ICCS: INSTITUTE OF COMMUNICATION AND COMPUTER SYSTEMS

Energy-Economy-Environment Modeling Laboratory E3M - Lab

PRIMES-TREMOVE transport model v3

Model description

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1. Introduction

The PRIMES-TREMOVE Transport Model projects the evolution of demand for passengers and freight transport by transport mode and transport mean, based on economic, utility and technology choices of transportation consumers, and projects the derived fuel consumption and emissions of pollutants. Operation costs, investment costs, emission costs, taxes and other public policies, utility and congestion influence the choice of transportation modes and means.

The mathematical structure of the PRIMES-TREMOVE is considerably enhanced. It is essentially a dynamic system of multi-agent choices under several constraints, which are not necessarily binding simultaneously. Part of the model (e.g. the utility nested tree) was built following the TREMOVE model. Other parts, as for example the component on fuel consumption, follow the COPERT model.

- Various policies and energy and environment related issues may be studied including:
- Pricing policies, e.g. subsidies and taxes
- Technology diffusion and infrastructure
- Development of new transport fuels (e.g. bio-fuels, hydrogen, electricity, etc.)
- Climate change policies (e.g. carbon tax, ETS)

The model can either be used as a stand-alone model or may be coupled with the rest of the PRIMES energy systems model. In the later case the integration with the PRIMES model enhances the dynamic character of the model, since the interaction of the different energy sectors is taken into account in an iterative way.

2. Model structure

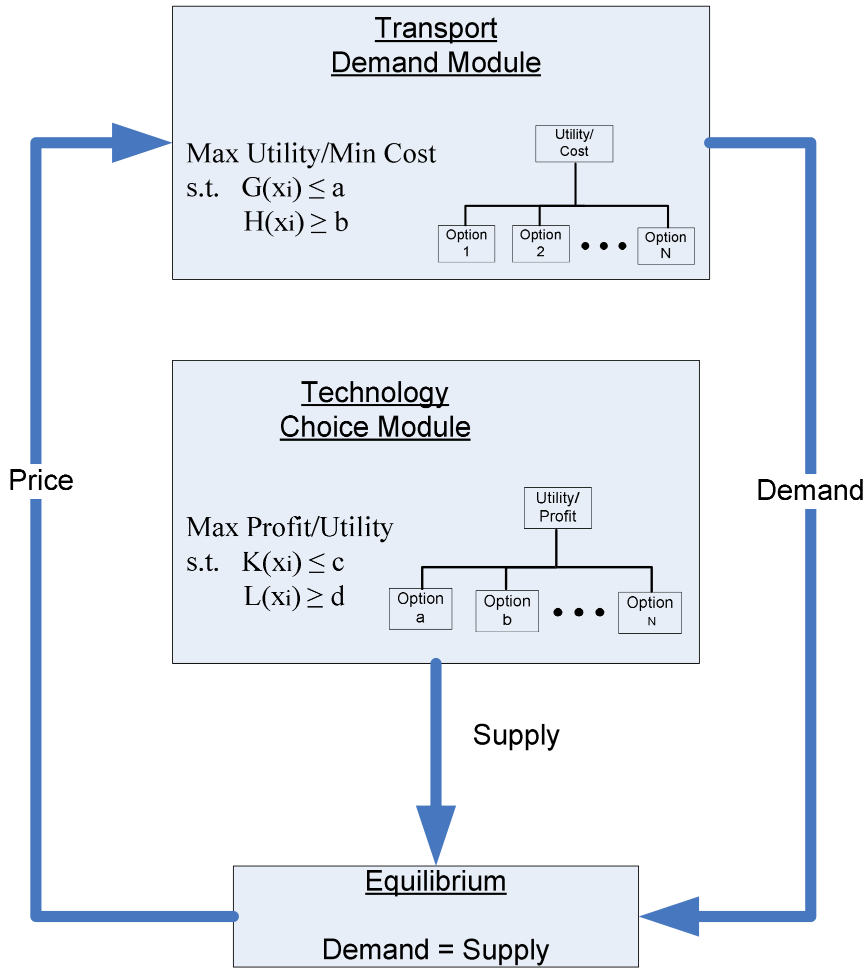
The model consists of two main modules, the transport demand allocation module and the technology choice and equipment operation module. The two modules interact with each other and are solved simultaneously.

The transport demand module simulates decisions regarding allocation of transport activity to the various modes, identifying transport service by mode of transport for both individuals and firms. The decision process is simulated as a utility maximisation problem with budget and other constraints in the case of the individual private passenger and as a cost minimisation problem in the case of firms.

The technology choice module determines the vehicle technologies (generally the transportation means) that will be used in order to satisfy each modal transport demand. It also enables the computation of energy consumption and emissions of pollutants from the use of the transportation means. The choice of technology is generally the result of a discrete choice problem in which consideration of cost is taken into account.

Both modules are dynamic over time, simulate capital turnover with possibility of premature replacement of equipment and keep track of equipment technology vintages.

The simulation of the transport market is formulated as a simplified Equilibrium Problem with Equilibrium Constraints (EPEC) transformed into a single Mixed Complementarity Problem (MCP). The transport demand module and the technology choice module are solved simultaneously in one single mathematical model, using the MCP algorithm PATH in GAMS. As the model is a single complementarity problem, it can handle overall constraints, for example to reflect environmental restrictions, the dual variable of which influence the endogenous choices of individuals and firms simulated by the model.



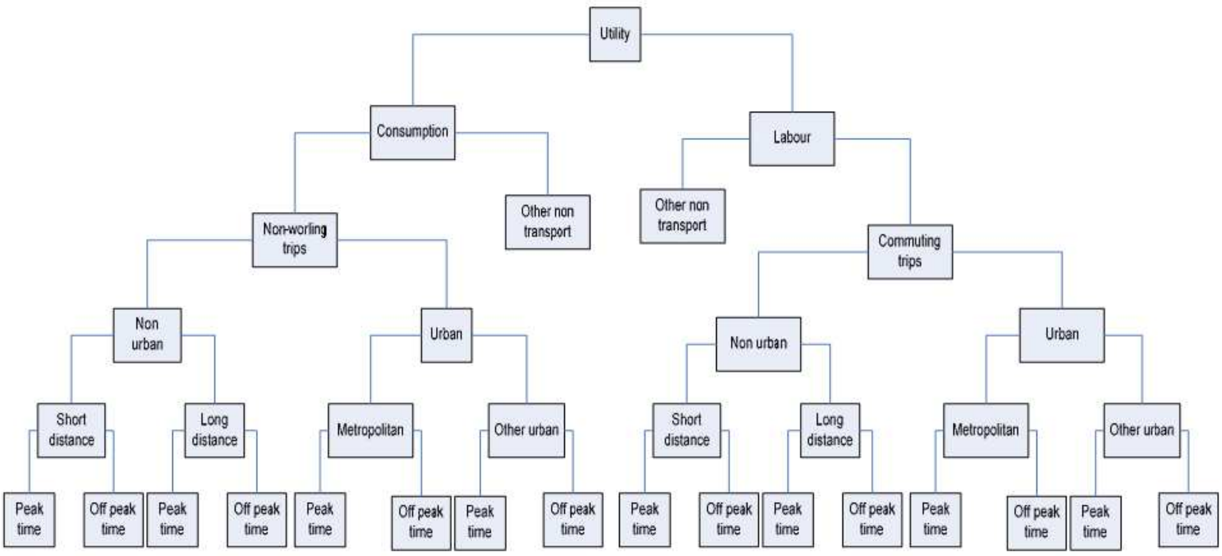
2.1.The transport demand module

The transport demand module simulates the decision process of the representative agent regarding the choice of transport activity. There is a distinction between private passenger transport and transport related to direct economic activity, such as transportation of commercial products and business trips. This distinction is triggered by the differences in the decision process between the individual passenger deciding on his/her own way of transport and the decision of a firm regarding budget allocation on logistics expenditures.

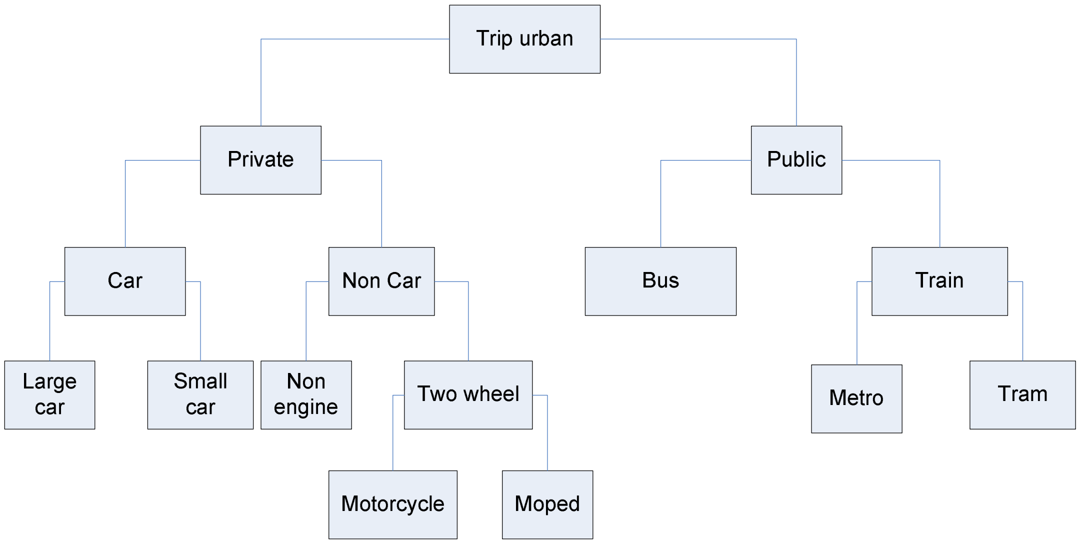
In passenger transport the representative individual, i.e. the passenger, is seeking to maximise a general utility function subject to a budget constraint that represents the total income. The cardinal expression of the individual's utility is assumed to be determined by modal transport cost, an individual's income and expenditure characteristics as well as historical behavioural features. The decision process of the private passenger is represented by a nested utility CES function, which involves also non transport spending.

This nested utility CES function which represents demand is articulated in the form of a utility tree. The top level of the tree is a node which denotes the overall utility. This node is then subdivided into other nodes which formulate the next (lower) level of the utility tree. All the nodes of the utility tree represent utility components which are defined through a function of the nodes of the lower level. The lowest level of the tree comprises of the elementary utility components which represent activity through different modes of transportation.

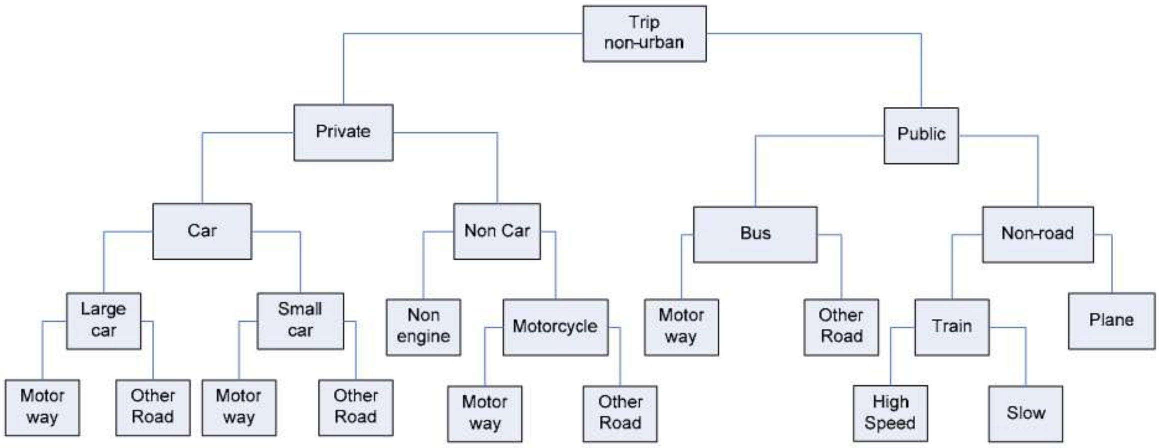
Initially the individual is deciding between the modal transport choices, i.e. whether to make a trip or not, the geographical and temporal identification of the trip etc. Each branch of the initial decision tree is further subdivided into several branches representing various modal choices. Two general decision processes of this type are identified depending on the geographical identity of the initial modal choice, namely urban and non-urban decision trees. The result of this secondary decision process is a more detailed modal identification of the agent's decision up to the level of the choice of general vehicle (mean) category.



Private passenger primary decision tree

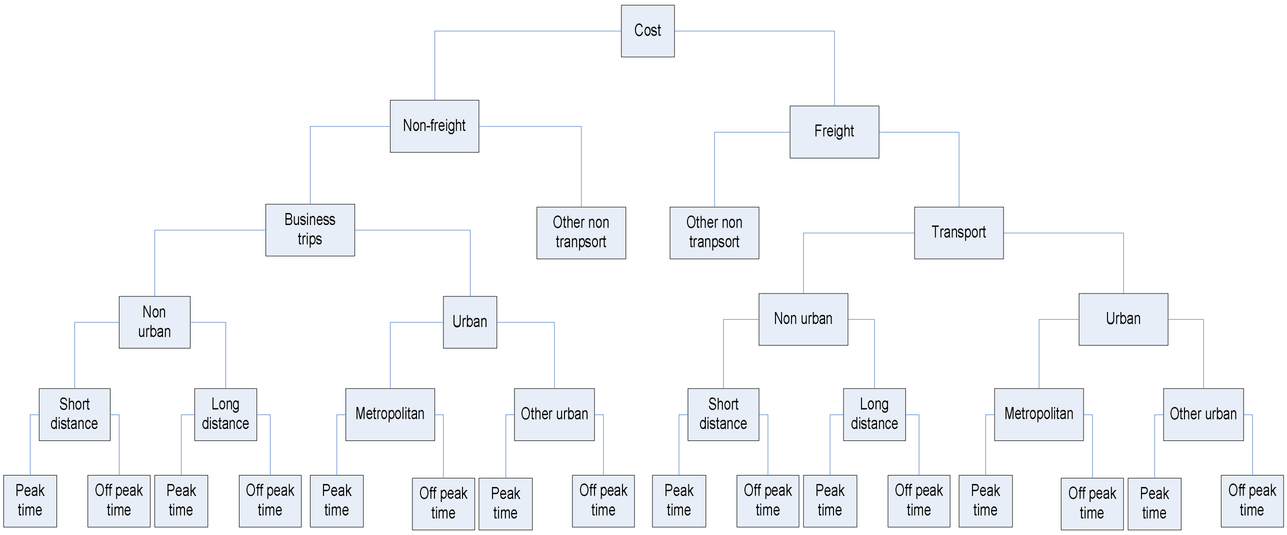


Private passenger secondary decision tree on urban transport

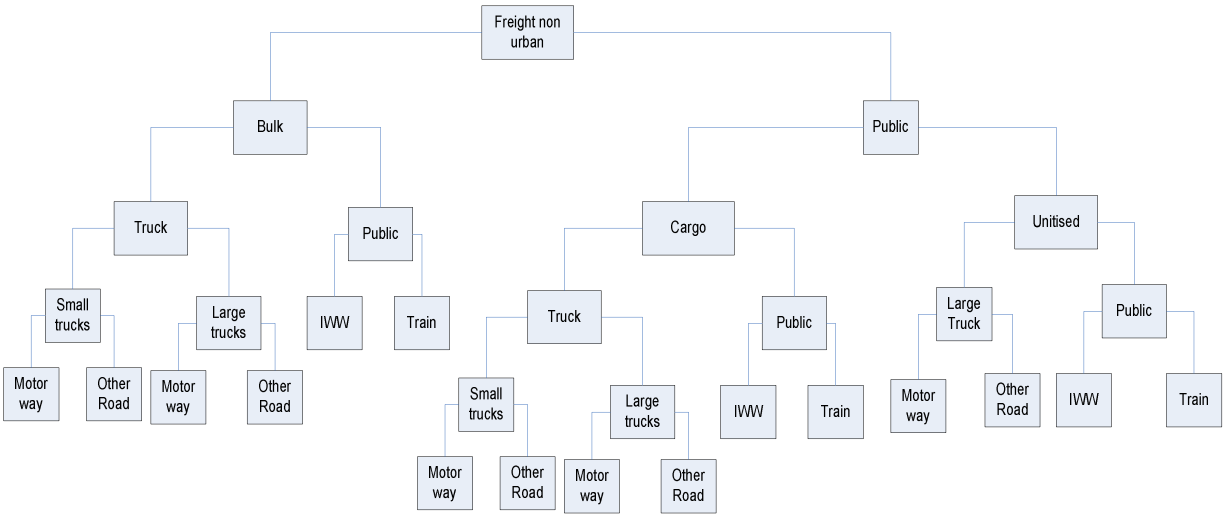


Private passenger secondary decision tree on non-urban transport

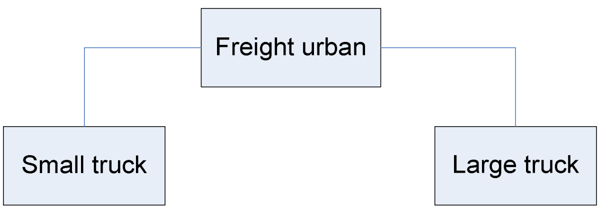
In a similar way the representative firm seeks to minimise total cost of satisfying its transport needs either regarding transportation of goods or business trips. The overall decision process of the firm is modelled as a nested CES cost function. The secondary decision process regarding the modal choice of business trips is similar to the decision process of the private passenger therefore they are not shown separately. As regards freight transport a representative secondary decision process is represented including all relevant modes of freight transportation.



Firm's primary decision tree



Firm's secondary decision tree on non-urban freight transport



Firm's secondary decision tree on urban freight transport

2.2.Generalised Price of Transportation

The decision of each individual or firm depends on preference characteristics, described by the elasticities of the CES functions, as well as on the endogenously defined "*generalised price of transportation*", which differs among the various modes of transportation.

In the case of private transportation, (i.e. personal cars and motorcycles for individual passenger and business trips as well as road vehicles for freight transport) the generalised price of transportation corresponds to total perceived costs of satisfying transportation demand at the level of each transport mode. These costs depend on actual cost of transportation as well as on the cost of time (travel time and congestion). Actual transport cost consists of:

- the capital cost of the vehicles, annualised by a subjective discount rate inclusive of risk premium
- fixed cost that includes annual maintenance, insurance, registration, etc.
- variable cost such as fuel expenses
- taxes and subsidies

Given that the endogenously defined vehicle stock satisfies the relevant modal transport demand (i.e. private cars satisfy all geographical and temporal modes of road transport) based on fixed annual utilisation indices, the aforementioned costs refer to the effective vehicle technology mix that serves each transport mode, which is endogenously determined by the model.

In the case of public transport (both for private passengers and for firms) the generalised price of transportation currently represents the sum of the average operational cost of the representative public transportation supplying firm and the cost of time. Average cost pricing of public transportation services is chosen because of the increasing returns to scale prevailing in this sector and because often public transportation forms incur budget deficits.

Average operational costs include the cost of the purchase and maintenance of the transport vehicle fleet, fuel cost, labour, taxation etc. Public transportation ticket prices are determined by using a Ramsey-Boiteux formulation which defines ticket prices by consumer type so as to recover total cost of the transportation service.

The technology choice model uses data reflecting the technical-economic characteristics of various vehicle technology and transportation means. The technology mix is endogenous to the model; hence the generalised price of transportation results from an interaction between the demand and the technology choice modules.

Cost of time is expressed as the product of travelling time (in hours/km) times the value of time (in €/km) and represents the value of travel time which differs between the individual passenger and the firm, and depends on temporally and geographically differences between transport modes. Travel time is directly influenced by traffic congestion and in the case of road transport a congestion function is used to calculate it. As for public transport, cost of time also includes waiting time which is determined too by a congestion function.

Travelling time for non-road transport is exogenously defined, taking into account average mileage and speed.

2.3.The technology choice module

The technology choice model defines the structure of the vehicle fleet that is optimum to deliver the transportation service as demanded for by the transport demand module. The technology mix and its operation is determined and so the model computes actual transport costs, energy consumption and pollutant emissions. The technology choice model is very detailed for road and rail transport, and less detailed for inland navigation and air transport.

2.3.1. Road transport

For road transport the actual vehicle stock is split into several vehicle types, and categories including passenger cars, motorcycles and mopeds, busses and coaches, light and heavy duty trucks. Different vehicle technologies and vintages depending on consumption, fuel type and emission standards are identified.

The calculation of the technology shares depends on total travel costs including purchase cost, fixed cost (maintenance, registration and insurance costs), fuel cost and time cost. The model includes all the technology classifications presented in Table 1 ranging from conventional ones complying with the EU emissions standards (EURO V, EURO VI) to alternative ones powered by compressed natural gas, biofuels, hydrogen and electricity. The shares of new conventional vehicle technologies have to comply with European emissions legislation which means that the new car registrations in 2010 for example, cannot comprise of EURO II gasoline cars.

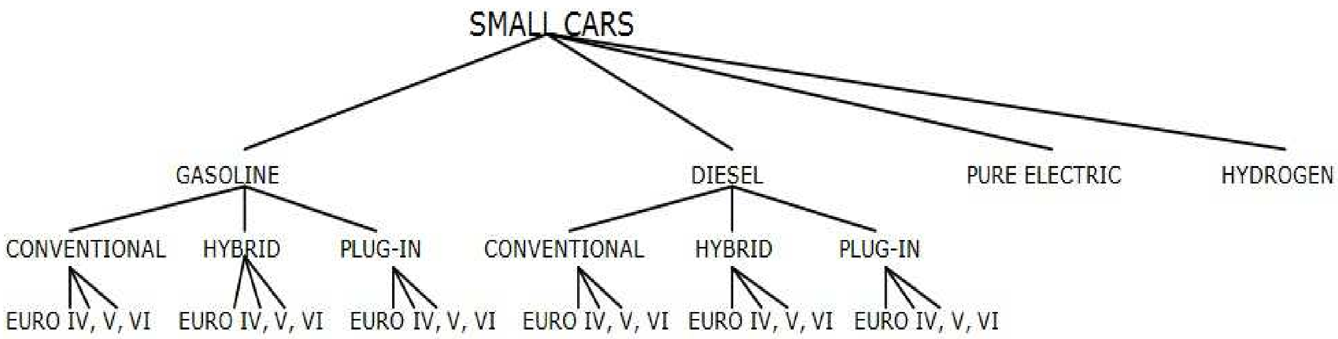
Vehicle technologies in the road transport sector using electricity as fuel have been fully incorporated into the Technology choice module. More specifically, as far as passenger cars and light duty vehicles are concerned, hybrid, plug in hybrid and pure electric powertrain technologies have been included into the choice Model.

Hybridisation of heavy duty trucks and urban busses has also been taken into consideration as an option for future freight and passenger transportation. The costs of new technologies are assumed to evolve dynamically, according to a learning curve which depends on cumulative production, reflecting economies associated with mass production. Such a learning curve is also assumed for batteries.

Decision making process is also influenced by the range provided by each vehicle technology and the availability of infrastructure; these features are particularly important when new fuels or new technologies enter the market.

Conventional technologies like ICEs do not have range limitations whereas battery and fuel cell electric vehicles do. This feature has been explicitly taken into account in the modelling approach of the choice of new vehicle technologies. The consumer upon the decision phase will certainly be in favour of vehicle technologies that will not pose range limitations. On the other hand, vehicles with limited range are endogenously penalised and the perceived costs to the consumer will increase due to loss of utility.

The choice of new vehicle technologies is based on the discrete choice theory and is modelled via decision trees. For each vehicle category (i.e. small, medium and big cars, light and heavy duty vehicles, busses, coaches and motorcycles) has been developed a decision tree. For illustrative reasons, the structure of the choice model for small cars is presented below:



In the above decision tree, consumer's behaviour is modelled as if choices between alternatives are made sequentially. For instance in the small car decision tree, the consumer is assumed to choose first between a diesel, a gasoline, an electric or hydrogen car. Once the consumer has made that choice, the next choice is between a conventional, a hybrid or a plug-in hybrid car. Thus, the latter choice is conditional upon the decision on the first node. Consumer's choice at each level is based on the concept of minimizing the aforementioned total transportation cost.

In general, the choice of new vehicle technologies is simulated using the following modified Weibull function:

$$sh_{j,t} = \frac{w_{j,t} * C_{j,t}^{-\gamma}}{\sum_j w_{j,t} * C_{j,t}^{-\gamma}}$$

where $sh_{j,t}$ refers to the share of the vehicle technology in a given year (i.e small car, gasoline, conventional EURO V or EURO IV), w is the "maturity factor" of the specific vehicle technology which is used to simulate technology availability as well as consumer preferences, γ denotes elasticity of substitution between the vehicle technologies and C is the annualised travelling cost attributable to each vehicle technology used.

Once the shares of the vehicle technologies are allocated, the shares of vehicle types need to be calculated (i.e. small car conventional gasoline versus small car hybrid gasoline). The shares are calculated according to the following function:

$$sh_{k,t} = \frac{w_{k,t} * IV_{k,t}^{-\gamma}}{\sum_k w_{k,t} * IV_{k,t}^{-\gamma}}$$

where $sh_{k,t}$ refers to the share of the vehicle type in a given year (i.e. small car, gasoline), w is the "maturity factor" of the specific vehicle type, γ is an elasticity of substitution between vehicle types and IV is calculated according to the mapping between each vehicle type shares and vehicle technologies as in the consumer's selection.

The calculation of IV is as follows:

$IV_{k,t} = \sum_j C_{j,t} * sh_{j,t}$

A vintage model with possibility premature scrapping has been formulated for vehicle turnover simulation. The model takes into account existing fleet structure and exogenously defined scrapping rates of vehicles based on calibrated Weibull distributions (for each country). The probability of a vehicle of type *k* with vintage *v* (year of first registration) to be in service in time *t* > *v* (termed surviving probability $SP_{k,t}$) is given by the following modified, two parameter Weibull reliability function:

$$SP_{k,t}(t-v) = \exp \; -\left[\left(\frac{(t-v)+F(t-v)_k}{T_k}\right)^{b_k}\right]$$

$$with\ SP_{k,v} \equiv 1$$

where $t - v$ denotes the age of the vehicle $F_k(v - t)$ is the failure steepness for vehicles of type *k* and T_k is the characteristic lifetime of vehicle of type *k*. Parameters $F_k(t - v)$ and T_k are estimated based on available data on vehicle fleet characteristics. The choice about whether to satisfy activity with existing or with new vehicles is not exogenously predetermined but is endogenous depending on relative costs and utilities.

2.3.2. Rail transport

A similar discrete choice methodology is formulated for determining the structure of the train fleet, which distinguishes between metro, tram, urban and non-urban trains. Choice of new types of rail transport is simulated through a logistic share function that depends mainly on total operational costs, taken into account capital costs, fuel consumption, emissions etc. The pre-existing rail infrastructure is taken into account through an aggregate indicator and influences the degree of renewal of the train fleet.

2.3.3. Air transport

For air transport, there exist three technologies indicating the potential technology progress of the sector. A conventional one baring current technological characteristics such as fuel consumption and emission factors, an improved and an advanced technology with better efficiencies and lower emission factors but with higher purchase costs.

In addition, as far as aircraft activity is concerned, it is discriminated into 5 distance classes depending on the trip length, according to TREMOVE database.

Each distance class is further disaggregated into the three aforementioned technologies.

Airplane distance classes
< 500
500 - 1000
1000 - 1500
1500 - 2000
>2000

2.4. Energy consumption and emissions

Consumption of transport fuels is endogenously determined by the model and is subject to environmental policy constraints. For road transport, fuel consumption and emissions of non-CO_2 pollutants are calculated by using the COPERT methodology. The computation covers a wide range of pollutants including NOx, CO, PM, CH_4, Non-Methane VOCs, N_2O, NH_3 and heavy metals.

The COPERT methodology enables calculation of fuel consumption of road vehicles as a function of their speed, which is determined by the endogenously calculated travelling time, the average mileage of trips per type of road transport mode, the occupancy factor for passenger trips and the load factor for freight transportations. The complete COPERT methodology has been integrated into the model providing a strong analytical tool for the calculation of the consumption of various fuels and consequent calculations of costs. For the technology choices not included in COPERT other data sources have been used such as results of the SAPIENTIA project. The calculation of fuel consumption for hybrid vehicles has been modelled in such a way that takes into account the region in which the vehicle is moving. For urban regions the fuel savings are significantly higher than in non urban ones because of the traffic congestion and the slower average speeds that lead to more braking and thus to more energy regenerated by the hybrid powertrain. As far as plug-in hybrid cars are concerned, they operate both as pure electric vehicles and as hybrids. The electric operation depends on the battery capacity which indicates an average all electric mileage between charges. When the battery supplies have been depleted, the vehicle switches to a hybrid mode burning conventional fuel. Pure electric vehicles have a single all electric operation and are equipped with high capacity batteries. Electricity consumption for plug-in hybrids and pure electric vehicles is being calculated using suggested efficiency figures from IEA and Argonne National Laboratory from the U.S. DOE. For rail, inland navigation and air transport, average mileage and specific fuel consumption factors are used for calculating fuel consumption and CO_2 emissions.

3. Model improvements compared to TREMOVE

Several model enhancements were made compared to the standard TREMOVE model, as for example for the number of vintages (allowing representation of the choice of used cars) for the technology categories which include vehicle types using electricity from the grid and fuel cells. The model also incorporates new fuels, such as biofuels (when they differ from standard fossil fuel technologies), LPG and methane fuels. Representation of infrastructure for refuelling and recharging are among the model refinements, influencing fuel choices. A major new model enhancement concerns the inclusion of heterogeneity in the distance of stylised trips. The previous version of the model was considering a homogenous average distance trip for each category of trip. The new version considers that the trip distances follow a distribution function with different distances and frequencies. The inclusion of heterogeneity was found to be of significant influence in the choice of vehicle-fuels especially for vehicles-fuels with range limitations.

PRIMES-TREMOVE transport model is linked with the overall PRIMES model to get fuel prices, electricity and hydrogen prices, as well as specification of blended fuels, including biofuels. The transport model results are conveyed to the entire PRIMES model for further life cycle evaluations of energy supply, resources, prices, costs-investment and emissions. The possibilities and the optimal configuration of the biomass and biofuels production system are assessed using the dedicated PRIMES-Biomass Supply Model which is also linked with the core PRIMES model and the transport model, taking from them demand figures and conveying to them bio-energy commodity prices. Externality costs and benefits (e.g. lifecycle emissions related to biomass and biofuels production) are evaluated through the PRIMES-Biomass Supply and the core PRIMES models.

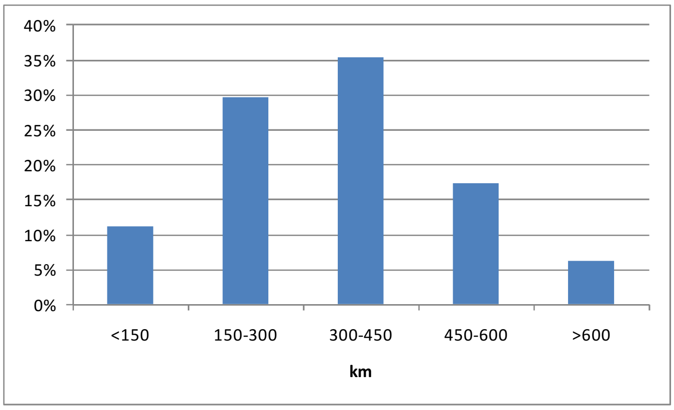
Infrastructure development and costs are included in the model cost structure, e.g. an increase in electricity demand may induce an increase in grid investments. Refuelling and recharging infrastructure is treated specifically in the PRIMES-TREMOVE transport model. Availability of such infrastructure influences the vehicle-fuel choices.

3.1.Range limitation and refuelling infrastructure density

An important new feature (compared to TREMOVE) developed and successfully implemented in the PRIMES-TREMOVE Transport model is the representation of vehicle range possibilities and the refuelling infrastructures. These are both deemed to influence the choice of vehicle technology by consumers. Conventional technologies like ICEs do not have range limitations due to the large availability of quick refuelling infrastructure whereas battery and fuel cell electric vehicles do, especially the former. The same applies to for example gas-fuelled car types because of low density refuelling infrastructure. Vehicle technologies with limited range are endogenously penalised and the corresponding perceived costs by consumer are increased.

Comparing the range possibilities of a vehicle technology against only the average trip length of a typical representative consumer is not sufficient to capture the large variety of situations that exist in reality. Approaches based on averaging fail to represent the true effects of range limitations on consumer choices. For this purpose, the model representation of trip categories was extended by introducing a distribution of trip lengths for each trip category of the model. The distributions have different shapes and standard deviations depending on the trip nature. By taking into account the distributions, the model compares the range possibilities of vehicle technology against each class of trip length within a trip category and derives cost elements from such comparison; a representative motorway trip distribution histogram can be seen below. These cost elements are then aggregated as weighted sums for each consumer type, depending on the involvement in the various trip categories and the relative distribution shapes in each category. The numerical parameters of the model reflect strong aversion for trip cases with high discrepancy between trip lengths and range possibilities of the technologies.

Representative histogram for a motorway trip

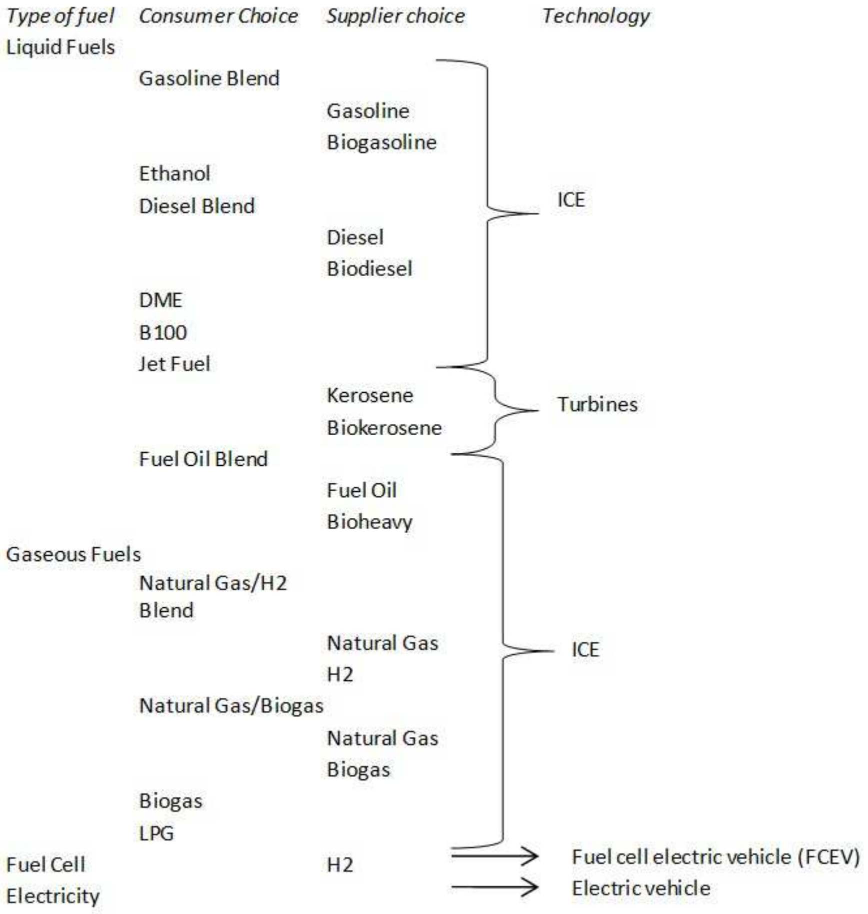


Similar situations arise when refuelling or recharging infrastructure has insufficient density. The density of this infrastructure (electricity, hydrogen, gas, LPG, biogas, etc. are distinctly represented in the model) is exogenously assumed and is taken into account in cost evaluations. Infrastructure development is further disaggregated according to the types of vehicles which use the infrastructure. Different infrastructure assumptions are made for larger and heavier vehicles like HDVs and buses compared to smaller private vehicles like cars and motorcycles. The model therefore has the possibility to introduce different infrastructure assumptions depending on the vehicle type (HDVs, cars) and on the area (urban, inter-urban) under consideration; these can vary for the different cases.

3.2.Lower nest fuel choice module

Once the consumer has decided upon the purchase of the new vehicle, for some technologies there is the possibility to further choose between fuels. A fuel choice module has been incorporated which simulates the choice between different substitutable fuels. This module highlights consumer's behaviour upon the choice of refuelling within the context of minimizing expenses. For example a diesel vehicle technology owner, can refuel with diesel blend or pure biodiesel if the technology allows for substitution between these fuels.

Classification of fuels and technologies as represented in the model



3.3.Energy efficiency standards implementation

For the CTS study energy efficiency regulations were implemented in the model for all road transportation modes; these regulations may be activated as an alternative option to the CO_2 standards (applying on passenger cars, LDVs and powered two-wheelers) which were already incorporated in the model. Energy efficiency regulation implementation is an important new feature of the model which, as in the case of CO_2 standards, allows for assessing the impacts of such policy measures. The energy efficiency standards similarly to the CO_2 standards are applied on a TTW basis.

3.4.Time Horizon

PRIMES-TREMOVE Transport Model is a long-term model that is being set to compute projections for the period 2000-2050 for each EU-27 member state, running by period of 5 years. For years 2000 and 2005 the model results are calibrated to Eurostat statistics.

4. Source of Data

Historical data on vehicle stock for road and rail transport are taken from the TREMOVE database. Vehicle stock data for road transport are being updated in the framework of the

FLEETS program and became available by the end of 2008. Data on vehicle costs, occupancy factors and average mileages are taken from the TREMOVE and SAPIENTIA databases. All other statistics are taken from EUROSTAT and DG TREN publications.

Classifications in the Transport model (road and rail)

Vehicle Category	Vehicle Type	Vehicle Technology
Small cars (<1.4 l)	Gasoline	Pre ECE, ECE, Conventional, Euro I-V
	Bio-ethanol	Bio-ethanol blend, E85 FFV
	Hybrid Gasoline	Euro IV-V
	Plug-in hybrid Gasoline	Plug-in hybrid technology
	Diesel	Euro IV-V
	Bio-diesel	Blended Bio-diesel
	Synthetic fuels	Synthetic fuels
	Hybrid Diesel	Euro IV-V
	Plug-in hybrid Diesel	Plug-in hybrid technology
	Pure electric	Pure electric technology
	Hydrogen	Hydrogen thermal, Hydrogen fuel cell
Medium Cars (1.4 - 2.0 l)	Gasoline	Pre ECE, ECE, Conventional, Euro I-V
	Bio-ethanol	Blended Bio-ethanol, E85 ethanol car
	Hybrid Gasoline	Euro III-V
	Plug-in hybrid Gasoline	Plug-in hybrid technology
	Diesel	Pre ECE, ECE, Conventional, Euro I-V
	Bio-diesel	Blended Bio-diesel
	Synthetic fuels	Synthetic fuels
	Hybrid Diesel	Euro III-V
	Plug-in hybrid Diesel	Plug-in hybrid technology
	Pure electric	Pure electric technology
	LPG	Conventional, Euro I-V
	CNG	Euro II-V
	Hydrogen	Hydrogen thermal, Hydrogen fuel cell
Big Cars (>2.0 l)	Gasoline	Pre ECE, ECE, Conventional, Euro I-V
	Bio-ethanol	Blended Bio-ethanol, E85 ethanol car
	Hybrid Gasoline	Euro III-V
	Plug-in hybrid Gasoline	Plug-in hybrid technology
	Diesel	Pre ECE, ECE, Conventional, Euro I-V
	Bio-diesel	Blended Bio-diesel
	Synthetic fuels	Synthetic fuels
	Hybrid Diesel	Euro III-V
	Plug-in hybrid Diesel	Plug-in hybrid technology
	Pure electric	Pure electric technology
	LPG	Conventional, Euro I-V
	CNG	Euro II-V
	Hydrogen	Hydrogen thermal, Hydrogen fuel cell
Motorcycles	2-stroke technology, Gasoline, biofuels	Conventional 4-stroke technology using gasoline/biofuels or electric motors
	Capacity 50-250 cc	
	Capacity 250-750 cc	
	Capacity 750cc	
Mopeds	Moped Conventional, Gasoline, biofuels	Conventional, Euro I-V
	Electric mopeds	Pure electric technology
Light Duty Vehicles	Gasoline	Conventional, Euro I-V
	Hybrid Gasoline	LDV gasoline hybrid technology

<table>
<tr><th>Vehicle Category</th><th>Vehicle Type</th><th colspan="3">Vehicle Technology</th></tr>
<tr><td rowspan="10">(<3.5 ton)</td><td>Plug-in hybrid Gasoline</td><td colspan="3">Plug-in hybrid technology</td></tr>
<tr><td>Diesel</td><td colspan="3">Conventional, Euro I-V</td></tr>
<tr><td>Hybrid Diesel</td><td colspan="3">LDV diesel hybrid technology</td></tr>
<tr><td>Biofuels</td><td colspan="3">Biofuels</td></tr>
<tr><td>LPG</td><td colspan="3">LPG</td></tr>
<tr><td>CNG</td><td colspan="3">CNG</td></tr>
<tr><td>Synthetic fuels</td><td colspan="3">Synthetic fuels</td></tr>
<tr><td>Plug-in hybrid Diesel</td><td colspan="3">Plug-in hybrid technology</td></tr>
<tr><td>Pure electric</td><td colspan="3">Pure electric technology</td></tr>
<tr><td>Hydrogen</td><td colspan="3">Hydrogen fuel cell</td></tr>
<tr><td rowspan="8">Heavy Duty Trucks
(> 3.5 ton)</td><td>Capacity 3.5-7.5 ton, Conventional</td><td rowspan="4">Diesel trucks</td><td rowspan="4">Methane trucks</td><td rowspan="4">LPG trucks</td></tr>
<tr><td>Capacity 7.5-16 ton, Conventional</td></tr>
<tr><td>Capacity 16-32 ton, Conventional</td></tr>
<tr><td>Capacity >32 ton, Conventional</td></tr>
<tr><td>Capacity 3.5-7.5 ton, Hybrid</td><td colspan="3" rowspan="2">Truck diesel hybrid technology , biofuels, synthetic fuels</td></tr>
<tr><td>Capacity 7.5-16 ton, Hybrid</td></tr>
<tr><td>Capacity 16-32 ton, Hybrid</td><td colspan="3" rowspan="2">Electric trucks, Hydrogen fuel cell trucks</td></tr>
<tr><td>Capacity >32 ton, Hybrid</td></tr>
<tr><td rowspan="8">Busses-Coaches</td><td>Diesel</td><td colspan="3">Conventional, Euro I-V</td></tr>
<tr><td>CNG</td><td colspan="3">CNG thermal</td></tr>
<tr><td>LPG</td><td colspan="3">LPG</td></tr>
<tr><td>Busses only Hybrid Diesel</td><td colspan="3">Hybrid Diesel technology</td></tr>
<tr><td>Pure electric</td><td colspan="3">Pure electric technology</td></tr>
<tr><td>Biodiesel</td><td colspan="3">Biodiesel technology</td></tr>
<tr><td>Synthetic fuels</td><td colspan="3">Synthetic fuels</td></tr>
<tr><td>Hydrogen</td><td colspan="3">Hydrogen fuel cell</td></tr>
</table>

According to FLEETS database there were no small diesel car reported till 2005 so they will be taken into consideration in the Technology choice model beyond 2010. The same goes for small diesel hybrid cars.

Passenger cars burning CNG and LPG are considered to be either Big or Medium but not Small ones.

Heavy duty trucks are supposed to be powered by diesel. In cases in which gasoline trucks occurred in national fleet statistics, they were assumed to be light duty vehicles.

Busses are considered to operate in urban environment whereas coaches in inter- urban.

Vehicle Category	Vehicle Type	Vehicle Technology
Metro	Metro Type	Metro Technology
Tram	Tram Type	Tram Technology
Passenger Train	Locomotive	Locomotive diesel
		Locomotive electric
	Railcar	Railcar diesel
		Railcar electric
	High speed train type	High speed train technology
Freight Train	Locomotive	Locomotive diesel
		Locomotive electric
	Railcar	Railcar diesel
		Railcar electric

Vehicle Category	Vehicle Type	Vehicle Technology
Aviation	Distance travelled -500 km	Conventional, improved, advanced /kerosene, biofuels
	Distance travelled 500-1000 km	Conventional, improved, advanced /kerosene, biofuels
	Distance travelled 1000-1500 km	Conventional, improved, advanced /kerosene, biofuels
	Distance travelled 1500-2000 km	Conventional, improved, advanced /kerosene, biofuels
	Distance travelled 2000- km	Conventional, improved, advanced /kerosene, biofuels

Energy Carriers for Transport		
Gasoline	Diesel	LPG
CNG	Bio-ethanol	Bio-diesel (RME, Fischer Tropsch,etc)
Hydrogen	Electricity	Synthetic fuels

Electricity infrastructure costs calculation

Electricity infrastructure costs are estimated based on ex-post calculations. Taking into account that a large part of the necessary infrastructure of electric vehicles already exists (i.e. electricity grid), the infrastructure costs are based on the number of charging stations needed to be developed. There has been assumed different electricity recharging infrastructure development for lighter electric vehicles (e.g. cars, LDVs and 2wheelers), heavier electric vehicles such as HDVs and coaches and dedicated urban battery swapping stations for electric buses.

Overview of possible costs of recharging points

Source	Year	Type of installation	Original currency		Comments	Cost in Euro
Future Transport Fuels Report	2010	per slow charging point				3000
Coulomb technology[1] homes, businesses and public locations		per charging point	$	8043	Total endeavour US$37000000; for 4600 charging points	6540
GM[2]		installation costs	$	1500		1220
BBC[3]	April 2009	fast charging point	£	2000		2960
Green Car guide[4]	2007/2008	charging posts	£	3300		4884
		charging posts	£	6379	185,000 in funding for 29 charging points in	9441

[1] http://gigaom.com/cleantech/coulomb-to-deploy-4600-electric-car-charge-spots-thanks-to-doe/
[2] http://gigaom.com/cleantech/coulomb-to-deploy-4600-electric-car-charge-spots-thanks-to-doe/
[3] http://news.bbc.co.uk/2/hi/business/8002184.stm
[4] http://www.green-car-guide.com/articles/westminster-council-launches-uks-largest-on-street-electric-car-charging-service.html

					London	
City of Westminster[5]	2006	SGTE Power France	£	1000	4 vehicles	1480
		DBT France	£	2500	4 vehicles	3700
			£	1500	1 vehicle	2220
			£	1500	1 or 2 vehicles	2220
		Transtex International France	£	1500	2 vehicles	2220
		Elektromotive UK	£	4500	1 vehicle	6660
		Ciant	£	2500	2 vehicles	3700
		Spie-Trindel France	£	1500	up to 10 vehicles per bay	2220
Plug in Points[6]		target	£	500		740

It has been assumed that for light electric vehicles such as cars, LDVs and 2wheelers there will be a dedicated slow charging point (e.g. private for each household) mainly for slow overnight charging; these slow residential charging points are operating on low voltage (220V) and charging time ranges between 4-7 hours depending on the battery capacity of the electric vehicle. Slow public charging points are assumed to be available in public areas such as parking lots; commuters will be able to park their car and recharge it throughout the day. Slow public charging points could also be available in other urban areas other than parking lots. Fast charging points are assumed to develop over time but at a slower rate compared to slow charging points. A fast charging station is designed to charge a multiple number of EVs simultaneously in a way the current refuelling stations operate.

In the ex-post calculations, it was assumed that the cost per private slow charging point declines from approx. 1000€ currently to 200€ by 2050.For slow public charge points, the cost per point is assumed to drop from 4000€ currently to 400€ by 2050. Companies like SGTE Power and DBT have already installed in Paris slow charging points for electric vehicles. In UK there are approx. 200 charging stations; the vast majority installed by Elektromotive. The table above provides details regarding costs and technical specifications of recharging stations as they have been found in a variety of sources, including internet sources.

As far as fast charging points are concerned, their costs decrease from 10000€ currently to 2000€ by 2050. It has been assumed that for large and heavy electric vehicles such as HDVs and coaches there will be dedicated electricity recharging infrastructure. The costs of the recharging stations for heavy electric vehicles are assumed to be higher than for lighter vehicles; the number of electric trucks and coaches though is limited and the additional infrastructure costs are lower than for lighter electric vehicles.

[5] It is assumed that all the charging points mentioned are slow charging points
[6] http://pluginpoints.com/Approach.htm