumes, Fuel efficiency passengers, Freight transport volumes, Fuel efficiency freight)
- Transport volumes (GDP) [1 tonne.km = 8 p.km]
- Income elasticities (Scenario) [constant over time but varying with region and scenario][Table A-12]
- Fuel efficiency (Scenario) [Table A-13]

Relationships 3 Schafer and Victor

- TV (TMB, GDP) [Time constraint]
- S_R (TV) [Path dependence]
- S_{LS} (TV) [Density constraint]
- $S_B = S_{LS} - S_R$
- S_{HST} (s, TV,FMMS, TTB_{mot}, S_B, S_R, t) [Money constraint]
- $S_C = 1 - S_{LS} - S_{HST}$

with S = Modal Share, TV = Travel Volume, TTB = Travel Time Budget, TMB_{mot} = Travel Money Budget (motorised transport), LS = Low Speed public transport, B = Bus, R = Rail, C = Car, HST = High Speed Transport, FMMS = Future Mean Modal Speeds, t = time.

5.3 Model comparison

5.3.1 Approach

From the literature evaluation of Chapter 3 and sections 5.1 and 5.2 , basically three approaches are derived with which future global passenger transportation can be modelled. The first approach is roughly said, ordinary extrapolation of historical trends, non-regarding underlying activities. Approaches that simply extrapolate past trends have the virtues of simplicity and transparency but they lack the possibility to provide an analyst the opportunity to examine the impacts of various alterations of past trends.

The second approach is an econometric approach that projects energy consumption along with underlying transport activities. The advantage of these models is that they are capable of incorporating explicitly complex feedback linkages. According to World Energy Council (1998) the principal drawback of econometric models is their lack of transparency. They can become so complex that they must be accepted on faith. The user applicability is consequently often limited to the model's architect[14].

The third approach is an approach that is found between the two extremes and can be described as parametric. Future energy consumption is directly projected, along with various megatrends (like GDP, prices, population, etc.).

The WEC 1995 (and possibly the WEC 1998 model too) apply an approach that keeps to the middle, between the parametric and the econometric approach, since these models do not

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[14] Author's note: It should be noted that econometric models are not always as non-transparent as claimed by World Energy Council (1998) . There are numerous examples of simple econometric models (models composed of mathematical equations) that give enough transparency to understand the outcomes and the structure of the model.

endogenise feedback relationships, but do project future transport energy consumption by combining estimated transport activity and transport energy intensities. Neither do Schafer and Victor use feedback relationships in the estimation of total transport volume, but they do use them in the projection of modal shares and thus in the overall transport energy intensity.

The IEA model corresponds in some way with the model of Schafer and Victor. In the IEA model, just like in Schafer and Victor's model, feedback relationship(s) are used: at least one is explicitly presented in Figure 4-2 (re-bound effect). Furthermore, both models project transport energy consumption by combining transport volume with transport energy intensity. However, Schafer and Victor combine modal shares with total transport volume to determine the activity per mode, while the IEA-model projects each modal transport activity autonomously (unaffected by the activity of the other modes). Schafer and Victor project the modal shares taking into account intermodal competition (not on economic grounds but on the basis of the Zahavi constraints, section 4.4).

In the IEA model, the focus has been placed on the transport mode car, as can be derived from both Figure 4- and from section 4.1. Schafer and Victor have placed approximately equal attention on all modes. The share of rail, low-speed transport (which is rail and bus), and high-speed transport are modelled explicitly, and car share and bus share are derived from the other shares.

5.3.2 Transport modes covered

Direct comparison of the overall results is not possible since the models presented in Chapter 4 include different modes. Table 5-3 presents the transport modes covered per model.
Only the models by World Energy Council (1995), World Energy Council (1998), Schafer and Victor (2000) and Azar *et al.* (2001) disaggregate the energy consumption into different transport modes. Four other global energy models (IEA, TIMER, POLES and WEC/IIASA) are taken up in the table as well. These models do not project transport energy consumption disaggregated to different transport modes; they implicitly cover all modes. The results of these models are more elaborately discussed in Chapter 6. It is noted that Azar *et al.* (2001) more explicitly discern between air and high-speed ground transport than Schafer and Victor (2000) from whom the basis for their passenger transport model is derived. The split of high speed transport between these two modes was considered necessary by Azar *et al.* (2001) because of their longer projection horizon.

Table 5-3 Transport modes covered per model

	WEC 1995	WEC 1998	Schafer and Victor	Azar Azar *et al.* (2001)	IEA model IEA (2000)	TIMER De Vries *et al.* (2001)	POLES Criqui (2001)	WEC/IIASA WEC/IIASA (1998)
Cars*	X	X	X	X				
Light duty trucks (pass.)		X		X				
Truck (freight)	X	X		X				
Buses			X	X				
Air (pass.)	X	X	X	X				
Air (freight)	X			X				
Rail (pass.)			X	X				
Rail (freight)	X	X		X				
HS Rail			X	X				
Waterborne international		X		X				
Waterborne national		X		X				
Results only available for all modes					X	X	X	X

* In the WEC 1998 model: Cars include Light-duty vehicles as well.
** What transport modes are covered by the IEA model are unknown.

5.3.3 Determinants

If we translate the relationships defined in models to determinants of passenger transport activity or passenger transport energy consumption, we get the following result:

Table 5-4 Determinants of transport activity (or energy consumption) included by the global transportation models of World Energy Council (1995), World Energy Council (1998), IEA (2000) and Schafer and Victor (2000)

	WEC 1995	WEC 1998	IEA	Schafer and Victor
Economic development				
GDP	X	X	X	X
Prices				(X)
Regional fuel prices			X	
Spatial organisation				
Population density				X
Technological development				
Modal energy intensity	X	X	X	X
Demography				
Population size	X	X	X	X
Other				
Travel Time (constraint)				X

The IEA model as presented in Figure 4-2 endogenises regional fuel prices which are omitted in all three of the other models. Many studies have shown that prices have considerable influence on transport activity (Wohlgemuth (1998), Goodwin (1992)). It is noted that at the moment, Schafer is working on an expansion of his model, including prices.

In Schafer and Victor (2000), the modal share of low speed transportation is determined (by region) as a function of population density and total traffic volume. The examined regions are classified on the basis of historical data as a region with low, medium or high density. The three different population density paths determine how the modal share of low-speed transportation is calculated as a function of total traffic volume. The relation between spatial organisation and transport energy consumption/activity is confirmed to urban level by studies done by Kenworthy and Laube (1999). They show for various cities that urban form (expressed as population density) largely determines the per capita transport energy consumption.

5.3.4 Results

The comparative analysis of the overall results focuses mainly on the two WEC models and Schafer and Victor's model, since the literature on the IEA model does not provide any information about how the energy consumption by the different transport modes is calculated. A small indication of the results is given by comparing the projected energy consumption in 2020 of the corresponding transport modes in the models.

The energy consumed by the transport modes "cars" and "aircraft passengers" can be compared for all three models. The transport modes truck (freight) and rail (freight) could be compared for the two WEC models but since this study does not focus on freight transport this will not be done.

Table 5-5 Global energy consumption and average annual growth rates of global energy consumption of passenger transportation by car and air in 2020, according to World Energy Council (1998), World Energy Council (1995) and Schafer and Victor (2000) (EJ/y)

	WEC 1995			WEC 1998	Schafer and Victor	
	GS[15]	MT	MR		Low	High
Cars (incl light duty vehicles)	20.0	42.9	55.5	55.0	50.5	61.8
Air	9.42	16.4	20.3	16.2	18.5	
AAGR Cars	-1.2% (1992-2020)	1.5% (1992-2020)	2.4% (1992-2020)	1.4% (1995-2020)	2.3% (1990-2020)	3.0% (1990-2020)
AAGR Air	2.5% (1992-2020)	4.3% (1992-2020)	4.5% (1990-2020)	3.8% (1995-2020)	3.5% (1990-2020)	

5.3.5 Conclusion

Interpretation of model projections is limited to comparison with other models since the actual values have not been generated yet. This also holds for projections of global transport energy consumption. The reliability of the results of the different global transport models presented in this Chapter can only be assessed by comparing the underlying models. The WEC 1995 and 1998 models are mere linear interpolations of trends. However, it should be noted that these models cover wider ground since they attempt to describe energy consumption of the complete transport sector, while Schafer and Victor's model focuses on passenger transport. The advantages of Schafer and Victor's model over the IEA model are

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[15] See Table A-14 for the characteristics of the WEC 1995 scenarios Green Shock, Muddling Through and Markets Rule.

(1) the inclusion of population density, supported by Kenworthy and Laube, and (2) the inter-modal approach, but the IEA model does take into account fuel prices neglected in the current version of Schafer and Victor.

6. Comparison of transport energy scenarios

For insight into how TIMER performs in comparison with other global energy models, a comparison is made in this chapter of the overall primary energy projections and, where possible, of the transport energy demand.

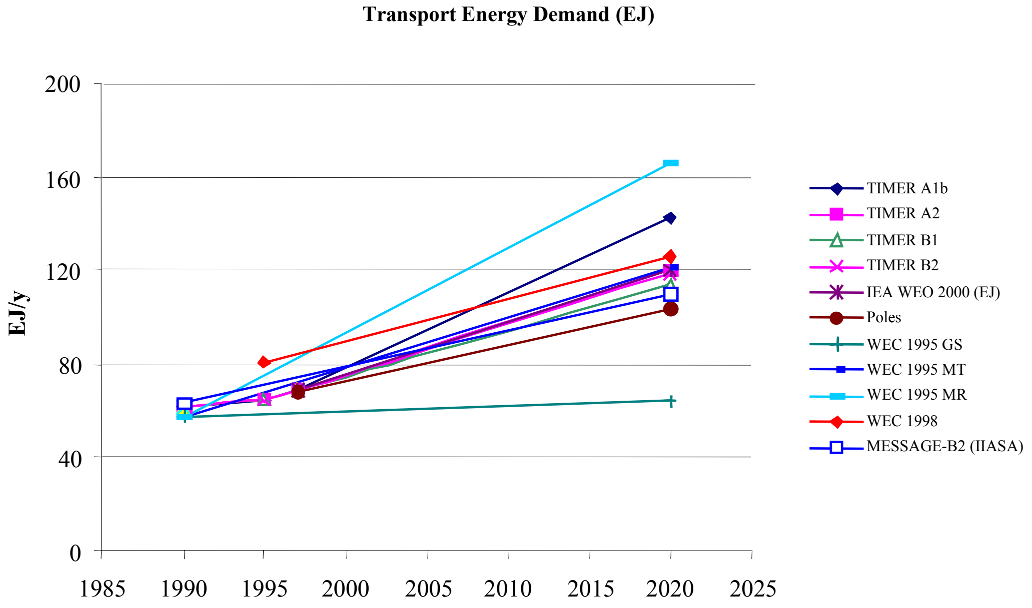

Figure 6-1: Transport Energy Demand projections until 2020[16].

In Figure 6-1 it can be seen that TIMER's projections of total transport energy demand for 2020 are all found in the upper regions. The most extreme projections stem from the Markets Rule and Green Shock scenarios from WEC 1995, projecting 166 EJ/y and 64 EJ/y, respectively. TIMER produces the next highest projection with its A1b scenario. The POLES and the MESSAGE-B2 scenarios close the ranks with lowest projections. The other WEC 1995 scenario, the Muddling Through scenario, the IEA-model and TIMER A2 produce similar results, respectively 122 EJ/y, 120 EJ/y and 120 EJ/y. Comparing the TIMER B2 scenario to the MESSAGE-B2 indicates that in 2020 the two models are still relatively close (the storylines, GDP projections and population scenarios have been harmonised): around 110 EJ for MESSAGE versus around 120 EJ for the TIMER model.

If we compare total primary energy consumption, we see that in the long run WEC/IIASA produces approximately the same projections as TIMER. The most energy-consumptive scenarios from both models project energy consumption in the order of 1700-1800 EJ/y and the least energy consumption in the order of 600-900 EJ/y. Both models have projection(s) in between.

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[16] In table form: see Table A-21

7. Discussion

Chapter 3 identifies various relationships describing car use and ownership. Some of the determinants mentioned in these references have in some way been incorporated in the global transportation models described in Chapter 4. For example, all models have taken technological development into account (operationalised through improving fuel economies). Geographical organisation has only been taken into account on a global scale by Schafer and Victor (2000) (through population density). Prices in turn are only included in the IEA model (Figure 4-) (through regional fuel prices). Blaas *et al.* (1992) and Schrijnen (1986) expect that mobility is also affected by demographic factors. For a certain region, the number of passenger kilometres per person per year by car will depend on the number of people with a driver's license. Also, gender and age appeared to affect the number of travelled kilometres.

Theoretically, inclusion of technology, spatial organisation, prices and demographic factors (other than population size alone) in models describing passenger transport demand may contribute to better predictions of future passenger mobility and related energy consumption. The question, is though, how these determinants should be operationalised (in TIMER).

7.1 Technology

One of the important determinant of passenger transport energy consumption is technology. All global models take into account this determinant, though in various ways. The most frequently adopted approach is to assume that vehicle propulsion systems become more efficient thanks to technological advancements[17]. Schafer and Victor (1999), World Energy Council (1995), World Energy Council (1998) and Azar *et al.* (2001) have all adopted exogenous assumptions about the development of the modal energy intensities. However, one could also think of "directed" technological advancement. If one believes that technological advancement goes faster when economic growth is higher, for example, transport energy consumption could differ in various scenarios assuming different economic development. Examination of the relationship between technological development and GDP might be something for further research.

7.2 Spatial organisation

As mentioned earlier, Schafer and Victor have already incorporated the determinant spatial organisation in their global passenger transport model. Urban population density determines how GDP is related to the model share of low-speed public transport. GDP itself is the explanatory variable of passenger transport activity. On a national/regional level GDP appeared to be able to explain the observed transport activity over time very well, though, on the urban scale, Kenworthy and Laube (1999) show that population density is better able to explain the observed level of activity (see section 3.9)[18].

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[17] In the past, the modal energy intensities have not always improved, since lifestyle changes have offset the energy-efficiency gains by a population driving larger, more comfortable cars and declining occupancy rates.

[18] Their conclusions focus on how spatial planning could contribute to a sustainable urban transport system. In section 3.9 their conclusions are criticised in the statement that the period in which urban areas can become more densely occupied is too long. Practically speaking, policies focusing on a higher urban density level can thus only be applied to new, yet to be built, residential areas and underdeveloped regions where the larger part

There is another approach to support the idea that spatial organisation in terms of urban density affects transport activity and transport energy consumption. It is not expected that current cities are able to sustain the growth of private car transport. Nowadays, heavy congestion is observed in most cities. With increasing vehicle ownership that problem will only worsen. An increasing GDP is thus not expected to cause unrestrained growth of car passenger kilometres in urban regions. Besides the congestion problem, available parking space might become insufficient to support the vehicle stock. Urban form is then likely to impose a mitigating effect on the growth of the vehicle stock and thus car use.

Now the question is how to implement spatial organisation in global transport models, in general, and in TIMER, in particular. Banister (1996) showed that both size and urban density affect transport energy consumption. Schafer and Victor (2000) and Kenworthy and Laube (1999) both use urban population density, which seems to be the most reasonable way to express spatial organisation in global transport models.

Outside urban regions, population density is not expected to have a significant impact on transport activity or energy consumption. The problems occurring within urbanised areas, like insufficient space for parking, are not encountered in rural areas. The congestion seen on roadways between urban regions in the Netherlands seem more affected by the purpose of travel (home to work) and a lower level of alternative means of transport, than by the local population density of the area between the urban regions.

Operationalising spatial organisation (or actually urban form) through population density seems thus reasonable. As mentioned earlier, Schafer has already adopted that approach in his passenger transport model. The implicit model assumptions of Schafer and Victor’s model (Zahavi constraints, travel time and money budget) have some implications for the geographical location of future development of passenger transport activity. If the maximum speed of the various transport modes within urban regions is limited (which is reasonable to assume), passenger transport activity will have to expand outside urban regions in order to meet the Zahavi constraints. With increasing GDP, the average distance between home and work, for example, will have to become larger since that distance is going to be covered with faster transport modes.

It is thus the question of whether (urban) population density can also affect the number of passenger kilometres directly (instead of indirectly by modal share). If a given urban area is becoming denser over time due to construction of more residential areas and services, people will probably travel less. This is expected to be the result of a lower transport demand (since all services are nearer by) so that other means of transport can be chosen. A denser area thus induces a shift in the modal shares *and* as a result, total distance travelled becomes less. It seems then reasonable to assume that urban population density affects the modal split. However, the question that remains is whether it is reasonable that people, who are more or less bound to a particular number of passenger kilometres *inside* urban areas, are going to travel more and more *outside* these urban areas?

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of the population is still living in rural areas. It will be extremely difficult from a technical, but also from a social, point of view to apply such policy on low-density urbanised areas with a well-developed transport infrastructure.

7.3 Prices

Prices are expected to play an important role in the future too. An important factor will be environmental taxes, as governments may eventually find themselves in the position where they will *have to* constrain mobility in order to preserve the environment and mitigate CO_2 emissions. Several studies have shown that prices have influenced transport activity in the past. Price and income elasticities for different regions over the period of 1960 to 1990 have been estimated by Wohlgemuth (1998); a summary of this study is presented in section 3.9. The effect of prices on energy demand should, however, not be overestimated. Evaluation and comparison of WEOs of the 1990s showed that prices have had much less influence than GDP (IEA, 2000). The demand for oil responds only modestly to changes in end-user prices (including taxes). High taxes on petroleum products mean that oil-price fluctuations have relatively little effect on demand, except in low-tax countries or for low-taxed products such as heavy fuel oil. In contrast, GDP showed in the past 25 years a clear, direct relationship with the demand for mobility services. World transport activity has followed economic output; it was largely unaffected by the 1973 and 1979 oil-price shocks.

There are numerous ways to operationalise prices in transportation models. In Wohlgemuth (1998), price and income elasticities are estimated with readily available data, though it is mentioned that more elaborate data sets could improve the outcomes of that study. In the ideal case, the price of personal car travel should incorporate both fixed and variable costs of possessing and operating a car. Data availability prohibits such an approach and therefore, for many regions, the price of fuel (gasoline, diesel) has been used to reflect the costs of car travel (see Table A-15 to Table A-18 Appendix 2). For public transport (buses, rail and air) the price of tickets should be used, though, also in this case, the fuel price (diesel, aviation fuel) has been used many times to reflect the costs of public transit.

This study is noted to embody a rather elaborate survey of various studies on income and price elasticities. The author consulted, among other studies, a survey by Johansson and Schipper (1997), Dahl and Sterner (1991) and Dahl (1986)[19]. Just as in the case of other determinants of transport activity, one should pursue an examination of the change in transport *activity* first instead of energy as a result of a change in price. Using this approach efficiency improvements can be dealt with separately. Yet in some cases, due limited data availability, Wohlgemuth (1998) had to adopt a simpler methodology to estimate transport energy demand for most regions; this makes it hard to compare the results between regions for which different data availability exists.

7.4 Demography

In the Netherlands, other demographic factors besides population size and density appeared to have a significant impact on traffic volume (Blaas *et al.* (1992), Schrijnen, 1986). An obvious factor of importance seemed to be age, since car driving, currently contributing to more than 50% of all passenger kms (Schafer and Victor (2000), is restricted to a certain age in most world regions. Regions with a higher percentage of people between 18 and 60 years are expected to show a higher level of car ownership and use, *ceteris paribus*. Gender also

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[19] For price elasticities for passenger air travel, one might take a look at the recently published report describing a meta-analysis of price elasticities for passenger air travel (Brons (2001)). It gives a clear overview of elasticities found in a broad range of elasticity surveys.

appeared to be influential, which can be explained by the lower participation of women in the labour market and the lower average income (Blaas *et al.*, 1992).

Schafer and Victor (2000) do not explicitly mention age (or demographic factors other than population size and density) as being an important determinant. It could be useful research to calibrate Schafer and Victor’s model on the basis of differentiated population data (e.g. the number of people between 15 and 65 years old, since they are expected to be most mobile).

If we examine Schafer’s transport data (Schafer, 2001) we see that the relationship between passenger kms by car and the size of the population between 15 and 65 years old show less correlation than the relationship between passenger kms by car and total population size (It has to be noted that this correlation gives just a slight indication since we assume that mobility is only dependent on population size while we have seen that GDP is a strong determinant of mobility. The influence of age on mobility requires thus more attention in further research since it is generally known that people between 15 and 65 years old are more mobile than people below 15 or older than 65 years old.
Table 7-1). The WEU shows a negative correlation since the absolute number of people between 15 and 65 years old have been decreasing while the number of car kilometres has increased. Africa shows a higher correlation, though the difference is hardly significant (0.984 against 0.986).

It has to be noted that this correlation gives just a slight indication since we assume that mobility is only dependent on population size while we have seen that GDP is a strong determinant of mobility. The influence of age on mobility requires thus more attention in further research since it is generally known that people between 15 and 65 years old are more mobile than people below 15 or older than 65 years old.

Table 7-1: Correlation between car mobility and population size for 11 world regions and world as a whole

Correlation	NAM	LAM	WEU	EEU	FSU	MEA	AFR	CPA	SAS	PAS	PAO	WOR
Total population	0,974	0,995	0,981	0,989	1,000	0,997	0,984	0,863	0,965	0,968	0,959	0,993
Pop 15-65y	0,878	0,995	-0,825	0,972	0,980	0,996	0,986	0,294	0,957	0,954	0,893	0,991

8. Conclusions and recommendations for TIMER

The objective of this report was to review existing literature and models on transport to evaluate the quality of the current world transport models and to indicate possible improvements in the modelling of transport activity in the TIMER model. In this chapter we will present some conclusions with reference to these objectives. We will discuss the requirements of a transport model in the context of TIMER, indicate which of the models would be most interesting to incorporate in TIMER and, finally, indicate what activities would be required for doing so.

Requirements for modelling transport in the TIMER context

TIMER is a system-dynamics energy model aimed at assessing possible trends in energy demand and production in the medium (2020/2050) and long-term (2050/2100). The TIMER model is integrated in the Integrated Assessment Model IMAGE 2.2. The TIMER model is also intended to take an in-between position in the debate between top-down (= macro-economic) and bottom-up (= technology-oriented) energy models. It describes certain technologies fairly explicitly, incorporating information on the “physical” world (e.g. biofuels including assessments on land availability) but also includes an overall consistent framework for energy demand and supply. Energy demand in TIMER is modelled for five different sectors: transport, industry, households, services and others. The modelling is based on an assumption on activity changes, changes in structure (e.g. shifts to heavy industry) and autonomous and price-induced energy-efficiency improvement. This description is fairly well aggregated for all sectors. One reason for this is the relatively long time frame of the model and its global coverage – which poses limitations to the amount of detail that can be incorporated in a meaningful way.

We have concentrated on the ways in which the transport model of TIMER can be improved. Obviously, changes in the transport formulations should still be compatible with the overall objectives of TIMER and the way other parts of the model are formulated. Several requirements can be derived from this:

- transport modelling should be done at the level of the 17 world regions identified in TIMER (also demands relevant information for the model variables used in the transport model).
- transport modelling should be possible until 2100 and still produce meaningful information. Obviously, for long-term scenarios certain more detailed model variables might lose their meaning – but it should be still possible to use the more aggregated variables.
- transport modelling should not be too detailed in terms of modes and fuels. Nevertheless, in view of the relatively important role of transport in the growth of energy demand, a slightly more detailed formulation than that for other sectors may be acceptable.
- the model should be connected to information in TIMER for fuel prices (price-induced efficiency improvement; changes in fuel mix) and technology development (autonomous and price-induced efficiency improvement).
- the model should preferably allow for connections to bottom-up efficiency improvement estimates.
- the model should be described as a simulation model, rather than as an optimalisation model, and focus on the relevant dynamics and physical parameters (system-dynamics orientation).

- the transport modelling needs to encompass the complete transport sector and not only passenger transport.

Which is the most suitable model for improving current transport modelling in TIMER
From the previous sections, we conclude that Schafer and Victor's model in its current form seems to provide a framework that is the most interesting to adopt for the TIMER model. The use of the Zahavi constraints, in combination with population density and the assumption of path dependence, would seem to be a reliable base for good projections. The current limitation of not taking into account transport prices is now being elaborated upon by Schafer. Furthermore, prices have not shown a considerable influence on the demand for mobility, not even during the oil-price shock in the 1970s (IEA, 2000) (at the same time, prices have a much stronger influence on transport energy demand). The main reason for our conclusion confirming the attractiveness of using the Schafer and Victor model is that no other transportation model projecting future levels of passenger transport takes more determinants and reliable assumptions into account than the transport model, enhanced with prices, of Schafer and Victor.

What are the advantages of adopting (an extended version of) Schafer and Victor's model in TIMER?
The question whether Schafer and Victor's model produce better "outcomes" than the current TIMER formulation can, of course, hardly be tested. A much more important reason to adopt a more detailed transport model in TIMER is that it allows users to work with better variables that have a more empirical meaning than the aggregated indicators used at the moment. Instead of describing transport activity in terms of Joules, we are able to define transport activity as kilometres (and freight tonne kilometres). Consequently, technological improvements can also be more easily described in terms of energy savings per km or energy savings per hauled tonne kilometre. This enhanced comprehensibility is also desirable from the point of view of policy support: more specific policies can be assessed, and more specific conclusions drawn. Furthermore, a more detailed formulation allows for a better formulation of environmental problems more closely related to actual activity (like noise and congestion) can probably be obtained as well.

What are the possible disadvantages of adopting (an extended version of) Schafer and Victor's model in TIMER?
The advantages mentioned above are clearest in a more foreseeable future. But what is the added value of describing transport activity in more detail for the periods up to 2050/2100? In periods of 50 of more years, complete new transport modes could be introduced and whole new means of vehicle propulsion invented. Our society in 2100 is probably as different from our current society as the current one is from society 100 years ago. For such long-term assessments, more abstract formulations of transport energy demand and activity might be more attractive than more concrete descriptions. The detailed results of the transport submodel might therefore only be presented in medium-term scenarios.

As mentioned, there is also no reason to assume that the projections themselves will improve. If we consider that TIMER's current projections do not strongly deviate from other models (see Chapter 6), why would we want to change? It should be noted that the TIMER projections are closed to the projections of other models that describe the energy sector as a whole. At the same time, there seems to be a significant difference in the projection of the passenger transport energy consumption of Schafer and Victor's model. For 2020, Schafer projects a yearly passenger transport energy consumption of 51 – 62 EJ/year, which is much higher than the MT-scenario of the WEC, for instance. The latter, however, seems to be comparable to the TIMER scenarios. It is thus expected that significant differences will occur when Schafer and Victor's approach is adopted.

Required actions
It should be noted that Schafer and Victor's model is only used up to 2050 and that it takes into account only 11 world regions in contrary to the 17 of TIMER. An expansion of the model to 17 world regions will be necessary and a method will have to be developed to extend the modelling time to 2100. Furthermore, Schafer and Victor's model is a passenger transportation model and consequently does not project freight transport activity. TIMER will therefore also need to split the transport sector between passenger and freight transport. Dependent on the structure of the model of Schafer and Victor enhanced with prices, the TIMER model will have to be expanded with an additional database (or model) to be able to provide the newly adopted passenger model with the data required (tariffs, ticket prices, fuel prices).

In Azar *et al.* (2001), the passenger transportation model of Schafer and Victor was altered and re-calibrated with other input data so that it was able to project passenger transport activity and energy consumption for the year 2100. The freight modelling approach from World Energy Council (1998)was far more simplistic than the passenger transport model. But despite the simplistic representation of freight transport, this combined approach of Schafer and Victor's model with a simpler freight-transport model derived from researchers like Azar *et al.* (2001) could be the initial step to a better modelling approach. This would be subject to the condition that Schafer and Victor's model is accepted in the scientific world and that data will not constrain the extension from 11 to 17 regions.

A schematic representation of the above-mentioned adjustments and the resulting model structure is presented in Figure 8-1.

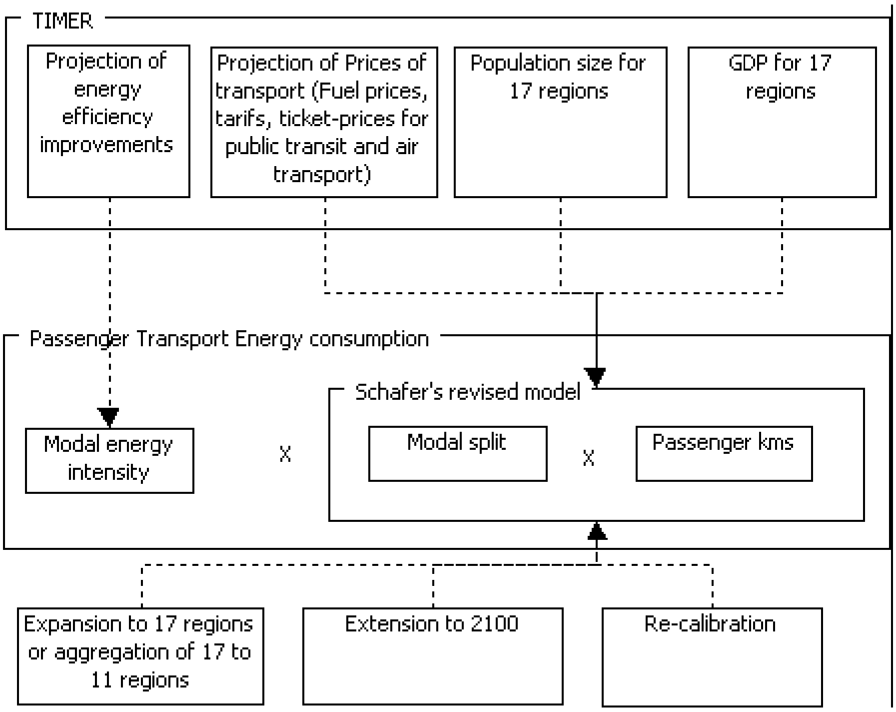

Figure 8-1 Schematic presentation of TIMER adjustments.

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Appendix 1: WEC 1995 model

Passenger cars

Fuel demand by cars is calculated from the following equation:

Car Fuel Demand = Car Stock x Vehicle Kilometres x Fuel Efficiency x Fuel Shares

Table A-1 Input variables to passenger car model (1992)

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
Car Stock (million)	161.05	164.84	48.46	18.00	18.02	24.61	10.02	24.70
Vehicle km per vehicle (km)	13,000	18,000	11,000	10,000	12,000	15,000	15,000	12,000
1/100 km	9	13	11	12	11	13	15	12

The relationship between GDP and car ownership is exponential below the saturation level of 250 per 1000 persons with an income elasticity of 1.3 (2.5 for Asia, FSU and CEE during the first 5 years), linear from 250 to 450, and logarithmic above 450. For each scenario, the relationships are somewhat altered according the in that scenario applied assumptions.

Table A-2 Total vehicle stock, in millions (2020)

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
GS	184.69	200.4	57.38	47.87	48.38	102.31	29.42	73.73
MT	213.97	229.14	78.71	54.77	48.46	168.99	31.12	83.07
MR	246.15	248.85	85.4	144.14	63.68	221.41	43.81	120.69

Table A-3 Average annual vehicle kilometres in 2020

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
GS	9,000	13,000	8,000	12,000	12,000	13,000	13,000	12,000
MT	10,000	14,000	9,000	13,000	12,000	15,000	13,000	12,000
MR	13,000	16,000	11,000	14,000	13,000	15,000	15,000	13,000

Table A-4 Average on the road fuel efficiency in 2020 (liters/100 km)

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
GS	4.98	7.19	6.08	6.63	6.08	7.19	8.29	6.63
MT	7.98	11.53	9.76	10.65	9.76	11.53	13.31	10.65
MR	7.09	10.24	8.66	9.45	8.66	10.24	11.81	9.45

Freight transport

Total fuel demand from the freight transport sector is calculated with the following formula:

Fuel demand = Total Freight Transport x Modal Share Road x Fuel Efficiency Road + Total Freight Transport x Modal Share Rail x Fuel Efficiency Rail

Freight transport is in principal linear related to GDP, however a temporary decoupling of this relationship is assumed so that freight intensity can be driven to different levels.

Table A-5 Initial road and rail freight activity values and energy intensity, 1992

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
Total freight, bn tonne km	1,335	3,270	351	4,480	255	2,240	160	820
Road	1,027	1,400	300	560	104	800	40	750
Rail	308	1,870	51	3,920	151	1,440	120	70
Freight Intensity, tonne km/USD	0.17	0.48	0.09	7.90	1.03	1	0.41	0.87
Fuel Eff. Road, KJ/tonne km	4,000	2,500	5,000	5,000	5,000	5,000	6,000	6,000
Fuel Eff. Rail, KJ/tonne km	350	260	350	350	350	400	400	600

Table A-6 Freight Transport Intensities, tonne km/GDP $92 (PPP)[20]*, 1995 and 2020*

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
1995	0.17	0.48	0.09	7.12	0.98	1	0.41	0.87
GS	0.15	0.43	0.08	3.43	0.66	0.95	0.41	0.87
MT	0.16	0.47	0.09	4.33	0.75	0.98	0.43	0.93
MR	0.18	0.51	0.1	5.23	0.93	1.14	0.46	0.99

Table A-7 Freight Transport Volumes in 2020, bn tonne km

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
GS	1,937	4764	587	3270	276	7250	454	2382
MT	2,202	5518	638	4275	326	8048	506	2653
MR	3,124	6983	858	8352	647	11505	682	3575

Table A-8 Freight Market Share for Rail

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
1995	23.04%	57.19%	14.53%	87.50%	59.22%	60.82%	70.68%	8.05%
GS	23.04%	57.19%	14.53%	68.10%	33.72%	55.25%	64.14%	7.30%
MT	17.79%	43.65%	10.69%	57.61%	25.28%	42.54%	42.78%	4.87%
MR	14.87%	38.79%	9.19%	41.16%	16.10%	30.65%	35.74%	4.02%

Table A-9 Fuel Efficiency for Trucks, KJ/tonne km, 1995 and 2020

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
1995	4,000	2,500	5,000	5,000	5,000	5,000	6,000	6,000
GS	2,700	1,688	3,375	3,207	3,207	3,375	4,050	4,050
MT	3,511	2,195	4,389	4,173	4,173	4,456	5,347	5,347
MR	3,080	1,925	3,580	3,660	3,660	3,850	4,620	4,620

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[20] PPP = Purchasing Power Parity, $92 = 1992 U.S. Dollar

Table A-10 Fuel Efficiency for Trains, KJ/tonne km, 1995 and 2020

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
1995	350	260	350	350	350	400	400	600
GS	236	176	236	270	270	270	270	405
MT	307	228	307	351	351	356	356	535
MR	270	200	270	308	308	308	308	462

Air transport

The modelling of air transport is based upon freight and passenger transport. Identical income elasticities have been assumed for air freight and passenger transport. The values vary with region and scenario but maintain the same value over the time span considered.

With the following formula the Air Transport Energy Demand is calculated:

Air Transport Energy Demand = Passenger Transport Volumes X Fuel Efficiency + Freight Transport Volumes X Fuel Efficiency

Table A-11 Air Freight and Passenger Activity + Fuel Efficiency, 1992

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
Passenger, bn pkm	369	826	170	149	11	293	41	88
Fuel Eff. Pass., KJ/pkm	2,000	2,500	2,000	3,500	3,500	2,500	3,000	3,000
Freight, bn tonne km	52	96	22	15	1	42	5	10
Fuel Eff. Freight KJ/tonne km	16,000	20,000	16,000	28,000	28,000	20,000	28,000	28,000

Table A-12 Air Transport Income Elasticities

	Europe	North America	OECD Pac	FSU	CEE	Asia	Africa	Latin America
GS	0.9	0.9	0.9	1.5	1.5	1.5	1.5	1.5
MT	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
MR	2	2	2	2	2	2	2	2

Table A-13 Annual Improvements in Aircraft Fuel Efficiency

	1995-2000	2000-2010	2010-2020
GS	2%	3.5%	1.5%
MT	2%	1.5%	1%
MR	2%	2%	1%

Table A-14 Scenario characteristics

Selected Megatrends	Markets Rule	Muddling Through	Green Shock
Economic Growth, OECD	2.8%	2.2%	2.0%
Economic Growth, ROW	5.2%	4.2%	4.0%
Oil Supply	Sufficient, moderate prices ($16/bbl)	Moderate, high prices (26$/bbl)	Abundant relative to demand, depressed prices ($12-13/bbl)
Environmental Concerns (global)	Low	None	High, CO_2 taxes implemented
Environmental Concerns (local), OECD	Moderate to high, wealth driven	Moderate to low	Very high
Environmental Concerns (local), ROW	Moderate, increasingly wealth driven	Low	Moderate, driven by Western initiatives and financial/technological aid
Regulation	Low levels, markets rule	Low, inertia and passiveness	Comprehensive environmental regulation
Lifestyle Changes	Rapid adoption of Western lifestyles in non-OECD with increased demand for mobility	Slower adoption of Western lifestyles in non-OECD, due to weaker economic growth	Some impact of green consumerism in the OECD area
Fuel efficiency	Increasing, because of high turn over in capital stock and rapid technological development	Moderate, following historical trends	Sharp increase, through environmentally driven price incentives and regulation
Alternative Fuels	Low penetration, due to weak competitive position	Low penetration, few government programs	Some penetration in the OECD, through environmentally driven price incentives and regulation

Appendix 2: Elasticities from Wohlgemuth (1998)

Table A-1 Long-term OECD transportation demand elasticities

	U.S.		Europe		Japan	
	Income	Price[21]	Income	Price	Income	Price
Distances travelled	0.88	-0.16	1.04	-0.71	1.12	-0.25
Total freight tonne-km/ton miles	1.00	-0.23	0.99	-0.21		
Truck share in freight		-0.04				
Truck tonne km	(1.13)	(0.11)	(1.37)	(-0.37)	1.38	-0.24
Air miles	1.75	-0.39				
Aviation fuel demand			1.35	-0.09	1.80	-0.025

Table A-2 Long-term OECD transportation demand elasticities using a consistent database

	U.S.		Europe		Japan	
	Income	Price	Income	Price	Income	Price
Vehicle kms (cars, light trucks)	1.04	-0.14	1.04	-0.71	0.85	-0.45

Table A-3 Short-term OECD transportation demand elasticities

	U.S.		Europe		Japan	
	Income	Price	Income	Price	Income	Price
Vehicle kms (cars, light trucks)	0.78	-0.04	0.23	-0.16	0.33	-0.02
Total freight tonne-km/ton miles	---	---	0.39	-0.08		
Truck share in freight		---				
Truck tonne km					0.88	-0.15
Air miles	1.75	-0.39	1.35	-0.04		
Aviation fuel demand					1.51	-0.02

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[21] See section 4.1.4.1 for the definition of “price”.

Table A-4 Long term non-OECD transportation (fuel) demand elasticities

	Approach[22]/endogenous variable[23]	Long term elasticities[24]	
		Income	Price
Mexico	TS/GSL	1.29 (GDP)	-0.21 (GSL)+0.09(DSL)
	TS/DSL	0.99 (GDP)	-0.08 (DSL)
	TS/AVG	1.72 (GDP)	-0.04 (DSL)
Brazil	TS/GSL per capita GSL including alcohol	1.01 (GDP per capita)	-0.26 (GSL per capita)
	TS/DSL	1.10 (GDP)	-0.10 (DSL)
	TS/AVG	0.88 (GDP)	NA
Other Latin America	CS	See Table A-19	(CRUDE)
South Africa	TS/GSL	1.28 (GDP)	-0.53 (GSL)
	TS/DSL	1.00 (GDP)	-0.20 (DSL)
	CS/AVG	See Table A-19	-0.15 (CRUDE)
Other Africa	CS	See Table A-19	(CRUDE)
Middle East	CS/vehicle stock per capita	0.32 (GDP per capita)	NA
	GSL per vehicle	0.99 (GDP per capita)	+0.25 (CRUDE)
	DSL per vehicle	0.89 (GDP per capita)	NA
	AVG per capita	0.95 (GDP per capita)	NA
China	TS/activity in transportation sector		
	Total passenger-km all modes	0.95 (GDP)	NA
	Total tonne-km all modes	0.91 (GDP)	NA
India	TS/activity in surface transportation		
	Surface passenger-km	1.70 (GDP)	-0.90 (GSL)+0.74 (DSL)
	Surface tonne-km	1.39 (GDP)	-0.07 (DSL)
	CS/AVG	See Table A-19	-0.15 (AVG)
East Asia	TS/GSL per capita	0.55 (car per capita)	-0.41 (GSL)
	CS/DSL per capita	See Table A-19	-0.25 (DSL)
	TS/AVG per capita	0.93 (GDP per capita)	-0.16 (AVG)
CEE	CS/GSL	See Table A-19	-0.6 (GSL)
	CS/DSL	See Table A-19	-0.25 (DSL)
	CS/AVG	See Table A-19	-0.15 (CRUDE)
FSU	CS		No price

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[22] TS=time series estimates; CS=cross-section estimates.

[23] GSL=gasoline consumption; DSL=diesel consumption; AVG=aviation fuel consumption

[24] In parentheses are the variables of the elasticities given, where GSL=gasoline consumption; DSL=diesel consumption; AVG=aviation fuel consumption and CRUDE=crude oil price.

Table A-5 Cross-section elasticities for non-OECD transportation fuel demand

Gasoline (GSL)	Income elasticity:	0.8	For Y>9000 U.S.$1987
		1.5	For Y>1000 U.S.$1987
		1.0	For Y>6000 U.S.$1987
	Price elasticity:	-0.6	With respect to gasoline price or
		-0.4	With respect to crude oil price
Diesel (DSL)	Income elasticity:	0.8	For Y>6000 U.S.$1987
		1.1	For Y>3000 U.S.$1987
	Price elasticity:	-0.2	With respect to crude oil price or
		-0.25	With respect to diesel price
Aviation fuels (AVG)	Income elasticity:	1.2	For Y>5000 U.S.$1987
		0.8	For Y>2000 U.S.$1987
	Price elasticity:	-0.15	With respect to crude oil price

Table A-6 Transport energy demand growth rates (% pa)

	1971-1993 Total	1993-2010 Transport	1993-2010 Gasoline	1993-2010 Diesel	1993-2010 Aviation fuels
North America	1.6	1.4	0.9	2.2	2.7
OECD Pacific	3.6	2.3	2.4	2.3	2.2
OECD Europe	3.0	2.0	1.4	2.2	3.1
OECD [25]	2.2	1.7	1.2	2.2	2.8
FSU/CEE	0.9	2.2	2.8	2.3	1.9
South-America	3.3	3.2	3.4	3.5	3.0
Africa	3.4	3.6	3.7	4.0	3.5
Middle East	9.9	3.3	2.9	3.8	2.6
East Asia	6.7	5.3	4.7	6.0	5.3
South Asia	3.6	6.4	7.6	6.6	4.4
China	11.8	5.6	6.6	7.7	8.8
Rest of the World	5.5	4.5	4.6	5.2	4.5
World	2.6	2.6	2.1	3.4	3.1

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[25] Excluding Hungary, Czech Republic, South-Korea and Poland

Appendix 3: Global energy model comparison

Table A-1 Total transport energy consumption projections various energy models[26]

Total Transport Energy Demand (EJ)	7	1971	1975	1980	1985	1990	1995	1997	2000	2010	2020	2030	2050	2100
TIMER A1b	Vries *et al.* (2001)	36	42	50	52	62	65	69	75	103	142	194	316	489
TIMER A2	Vries *et al.* (2001)	36	42	50	52	62	65	69	75	96	120	145	211	433
TIMER B1	Vries *et al.* (2001)	36	42	50	52	62	65	69	74	94	114	136	179	190
TIMER B2	Vries *et al.* (2001)	36	42	50	52	62	65	69	74	96	118	143	188	291
IEA WEO 2000 (EJ)	IEA (2000)	35						69			120			
POLES	Criqui (2001)							68	73	87	104	122		
WEC 1995 GS	World Energy Council (1995)					58					64			
WEC 1995 MT	World Energy Council (1995)					58					122			
WEC 1995 MR	World Energy Council (1995)					58					166			
WEC 1998	World Energy Council (1998)						80				125			
MESSAGE-B2 (IIASA)						64			76	91	110	136	179	241

Table A-2 Primary Energy demand from 1971 - 1995

Primary Energy Demand (EJ) Working Group III IPCC (2000)	1971	1975	1980	1985	1990	1995	AAGR 1971-1990	AAGR 1990-1995
Industrial	88	98,5	113,5	119,8	129,4	130,8	2,1%	0,2%
Buildings sector	61,5	70,3	81,3	92,6	105,6	109,8	2,9%	0,8%
Agriculture	4,4	5,1	6,1	7,5	8,9	9,3	3,8%	0,8%
Transport	37,5	43,6	50,1	54,4	63,3	69	2,8%	1,7%
Total	191,4	217,5	251	274,2	307,2	318,8	2,5%	0,7%
Fraction transport of total	0,196	0,200	0,200	0,198	0,206	0,216		

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[26] *See*

Table 5-3 for modes covered per model

Appendix 4: Schafer and Victor’s transport data and dependency ratios from IMAGE 2.2

Table A-1 Dependency ratios[27] *17 world regions*

t	Canada	USA	Central America	South America	Northern Africa	Western Africa	Eastern Africa	Southern Africa	OECD Europe
1970	0,632	0,612	0,950	0,834	0,941	0,906	0,950	0,900	0,625
1971	0,615	0,601	0,944	0,825	0,933	0,911	0,952	0,899	0,625
1972	0,597	0,590	0,938	0,815	0,924	0,915	0,955	0,899	0,624
1973	0,580	0,580	0,933	0,806	0,915	0,919	0,958	0,898	0,624
1974	0,563	0,569	0,927	0,796	0,906	0,924	0,961	0,898	0,623
1975	0,545	0,558	0,921	0,787	0,898	0,928	0,963	0,897	0,623
1976	0,533	0,551	0,908	0,777	0,888	0,930	0,966	0,897	0,615
1977	0,520	0,544	0,896	0,767	0,879	0,933	0,969	0,896	0,607
1978	0,508	0,536	0,883	0,757	0,870	0,936	0,971	0,895	0,600
1979	0,496	0,529	0,870	0,747	0,861	0,938	0,974	0,895	0,592
1980	0,483	0,522	0,858	0,737	0,852	0,941	0,977	0,894	0,584
1981	0,480	0,520	0,841	0,728	0,845	0,943	0,977	0,894	0,571
1982	0,476	0,519	0,825	0,720	0,838	0,945	0,978	0,893	0,557
1983	0,473	0,517	0,808	0,711	0,831	0,947	0,979	0,893	0,544
1984	0,469	0,516	0,792	0,702	0,824	0,948	0,980	0,893	0,530
1985	0,466	0,514	0,775	0,693	0,817	0,950	0,981	0,893	0,516
1986	0,468	0,517	0,761	0,684	0,810	0,951	0,978	0,891	0,515
1987	0,471	0,520	0,747	0,675	0,803	0,951	0,976	0,889	0,513
1988	0,474	0,523	0,733	0,667	0,796	0,951	0,973	0,887	0,512
1989	0,477	0,526	0,719	0,658	0,790	0,951	0,971	0,885	0,510
1990	0,480	0,529	0,705	0,650	0,783	0,952	0,968	0,884	0,509

Table A-2 Dependency ratio 17 world regions

t	Eastern Europe	Former USSR	Middle East	South Asia	East asia	South East Asia	Oceania	Japan	World
1970	0,544	0,581	0,952	0,855	0,819	0,864	0,665	0,459	0,782
1971	0,540	0,575	0,942	0,851	0,812	0,857	0,658	0,462	0,777
1972	0,536	0,569	0,932	0,847	0,805	0,849	0,651	0,464	0,773
1973	0,532	0,563	0,921	0,842	0,797	0,842	0,644	0,466	0,769
1974	0,528	0,556	0,911	0,838	0,790	0,834	0,637	0,469	0,764
1975	0,524	0,550	0,901	0,834	0,783	0,827	0,630	0,471	0,760
1976	0,528	0,549	0,898	0,827	0,769	0,817	0,625	0,474	0,753
1977	0,531	0,547	0,894	0,821	0,756	0,807	0,620	0,476	0,746
1978	0,535	0,546	0,890	0,814	0,742	0,797	0,614	0,479	0,740
1979	0,538	0,544	0,887	0,807	0,729	0,787	0,609	0,481	0,733
1980	0,542	0,542	0,883	0,801	0,716	0,777	0,604	0,483	0,727
1981	0,541	0,541	0,883	0,794	0,697	0,767	0,601	0,481	0,719
1982	0,539	0,539	0,884	0,788	0,679	0,758	0,598	0,478	0,711
1983	0,538	0,537	0,884	0,782	0,661	0,749	0,594	0,476	0,703
1984	0,537	0,535	0,884	0,775	0,642	0,739	0,591	0,474	0,695
1985	0,536	0,533	0,885	0,769	0,624	0,730	0,588	0,471	0,687
1986	0,535	0,535	0,884	0,762	0,608	0,721	0,586	0,467	0,681
1987	0,534	0,537	0,883	0,756	0,592	0,712	0,583	0,463	0,675
1988	0,532	0,539	0,882	0,749	0,575	0,704	0,581	0,460	0,669

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[27] Ratio: Number of persons between 15 and 65 years old / Total population

1989	0,531	0,542	0,881	0,742	0,559	0,695	0,579	0,456	0,663
1990	0,530	0,544	0,880	0,736	0,543	0,686	0,576	0,452	0,657

Table A-3 Historical car mobility 11 world regions (in billion pkms)

bpkm car	NAM	LAM	WEU	EEU	FSU	MEA	AFR	CPA	SAS	PAS	PAO	WOR
1970	3216211	266745	1663357	81324	43963	109487	321177	311	28346	48630	317111	5829925
1971	3399490	299593	1805167	92652	60384	124072	340593	374	30694	51399	356453	6274963
1972	3602559	327442	1910848	104591	76593	141785	363744	440	33176	55368	377075	6695218
1973	3698932	361212	1953405	117994	92576	153209	381415	466	35519	60631	391643	6929840
1974	3571085	403096	2036089	134154	108345	164521	405645	377	37968	66996	405397	7001398
1975	3674925	472940	2103729	150123	123922	176913	434188	411	40380	73049	432337	7334607
1976	3840555	509389	2176747	166554	137490	189679	464425	629	43375	78244	442947	7686548
1977	3959505	557852	2274676	183197	150867	203343	488381	854	46489	87925	453551	8027957
1978	4088974	629474	2388011	200561	163993	218328	513894	1085	49465	100414	489710	8445389
1979	3965999	670966	2415203	207182	176942	235254	532987	1322	52630	107566	517851	8476675
1980	3950564	729978	2469090	213300	189684	253846	550273	1567	55784	116621	523215	8635806
1981	4009180	790760	2482320	218975	206390	272361	576437	1703	58969	125428	534385	8842833
1982	4122224	817426	2511746	223537	222805	295140	610412	2035	63975	138584	557570	9124313
1983	4219034	823067	2542034	230086	238969	317275	635145	2018	71531	153146	575849	9353640
1984	4290261	834968	2648189	234638	254866	341498	669433	1949	79211	166298	585118	9637081
1985	4390651	864367	2646619	236848	270520	357744	693790	2469	85147	177794	607428	9866693
1986	4506454	930815	2789688	246550	286502	370166	701172	2702	89741	195504	625855	10264571
1987	4597919	955862	2936151	255476	302670	383428	707823	3471	95487	209775	688429	10644538
1988	4893605	1047561	3096536	264134	318415	397720	720079	5213	113728	234667	738044	11335960
1989	5027550	1082638	3277583	275397	334969	412923	732922	6769	126436	269403	794158	11837333
1990	5116060	1125520	3357480	295973	352472	428919	743584	7707	140780	309582	816661	12186879

Source: Schafer (2001)

Appendix 5: Freight transport energy demand modelling in Azar *et al.* (2001)

Freight transport energy demand is projected with freight activity intensities (tonne km/GDP) and economic growth (GDP).The intensities are calculated from values for 1995 World Energy Council (1998). These initial freight activity intensities reflect differences in demographic patterns as well as industrial structure and income level. One assumption determines the change of activity intensities: the income elasticity for freight transport is set to –0.5 for all regions and all time periods. This means that if the per capita GDP grows with 2%, the freight activity intensity decreases by 1%.
The modal split of continental freight is determined by the assumption that road and air transportation will continue to grow faster than rail and water transportation (a.o. World Energy Council (1998)).
The author assumes that the shares of rail and water transport (expressed as the number of tonne kms hauled) decrease by 0.5% per year in all regions. Road and air transport shares increase proportionally to their initial values.
In the resulting scenario (from 1990-2100) freight transport per capita increases about two times while the average income grows by a factor four. Intercontinental ocean transport dominates but road transport has the highest relative growth rate. Road transport grows by a factor six, air and ocean transport by a factor four and continental water and rail doubles.

The energy intensities in 1990 are calculated from figures given for 1995 in World Energy Council (1998). The efficiency improvements of the energy intensities are stated in Table A-26.

Table A-1: Freight energy intensities improvements (%/year)

Transport mode	Efficiency gain
Road	0.7
Continental water	0.4
Ocean	0.4
Air	1-2 (1990-2020) and 0.7 (2020-2100)
Rail	0.4

The resulting energy intensities are presented in Table A.27.

Table A-2: Energy intensities in freight transportation (MJ/tonne km)

	1990	2100
Air	4.5	2.2
Road	3.6	1.8
Rail	0.50	0.32
Water	0.48	0.32
Continental average	1.8	1.3
Ocean	0.20	0.13

Appendix 6: Region definition

Table A-1 Region description as used in Schafer and Victor's model

North America (NAM)	Canada, USA
Pacific OECD (PAO)	Australia, Japan, New-Zealand
Western Europe (WEU)	European Community, Norway, Switzerland, Turkey
Former Soviet Union (FSU)	Russia, Ukraine
Eastern Europe (EEU)	Bulgaria, Hungary, Czech and Slovak Republics, former Yugoslavia, Poland, Romania
Latin America (LAM)	Argentina, Brazil, Chile, Mexico, Venezuela
Middle East and North Africa (MEA)	Algeria, Gulf States, Egypt, Iran, Saudi-Arabia
Sub-Saharan Africa (AFR)	Kenya, Nigeria, South-Africa, Zimbabwe
Centrally Planned Asia (CPA)	Bangladesh, India, Pakistan
South Asia (SAS)	Indonesia, Malaysia, Philippines, Singapore, South-Korea
Other Pacific Asia (PAS)	Taiwan, Thailand