EC4MACS
Modelling Methodology

The PRIMES Energy Model

European Consortium for Modelling of Air Pollution and Climate Strategies - EC4MACS

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PRIMES MODEL

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HISTORY

The PRIMES energy system model has been developed by the Energy-Economy-Environment modelling laboratory of National Technical University of Athens in the context of a series of research programmes of the European Commission. The model has been successfully peer reviewed in the framework of the European Commission in 1997. From the very beginning, in 1993-1994, the PRIMES energy model was designed to focus on market-related mechanisms influencing the evolution of energy demand and supply and technology penetration in the markets. Since then the model was continuously extended and update to study medium and long term restructuring of the EU energy system, in view of climate change, RES, energy efficiency and other Community energy and environmental policies. The PRIMES model has served to quantify energy outlook scenarios for DG TREN and DG ENER, impact assessment studies for DG ENV, DG TREN, DG CLIMA and DG ENER and others and also to quantify sector-specific or country-specific scenarios for various final users, including EURELECTRIC, EUROGAS, private energy companies and several governments of the EU member-states.

COMPARISON WITH OTHER ENERGY MODELS

PRIMES differ from optimization energy models, often categorised in bottom-up approaches, as for example MARKAL, TIMES, EFOM. Such models formulate a single, overall mathematical programming (optimisation) problem that covers the energy supply system, do not consider energy price formation and have no or a simple aggregate representation of energy demand. PRIMES formulates separate objective functions per energy agent, simulates in detail the formation of energy prices and represents in detail energy demand, as well as energy supply.

PRIMES differ from econometric-type energy models, such as POLES, MIDAS and the IEA's World Energy Model. These models use reduced-form equations that relate in a direct way explanatory variables (such as prices, GDP etc.) on energy demand and supply. Also these models do not represent in detail the structure of energy demand, in terms of useful energy, processes, etc. These models usually are poor in representing in detail capital vintages and technologies in energy supply sectors and lack engineering evidence, as for example the operation of interconnected grids.

PRIMES perform a full scale representation of the energy system, in its current and possible shape in the future, covering all sectors and technologies. However, the model does not close the loop with the rest of the economy. This justifies characterizing the model as a partial equilibrium model, contrasting general equilibrium models, like GEM-E3 and others, which however represent the energy system in an aggregate way lacking also engineering evidence.

Obviously PRIMES differs substantially from accounting-type models which usually focus on specific sectors, such as MEDEE, MAEDS (on energy demand), GREEN-X (renewables), BIOTRANS (biofuels), etc.

The distinguishing feature of PRIMES is the representation of each sector separately by following microeconomic foundations of energy demand or supply behaviour and the representation of market clearing through energy prices. Similar models have been developed in the USA, including PIES, IFFS and the NEMS model which is currently used by DOE/EIA. These models are characterized as generalised equilibrium models because they can formulate the behavioural conditions for the economic agents in a variety of mathematical formulations for the sub-models, and represent different market clearing regimes, reflected in the choice of algorithm for global model convergence (equilibrium). These models are also characterised as hybrid models combining engineering-orientation with economic market-driven representations.

OVERVIEW OF THE MODEL

The PRIMES model is a modelling system that simulates a market equilibrium solution for energy supply and demand. The model determines the equilibrium by finding the prices of each energy form such that the quantity producers find best to supply matches the quantity consumers wish to use. The equilibrium is static (within each time period) but repeated in a time-forward path, under dynamic relationships.

The model is organized in sub-models (modules), each one representing the behaviour of a specific (or representative) agent, a demander and/or a supplier of energy.

The agent's behaviour is modelled according to microeconomic foundation: the agent is represented to perform maximisation of benefit (profit, utility, etc.) from energy demand and/or supply (for industry also from use of non energy production factors), under constraints that refer to activity, comfort, equipment, technology, environment or fuel availability. Microeconomic foundation is a distinguishing feature of the PRIMES model and applies to all sectors. Although the decision is assumed to be economic, many of the constraints and possibilities reflect engineering feasibility and restrictions. The model thus combines economics with engineering, in order to ensure consistency. PRIMES is clearly more aggregated than engineering models and far more disaggregated than econometric (or reduced form) models.

The agent is assumed to be a price-taker as energy demander and a price-maker as energy supplier, depending on assumptions about the prevailing market competition regime. All economic decisions of the agents are dynamic and concern both operation of existing equipment and investment in new equipment, both when equipment is using energy and when it is producing energy. Capital formation is represented as a dynamic series of equipment technology vintages: equipment invested on a specific date inherits the technical-economic characteristics of the technology vintage corresponding to that data. Capital turnover is dynamic and the model keeps track of capital vintages and their specific technical characteristics. The agent's investment behaviour consists in building or purchasing new energy equipment to cover new needs, or retrofitting existing equipment or even for replacing prematurely old equipment for economic reasons.

All formulations of agent behaviours consider explicit technologies, either existing or expected to become available in the future. The technology selection decisions depend on technical-economic characteristics of these technologies, which change over time either autonomously (exogenous) or because of the technology-selection decisions (learning and scale effects).

The agent's investment behaviour, the purchasing of durable goods and the energy saving expenditures involve capital investment, which enter the economic calculations as annuity payments for capital. Annuity payments depend on a (real) interest rate which is assumed to be specific to each agent (sector). The determination of this rate is based on the concept of WACC (weighted average cost of capital), which involve a basic risk-free interest rate applied on equity capital, a bank lending interest rate applied on the part of capital borrowed and a risk premium. All rates are net of inflation. The rate applied on equity capital is assumed to have a subjective nature and is specifically assumed for each sector[1]. The risk premium has two components: one specific to each sector and one specific to the candidate technology. For the latter it is assumed that innovative technologies that may not be sufficiently mature or that may not dispose a sufficiently broad maintenance service support are considered as more risky than market established technologies.

The model computes emissions from energy use and production and considers emission-related and technology-related policies and standards. Energy prices are calculated from supply costs and infrastructure costs depending on assumptions about the prevailing market competition regime and price regulations. Energy prices are influenced by tax policy and by various policy instruments, such as trading of emission allowances, trading of certificates, etc. The prices influence energy demand and so the model simulates a closed loop between energy demand, supply and prices. Exchanges and trade among energy suppliers are represented (for example for electricity, gas and distributed steam/heat) as function of relative prices, infrastructure and market regulation constraints.

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[1] Empirical studies have shown that individuals apply higher subjective discount rates than business firms.

The model represents time-of-use varying load of network-supplied energy carriers to synchronize electricity, gas and steam/heat in all sectors of demand, supply and trading. Load curves are computed by the model in a bottom up manner depending on the load profiles of individual uses of energy.

The model is generally non-linear. Non-linear relations include the economies of scale and learning by doing for technologies, the consumer choices and saturation effects, the supply cost-curves for potential of resources, new technologies and the use of new sites for energy plants and the perceived costs of technologies.

The model incorporates alternative policy instruments that are meant to influence energy demand, supply and prices, such as: taxes and subsidies, tradable certificates, tradable emission allowances, emission limitation standards, energy efficiency performance standards, obligations (e.g. for renewables, CHP, etc.) and technology push mechanisms (e.g. promotion of energy savings, etc.).

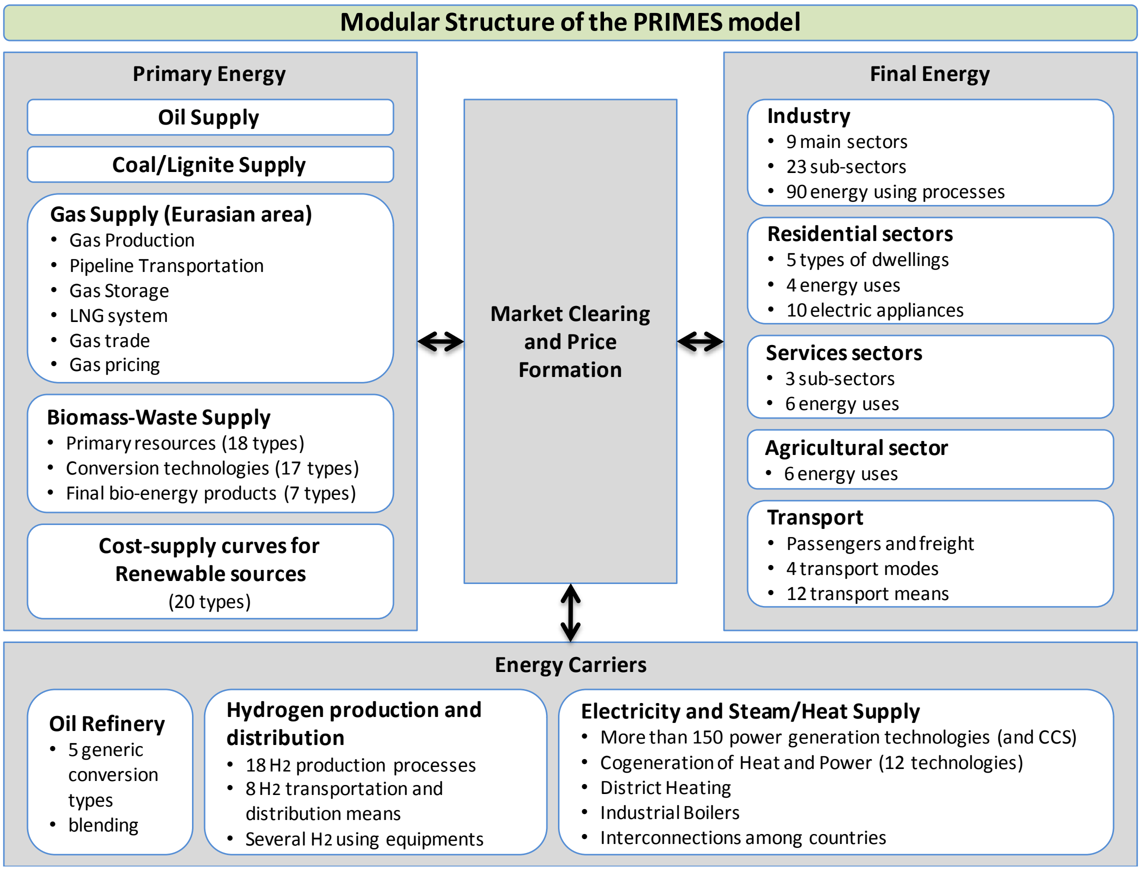
The PRIMES model is a general-purpose model. It is conceived for energy outlooks, scenario construction and impact assessment of policies. It covers a medium to long-term horizon. It is modular and allows either for a unified model use or for partial use of modules to support specific energy studies.

The model can support policy analysis in the following fields:

- standard energy policy issues: security of supply, strategy, costs etc.,
- environmental issues incl. climate change mitigation,
- pricing policy, taxation, standards on technologies,
- new technologies and renewable sources,
- energy efficiency in the demand-side,
- alternative fuels,
- conversion decentralisation, electricity market liberalisation,
- policy issues regarding electricity generation, gas distribution and new energy forms.

The model is organised by energy production sub-system (oil products, natural gas, coal, electricity and heat production, biomass supply, and others) for supply and by end-use sectors for demand (residential, commercial, transport, nine industrial sectors). Some demanders may be also suppliers, as for example industrial co-generators of electricity and steam.

The different modules interact via the exchange of fuel quantities and prices, leading to the overall equilibrium of the energy system.



Typical Inputs to the PRIMES Model

- GDP and economic activity per sector
- World energy supply outlook – world prices of fossil fuels
- Tax and subsidy policies
- Interest rates, risk premiums, etc.
- Environmental policies and constraints
- Gas and electricity network infrastructure
- Technical and economic characteristics of future energy technologies
- Energy consumption habits and comfort parameters
- Cost-supply curves of potential for primary energy, potential of sites for new plants, energy efficiency potential, renewables potential per source type, etc.

Typical Outputs of the PRIMES Model (per country and time period)

- Detailed energy balances (EUROSTAT format)
- Detailed balance for electricity and steam/heat
- Production of new fuels
- Transport activity, modes/means and vehicles
- Association of energy use and activities
- Investment, technologies and vintages in supply and demand sectors
- Energy costs, prices and investment expenses per sector and overall
- CO_2 Emissions from energy combustion and industrial processes
- Emissions of atmospheric pollutants
- Policy Assessment Indicators

MODEL NOMENCLATURE

REGIONS: The PRIMES model is currently built and is fully operational for all EU27 member-states and also for the Western Balkans countries (Albania, Croatia, Bosnia-Herzegovina, FYR of Macedonia and Serbia including UNMIK and Montenegro), the EFTA countries (Switzerland, Norway) and Turkey. It projects also the flows of electricity and gas among all countries.

FUEL TYPES: 26 energy forms in total; Coal, Lignite, Coke, Peat and Other solid fuels, Crude-oil, Residual Fuel Oil, Diesel Oil, Liquefied Petroleum Gas, Kerosene, Gasoline, Naphtha, Other oil products, Bio-fuels, Natural and derived gas, Thermal Solar (active), Geothermal low and high enthalpy, Steam/Heat (industrial and distributed heat), Electricity, Biomass and Waste (5 types), Hydrogen, Solar PV electricity, Solar thermal electricity, Wind Onshore, Wind Offshore, Hydro Lakes, Hydro run of river, Tidal and Wave energy.

DEMAND SECTORS

RESIDENTIAL*:* The residential sector distinguishes five categories of dwelling. These are defined according to the main technology used for space heating. They may use secondary heating as well. Each type of dwelling is further subdivided in 4 typical energy uses. The electric appliances for non-heating purposes are considered as a special sub-sector, which is independent of the type of dwelling. There is no distinction between rented and owned dwelling.

SERVICES AND AGRICULTURE*:* The model distinguishes between the commercial sector (subdivided in three sub-sectors) and the agricultural sector. At the level of each sub-sector, the model calculates energy services (useful energy), which are further subdivided in energy uses defined according to the pattern of technology. In total more than 30 end-use technology types are defined.

INDUSTRY*:* The industrial model formulates 9 industrial sectors separately, namely iron and steel, non ferrous, chemicals, non-metallic minerals, paper and pulp, food drink tobacco, engineering, textiles, other industries. For each sector different sub-sectors are defined (in total about 23 sub-sectors, including recycling of materials). At the level of each sub-sector a number of different energy uses are represented (in total about 100 types of energy process technologies are included).

TRANSPORTATION*:* The transport sector distinguishes passenger transport and goods transport as separate sectors. They are further subdivided in sub-sectors according to the transport mean (road, air, etc.). At the level of the sub-sectors, the model structure defines several technology types (car technology types, for example), which correspond to the level of energy use. Within modes like road transport there is therefore a further subdivision, i.e. the model distinguishes for road passenger transport between public road transport, motorcycles and private cars. The model considers 6 to 10 alternative technologies for transport means such as cars, busses, trucks; the number of alternatives is more limited for rail, air and navigation

SUPPLY SECTORS

ELECTRICITY AND STEAM PRODUCTION*:* 72 different plant types per country for the existing thermal plant types; 150 different plant types per country for the new thermal plants; 3 different plant types per country for the existing reservoir plants; 30 different plant types per country for the existing intermittent plants. Chronological load curves, interconnections (DC linear electricity network), network capacity representation; distinction between utilities and industrial power generation; Cogeneration of power and steam (12 generic technologies), district heating, industrial boilers and their substitution possibilities represented in a single module.

NATURAL GAS*:* Very detailed sub-model covering regional supply detail (Europe, Russia, CIS countries Middle Africa, North Sea, China, India for pipeline gas and global market for LNG). Detailed representation of gas infrastructure (field production facilities, pipelines, LNG Terminals, Gas Storage, Liquefaction Plants); oligopolistic competition.

BIOMASS SUPPLY*:* Very detailed sub-model covering supply of biomass and waste energies that compute the optimal use of biomass/waste resources and investment in secondary and final transformation, so as to meet a given demand of final biomass/waste energy products; the model computes the consumer prices of the final biomass/waste products used for energy purposes and also the consumption of other energy products in the production, transportation and processing of the biomass/waste products; detailed representation of resources (crops, forestry, aquatic biomass and wastes) and of more than 20 transformation processes.

REFINERIES*:* Simple oil refinery with typical refinery structure defined at the level of each country; 5 typical refining units (cracking, reforming etc.)

HYDROGEN*:* Detailed hydrogen production and transportation sub-model with 18 H_2 production technologies, 8 H_2 transport/distribution means and several types of H_2 using equipment.

PRIMARY FOSSIL FUEL PRODUCTION*:* Simple Cost – Supply curves limited by available resources.

TIME HORIZON

PRIMES is a long-term model that is being set to compute projections for the period 1990-2050, running by period of 5 years. For years 1990, 1995, 2000 and 2005 the model results are calibrated to Eurostat statistics. For year 2010 the model results are semi-calibrated by taking into account the latest statistics and short-term expectations.

DATA BASE

EUROSTAT:

Energy Balance sheets, Energy prices (complemented by other sources, such IEA), Macroeconomic and sectoral activity data (PRIMES sectors correspond to NACE 3-digit classification), Population data and projection, Physical activity data (complemented by other sources), CHP, CO_2 emission factors (sectoral and reference approaches) and EU ETS registry for allocating emissions between ETS and non ETS

TECHNOLOGY DATABASES DEVELOPED UNDER EC PROGRAMS:

MURE, ICARUS, ODYSEE – demand sectors, VGB, SAPIENTIA, TECHPOL – supply sector technologies, NEMS model database, US DOE/EIA

POWER PLANT INVENTORY:

ESAP SA and PLATTS

RES POTENTIAL:

ECN, DLR and Observer (up to 2007)

GRID INFRASTRUCTURE

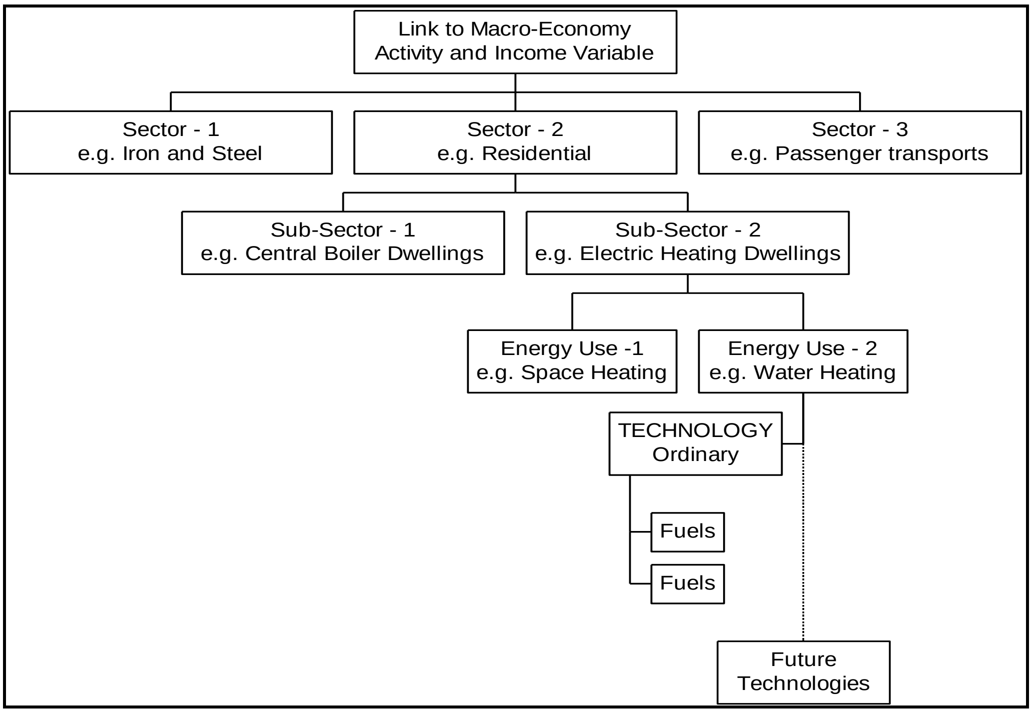
ETSO, GIE

COMPUTATION OF ENERGY BALANCES AND INDICATORS

The PRIMES' main output is a fully detailed energy balance per country which is projected to the future. The energy balance follows exactly the conventions of Eurostat. The model computes also a series of indicators, according to Eurostat definitions, including the indicator of RES as percentage of total gross energy consumption.

THE DEMAND SIDE SUB-MODELS

The demand-side sub-models represent a sector that is further decomposed into sub-sectors and then into energy uses. A technology operates at the level of an energy use and utilizes purchased energy forms (fuels and electricity). The calculation starts from activity or income, then it computes useful energy and then by using technology equipment useful energy is produced by converting purchased energy forms. The following graphic illustrates the hierarchical decomposition of the demand-side models.



For each sector a representative decision making agent is assumed to operate, which optimizes an economic objective function: Utility maximization for households and passenger transportation; Profit maximization (or cost min) for Industrial, tertiary and freight transport sectors. The decision is represented as a nested budget allocation problem: At the upper level of the nesting, energy is a production factor or a utility providing factor and competes with non energy inputs; Useful energy, as derived, is further allocated to uses and processes. The decisions at each nesting level are based on an equivalent perceived cost reflecting actual costs, utility (e.g. comfort) and risk premium. Demand for energy at a certain level is met by optimizing final energy demand processing costs, which includes a) Endogenous choice of equipment (vintages, technologies and learning), b) Endogenous investment in energy efficiency (savings), c) Endogenous purchase of associated energy carriers and fuels. The decisions can be influenced by policies, such as, taxes and subsidies, promotion of new technologies (reducing perceived costs), promotion of energy efficiency, including standards.

The model evaluates consistently the potential of new technologies, by considering simultaneously three types of mechanisms: a) economic optimality, b) dynamics, i.e. constraints from existing capacity, and c) gradual market penetration and acceptance.

The non-linear optimization per agent (sector) is performed period by period in a time forward direction. In a given period a set of lagged values are used that are updated dynamically by the single-period optimization results. Choices are constrained dynamically by the existing energy-use equipment which may change through investment while existing equipment is retired on the basis of retirement rates or by premature replacement decisions. Technology (energy equipment that converts purchased energy to useful energy) and energy savings equipment (e.g. insulation) is considered to evolve over time, and is categorized in vintages (generations) presenting different characteristics.

INDUSTRY

In PRIMES, industry consists of nine sectors. For each sector different sub-sectors are defined. At the level of each sub-sector a number of different energy uses are represented. A technology at the level of an energy use may consume different types of fuels (one of which is steam generated from the power and steam sub-model of PRIMES, so only steam distribution and use costs are accounted for in the demand-side, together with a price for steam).

The scope of the industrial demand sub-model of PRIMES is to represent simultaneously:

- the mix of different industrial processes (e.g. different energy intensity for scrap or recycling processes and for basic processing);
- the mix of technologies and fuels, including the use of self-produced by-products (fuels) and renewable energy forms;
- the links to self-supply of energy forms (e.g. cogeneration of electricity-steam, steam by boilers, use of by-products (fuels), heat recovery);
- the explicit and engineering-oriented representation of energy saving possibilities;
- the satisfaction of constraints through emission abatement, pollution permits and energy savings, and
- the rigidities of system change evolution because of existing capacities or dynamic technical progress
- Possible substitutions between processes, energy forms, technologies and energy savings

The structure for the industrial sector is given below:

SECTOR	SUB-SECTORS	ENERGY USES
Iron and Steel	Electric arc	Air compressors
	Iron and Steel integrated	Blast furnace
		Electric arc
		Electric process
		Foundries
		Lighting
		Low enthalpy heat
		Motor drives
		Process furnaces
		Rolled steel
		Sinter making
		Steam and high enthalpy heat

SECTOR	SUB-SECTORS	ENERGY USES
Non ferrous metals production	Primary aluminium production	Air compressors
	Secondary aluminium production	Lighting
	Copper production	Motor drives
	Zinc production	Electric furnace
	Lead production	Electrolysis
	Other NF metals production	Process furnaces
		Electric kilns
		Low enthalpy heat
		Steam and high enthalpy heat

SECTOR	SUB-SECTORS	ENERGY USES
Chemicals production	Fertilizers	Air compressors
	Petrochemical	Low enthalpy heat
	Inorganic chemicals	Lighting
	Low enthalpy chemicals	Motor drives
		Electric processes
		Steam and high enthalpy heat
		Thermal processes
		Energy use as raw material

SECTOR	SUB-SECTORS	ENERGY USES
Building materials production	Cement dry	Electric kilns
	Ceramics and bricks	Cement kilns
	Glass basic production	Air compressors
	Glass recycled production	Lighting
	Other building materials production	Motor drives
		Glass annealing electric
		Glass tanks electric
		Low enthalpy heat
		Glass annealing thermal
		Glass tanks thermal
		Material kilns
		Drying and separation
		Tunnel kilns

SECTOR	SUB-SECTORS	ENERGY USES
Paper and pulp production	Pulp production Paper production	Lighting Motor drives Pulping electric Refining electric Steam and high enthalpy heat Low enthalpy heat Pulping steam Drying and separation Refining steam

SECTOR	SUB-SECTORS	ENERGY USES
Food, Drink and Tobacco production	Food, Drink and Tobacco goods	Air compressors Cooling and refrigeration Lighting Motor drives Drying and separation electric Steam and high enthalpy heat Low enthalpy heat Space heating Drying and separation thermal Specific heat Direct heat

SECTOR	SUB-SECTORS	ENERGY USES
Engineering	Engineering goods	Air compressors Lighting Motor drives Drying and separation electric Machinery Coating electric Foundries electric Steam and high enthalpy heat Low enthalpy heat Space heating Drying and separation thermal Coating thermal Foundries thermal Direct heat

SECTOR	SUB-SECTORS	ENERGY USES
Textiles production	Textiles goods	Air compressors Cooling and refrigeration Lighting Motor drives Drying and separation electric Machinery Steam and high enthalpy heat Low enthalpy heat Space heating Drying and separation thermal Direct heat

SECTOR	SUB-SECTORS	ENERGY USES
Other industrial sectors	Other industrial sectors goods	Air compressors Lighting Motor drives Drying and separation electric Machinery Steam and high enthalpy heat Low enthalpy heat Space heating Drying and separation thermal Specific heat Direct heat

TERTIARY SECTOR

The purpose of the tertiary sub-model of PRIMES is to project final energy demand of the services and agriculture sectors, as a function of economic activity of the sector, which is exogenous, and the prices of the energy forms as transmitted to these sectors from energy supply.

The scope of the tertiary demand sub-model of PRIMES is to represent simultaneously:

- the mix of different energy uses;
- the mix of technologies and fuels, including the use of renewable energy forms;
- the links to district heating, steam production from boilers and cogeneration;
- the explicit and engineering-oriented representation of energy saving possibilities;
- the satisfaction of constraints through emission abatement, pollution permits and energy savings, and
- the rigidities of system change evolution because of existing capacities or dynamic technical progress.

The aggregate tertiary comprises of 4 sectors: three service sectors and agriculture. At the level of the sub-sectors, the model structure defines groups of energy uses, which are further subdivided in energy uses defined according to the pattern of technology.

The structure of the tertiary sector is as follows:

SECTOR	ENERGY USES	ENERGY TECHNOLOGIES
Agriculture	Lighting	Lighting
	Space heating	Heating/Cooling
	Greenhouses	Pumping
	Electrical uses	Motor drives
	Pumping	Electrical equipment
	Motor energy	Greenhouse types

SECTOR	ENERGY USES	ENERGY TECHNOLOGIES
Services		
Market Services	Lighting	Lighting
	Space heating	Electric heating/cooling
	Air conditioning	Gas heating/cooling
	Steam uses	Boiler heating/cooling
	Electrical uses	District heating
	Water heating	Electrical equipment
Trade	Lighting	Lighting
	Space heating	Electric heating/cooling
	Air conditioning	Gas heating/cooling
	Steam uses	Boiler heating/cooling
	Electrical uses	District heating
	Water heating	Electrical equipment
Public services	Lighting	Lighting
	Space heating	Electric heating/cooling
	Air conditioning	Gas heating/cooling
	Steam uses	Boiler heating/cooling
	Electrical uses	District heating
	Water heating	Electrical equipment

RESIDENTIAL SECTOR

In the residential sector, energy is consumed as input in processes that provide services to the households, such as space heating, water heating, cooking, cooling, lighting and other needs. The decision about the level of energy consumption is related to the need for services covered by energy, which are further related to changes in prices and income as is true for other consumption commodities.

Energy consumption has, however, several special features, which need to be considered especially concerning the way they affect the dynamics of consumer response. In particular:

- The pattern of energy consumption is not usually controlled directly by the consumer, but is determined by the household technology (i.e. the type of fuel and equipment used for an energy service); the level of consumption is controlled, in the short run, by behavioural decisions in utilisation intensity;

- The household technology for energy consumption is largely embodied in the characteristics of dwellings and durable equipment. Consequently, responses to price shifts may involve long lags;
- Energy costs are normally billed to households periodically for several uses combined. Due to this fact, there may be no direct linkage between policy and cost, even for highly rational consumers; this also causes a delay of response when price shifts occur;
- Energy covers primary needs of households. The income elasticity is expected to be less than one, while substitutions by non-energy commodities are rather limited. In developed countries the share of energy in total consumption is close to saturation (taking account of price variations), a fact that explains the observed asymmetry in price elasticities with respect to positive or negative shifts. It should be noted, however, that PRIMES is not solely based on such overall elasticities but on a much more structural representation of demand and supply.

Taking into account these special features of energy consumption in the residential sector, the model includes both technological and behavioural components. Technological components capture the physical constraints on energy conservation and use, while behavioural components are used to explain consumer expectations and their influence on equipment choice as well as to explain the influence of energy prices on energy consumption intensity. The model is designed to provide energy consumption forecasts for each end-use by fuel.

The fuel shares, for each end-use in which we have substitution between fuels, are assumed to represent fuel choice frequencies (which express the percentage of households that choose a specific fuel to serve an end-use). The probability that a given appliance (for space heating, water heating and cooking) is chosen to be installed in a dwelling is calculated as a function of a total perceived cost and of the maturity of equipment (so that inter-fuel substitution is constrained). The total perceived cost is a function of capital, maintenance and fuel (operating) cost of the equipment, as well as of the income of households. Especially, for cooking and water heating it is assumed that the total perceived cost also depends on the fuel choice made for space heating following the decision-tree approach mentioned above. This assumption leads to a "nested logit model" approach. The fuel shares obtained are implemented for new dwellings and for the installation of new equipment due to normal replacement. As a result, updated fuel shares by end-use are computed, concerning both existing and new dwellings.

Specific electricity use is considered as non substitutable, for which an analysis in terms of electric appliances is formulated.

The residential sector distinguishes five categories of dwelling. A category of dwelling is defined according to the pattern of heating that is the main technology used for space heating (no distinction between urban and rural, no distinction by age of house). The dwelling may use secondary heating as well. The model does not include endogenous choice about the degree of thermal insulation of the house, but includes only possibility for retrofitting in order to improve thermal insulation. The model defines the different uses of energy for each category of dwelling. The electric appliances for non-heating and cooling are considered as a special sub-sector, which is independent of the type of dwelling. The structure is as follows:

SECTOR	HOUSEHOLD TYPES	ENERGY USES
Dwellings	• Central boiler households that may also use gas connected to the central boiler (flats) • Households with mainly electric heating equipment (non partially heated) • Households with direct gas equipment for heating (direct gas for flats and gas for individual houses) • Households connected to district heating • Partially heated dwellings and agricultural households	Space heating Cooking Water heating Air conditioning

SECTORS	ENERGY USES
Electric Equipment	Washing machines Dish washers Dryers Lighting Refrigerators Television sets

TRANSPORT SECTOR

The transport module of PRIMES (as available in 2008) has been developed to study mainly the penetration of new transport technologies and their effects on emissions, besides the evaluation of the energy consumption and emissions in the transport sector. The emphasis is on the use of car technologies and on the long term (2030).

The transport sector distinguishes passenger transport and goods transport as separate sectors. They are further subdivided in sub-sectors according to the transport mode (road, air, etc.). At the level of the sub-sectors, the model structure defines several technology types (car technology types, for example), which correspond to the level of energy use.

The overall demand for transport (passenger kilometres, ton kilometres) is determined by income/activity growth and by the overall price of transport. The overall price of transport is determined endogenously, as a function of the modal split and of the price per mode. The split of the overall transport activity over the different modes is driven by the price per mode and by behavioural and structural parameters. The price per mode depends on the choice of technology for new investment and on past investment for each transport mode. The technologies for new investment are chosen, based on the lowest expected usage costs.

The stock of vehicles inherited from the previous period is expanded in function of the transport needs per mode. The new stock composition determines the stock for the next period and influences the aggregate price per mode.

The structure of the transport sub-model is as follows:

SECTOR	SUB-SECTORS	ENERGY TECHNOLOGIES
Passenger transport	Busses	Internal combustion engines
	Motorcycles	Electric motors and hybrid
	Private cars	Fuel cell
	Passenger trains	Gas turbine and CNG
	Air transports	
	Navigation passengers	

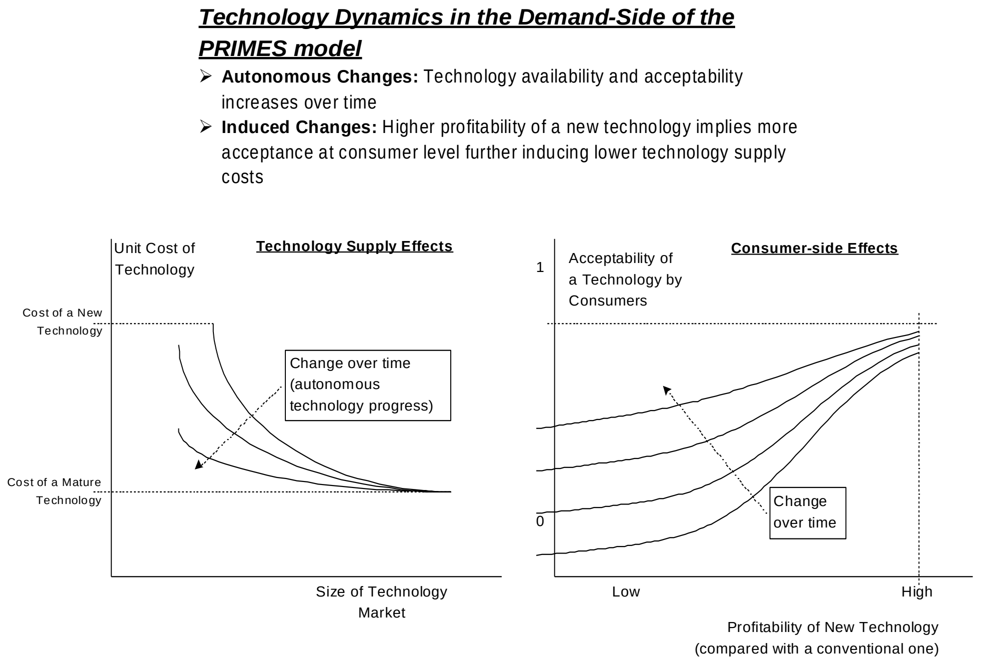
SECTOR	SUB-SECTORS	ENERGY TECHNOLOGIES
Goods transport	Trucks	Internal combustion engines
	Trains	Electric motors and hybrid
	Navigation	Fuel cell
		Gas turbine and CNG

A new transport sub-model of PRIMES was made operational in 2010. A description is given in this document.

TECHNOLOGY DYNAMICS IN THE DEMAND SIDE

The PRIMES dynamics consist of a sequence of static equilibriums linked to each other through capital accumulation. Dynamics depend on capacity expansion decisions and technology choice. The PRIMES model incorporates induced technology change in the demand-side of the model. Technology choice at the consumer level is based on total technology cost, which further depends on technology supply costs and acceptability of technology by the consumer. Both cost components change endogenously. For example if a carbon constraint applies, the consumer might perceive more profitability from new technologies, the technology gets more acceptance and its penetration is further facilitated by decreasing technology supply costs; this leads to lower economic costs from complying with carbon constraints. These dynamic projections having autonomous components for technology progress, and represent different conditions over time for technology choice, acceptability and technology supply effects.

The following graphic illustrates these concepts regarding demand-side technologies in PRIMES.



Advanced technologies are, almost by definition, significantly more costly to adopt initially, in terms of capital spending. However, once the adoption of these technologies becomes marginally cost effective their market penetration develops a strong momentum leading to the decline in the additional capital charges involved in the use of the new technology. In other words, the anticipation of higher demand for advanced technologies leads energy equipment suppliers (manufacturers, maintenance and technical support operators) to make them more attractive and more acceptable by the market. This technology supply-side effect contributes to the acceleration of adoption of new technologies by consumers. Of course, both the availability of technologies and the technology adoption mechanism take into account the time limitations for system adjustment.

The above-defined mechanism allows for lower adaptation costs for the system and higher penetration of demand-side technologies, compared with cases that have a static view on technology change in demand-side energy technologies.

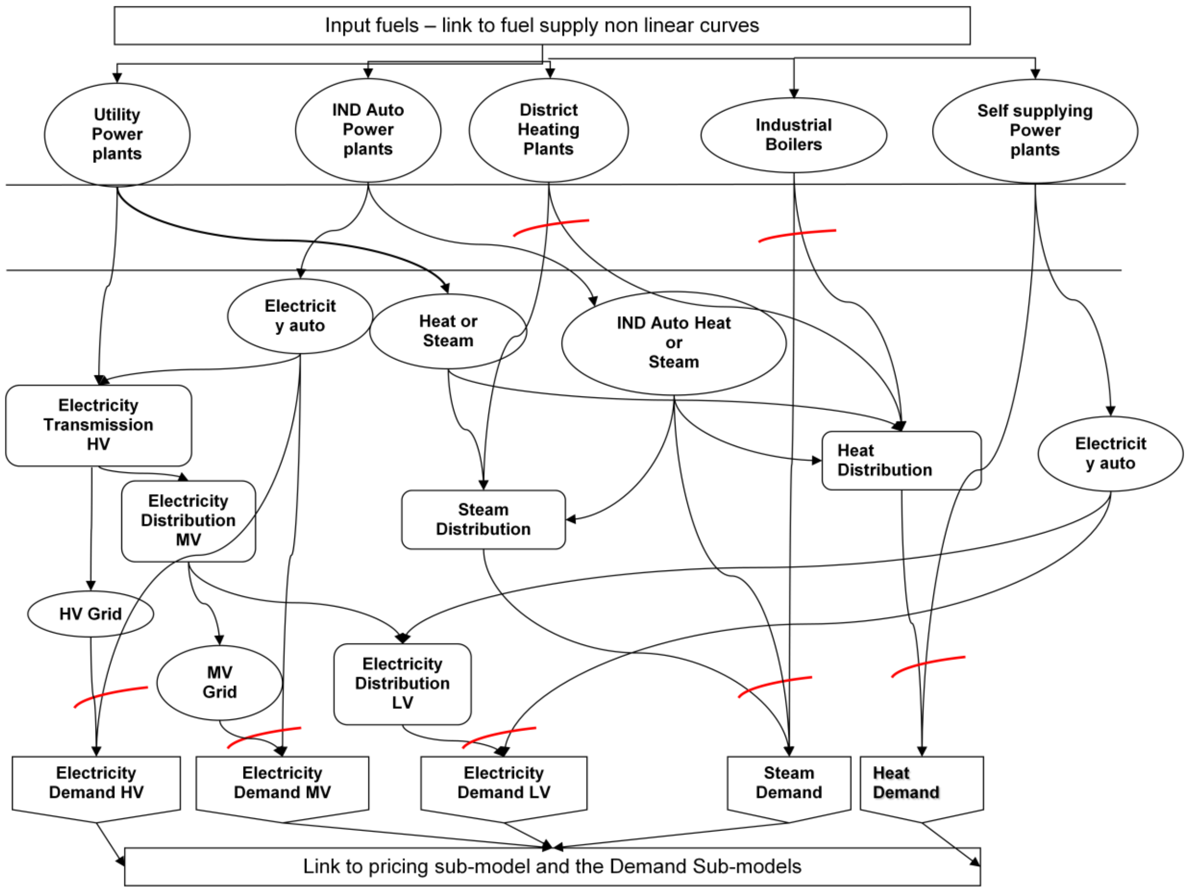
Under different scenario assumptions (e.g. high economic growth, introduction of global emission constraints, energy-efficiency supporting policies such as campaigns, labelling etc.), the above mechanism triggers dynamics of technology change that differ from baseline conditions. The consumer may accelerate (or decelerate) the adoption of more efficient technologies along the schedule of normal replacement of his equipment, or even perform premature replacement of equipment. The way that alternative assumptions affect different energy consumers depends on the ability of the latter to adapt through investment in different -compared to baseline- technologies, structural shifts and changes in their choice of fuel mix.

THE POWER AND STEAM GENERATION SUB-MODEL OF PRIMES

The PRIMES model simulates power generation and investment as a result of non linear optimization of the sector, assuming operational and grid constraints. The optimisation is intertemporal (perfect foresight) and solves simultaneously a unit commitment-dispatching problem; a capacity expansion problem; and a DC-linearized optimum power flow problem (over interconnectors). The optimisation is simultaneous for power, CHP, distributed steam, distributed heat, district heating and industrial boilers and satisfies synchronised chronological demand curves of power, steam and heat, which result from the sectoral demand sub-models.

Non linear relationships regard the cost of access to resources, such as fuels, RES and plant sites. Such resources are represented as upward sloping cost-supply curves linking unit costs to cumulative exploitation. The cost-supply curves are country and resource specific and change over time in order to reflect changing conditions about potential and technology.

The model introduces competition between electricity only plants, CHP, industrial boilers and district heating and their deliveries. A stylized grid for electricity and steam/heat networks are represented in a way to allow some degree of substitution, as illustrated in the following scheme:



Three voltage types are distinguished, namely high voltage (HV), medium voltage (MV) and low voltage (LV). Industrial producers (denoted by IND in the above scheme) compete with utilities in power and steam generation: they have higher unit costs because of diseconomies of scale but lower grid costs (production for self-use) and exploit CHP. District heating plants, industrial boilers and CHP compete against each other through the distinct steam and heat networks. Highly decentralized power generation and heat production is also represented in the stylized competition. Electricity trade among countries is endogenous but is constrained by interconnectors for which thermal capacity (today and in the future) and reactance are supposed known. The model simulates a DC linearized power flow over a network with a single load node per country and multiple interconnectors among the nodes. Electricity and steam/heat load are represented as chronological load curves with 11 typical time zones annually.

The representation of different technologies that are now available or will be available in the future is a major focus of the model, as it is intended to also serve for strategic analyses on technology assessment. To support such analyses, the model uses a large list of alternative technologies and differentiates their technical-economic characteristics according to the plant size, the fuel types, the cogeneration techniques, the country and the type of producer. A model extension is also designed aiming at representing a non-linear cycle of the penetration of new technologies, for which learning through experience (and other industrial economic features) relates penetration with the technology performance.

Decision-making by electric utilities (or steam producers) may be considered in three different, yet interrelated, problems:

- the *strategic capacity expansion problem* which concerns the choice of new plants for construction, so as to meet future demand at a least long-run generation cost; the model distinguishes between Greenfield investment, expansion in an existing plant site, replacement of an existing plant, retrofitting of an existing plant and decommissioning.
- the *operational plant selection and utilisation problem* which concerns the choice of existing plants to be committed in the system, so as to meet load at a least operation cost; reliability constraints are represent in a simple deterministic way through capacity credits per plant type, maximum operational hours per plant type and total expected loss of load constraint.
- the *cost evaluation and price formation (tariffs)* that has to be in conformity both with the long-term financial objectives of the company and with the aim to influence demand load; this determines electricity pricing.

The model formulates long run marginal cost principles for capacity expansion and short run marginal costing for dispatching and plant commitment. However, for price setting the model formulates Ramsey-

Boiteux pricing model, consisting in determining total revenue requirement as reflecting total costs plus market power mark-up and prices per sector depending on demand elasticities. Ramsey-Boiteux pricing regards the electricity tariffs per consumer category, whereas pricing of grid infrastructure is based on a price reflecting "socialised" recovery of total (including capital) grid costs, levelised over a long period of time. Market power mark-ups are exogenous and reflect assumptions about the prevailing market competition regime. A similar method is used to reflect the degree of passing through to consumer prices of opportunity costs that may arise of emission allowances are allocated for free to power companies.

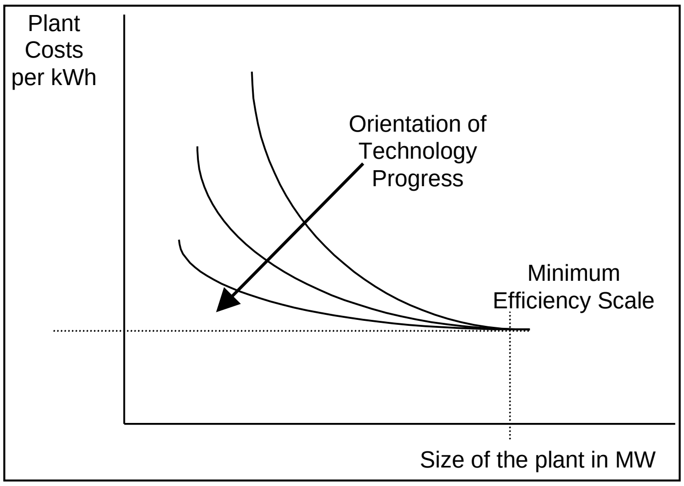
Regarding the dynamics of the decision-making, the model is flexible. Two anticipation regimes, activated through an optional switch, are formulated in the model:

- The myopic time-forward anticipation, in which the decision-maker has information only about the past and the present time-period while the model is solved dynamically along time-steps in a time-forward manner.
- The perfect foresight over finite horizon, in which the decision-maker has full and correct information about the future, over a finite horizon, and the model solves simultaneously (inter-temporally) for the set of time periods from present up to the horizon examined. Perfect foresight is commonly used for the power and steam sub-model.

The building of equipment in the electricity and steam system requires several years. This has important implications for planning and plant type choice. The model considers the financial costs associated to the construction period but ignores the fact that the plant types differ in construction time, which may influence plant selection in particularly uncertain circumstances. Furthermore, under the myopic anticipation regime, the model considers that the plants can be constructed and immediately used within the 5-years runtime period of the model. In this sense, the model operates as if the current 5-years period is perfectly known by the decision-maker.

Power technologies are characterised by the type of fuel they can use, their efficiency in generating heat and/or power, their cogeneration technique (if applicable), their availability, their investment costs and their operating costs.

The model put emphasis on the representation of plant efficiency and performance as a function of plant size. It is assumed that utilities can invest in large size plants and benefit from economies of scale, while industrial power and steam producers can invest only in relatively small size plants.



The relationship of plant performance as a function of plant size is considered as varying with the type of technology and time. Through this assumption, the model attempts to capture a technology progress that would bridge the gap between the plant sizes, in terms of performances and costs. Such an example has been recently observed with the developments in gas turbine technologies and the combined cycle plants. The scheme illustrates how a certain type of technology progress reduces differences of plant performance across plant sizes.

The model distinguishes the old plants existing in the base year (a full inventory of plants is included in the PRIMES data base) and the potential plants, i.e., those that might be built through investment. No further investment in old plants is considered. However the model treats endogenously retrofitting options for these plants, as the extension of their lifetime may be judged as economical when existing plants reach the end of their lifetimes. Retrofitting involves capital costs and fixed costs that rapidly increase over time.

Optionally the model treats power plant investment in new plants as integer multiples of generic plant sizes (which are different per plant type).

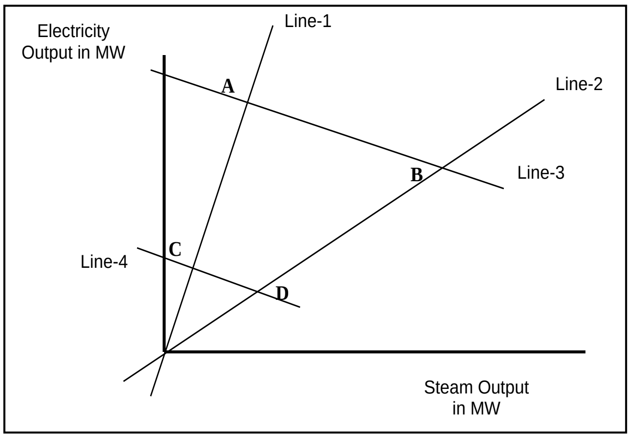
The variety of different plant types is incrementally specified in the model, by combining the elements from the following sets: generic plant technology, type of fuel combustion including multiple fuel capability (if applicable), cogeneration technique (if applicable), company type and country. The technical-economic characteristics of the plants differ across the above items. Regarding new plants, technology progress is represented as technological generations that are considered as different plant types.

The model considers the following information to characterize a plant technology:

- capital cost (Euro'00/kW) and financial charges during construction;
- variable cost (per kWh produced) and annual fixed costs (per kW). The fixed costs increase over time, as the plant becomes older;
- thermal efficiency rate and multiple fuel capability, if applicable. Rate of electricity auto-consumption per plant;
- plant availability rate and rate of utilization for intermittent plants.

- time-related characteristics of a plant, like technical lifetime and economic lifetime (used for capital amortization);
- technical parameters for the feasible combinations of electricity and steam output, if applicable;
- old plant (in the category of existing plants) retrofitting technical and economic parameters;
- intermittent plants are linked to renewable resources for which the time pattern of supply is given;
- reservoir plants can operate at the limits of energy available from inflow water (exogenous) in the lakes, during each year;
- to reflect future technologies, it is assumed that new plant technologies will become available at different points in time (exogenous parameter).

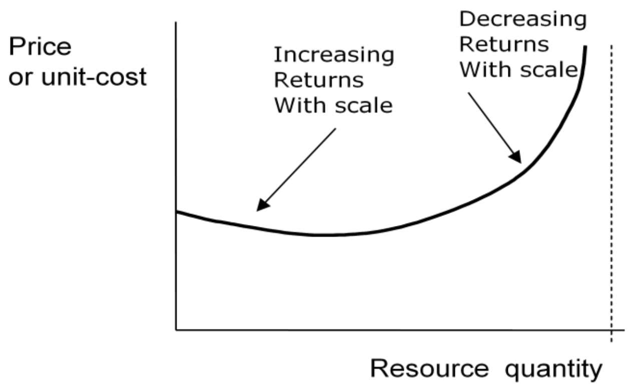
Cogeneration is represented as an efficient frontier of possible electricity and steam combinations from a plant. The possibility frontiers are specified for the following technologies: Combined cycle with extraction, ,Combined cycle with Heat Recovery, Backpressure steam turbine, Condensing steam turbine with post firing, Condensing steam turbine of large power plants, Gas Turbine with heat recovery, Internal combustion engine with cogeneration, Others - backpressure steam for district heating, Fuel Cell, Very small scale Gas Turbine with Heat recovery. The cogeneration facility is modelled as an add-on on new plant types or on existing plants (if option allows) and both the choice of CHP technology and the operation mode are endogenous to the model. The model considers that the feasible combination of electricity and heat output from a thermal plant are constrained within a surface delimited by four lines, as in the following scheme.

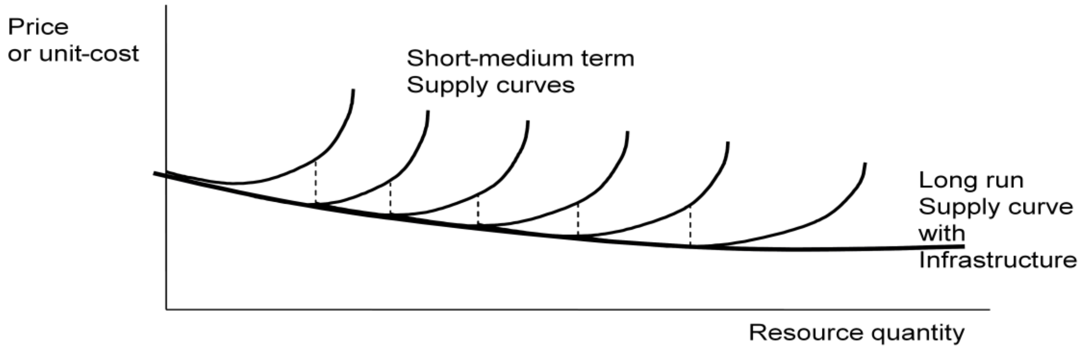


The feasible domain of cogeneration is the area ABCD. Line 1 denotes the maximum electric power and minimum steam combinations. Line 2 denotes the minimum electric power and maximum steam combinations. Line 3 is an iso-fuel line (equal electric efficiency of the plant), per unit of maximum use of nominal electric power. Finally, line 4 is also an iso-fuel line, defined for the minimum electric output necessary to obtain a steam output. Of course, depending on the cogeneration techniques, the slope and the exact position of these lines can change, but the basic shape of the feasible domain for electric and steam output combinations remain the same. The above lines are introduced in the model as linear constraints, specifically calibrated for each cogeneration technique and type of plant. Line 4 (the minimum power) is incompatible with the continuous character of the activity variables, as assumed in the model and therefore of no relevance within the modelling context.

The PRIMES database includes three generic carbon capture technologies (CCS), namely capture at post-combustion stage, capture at pre-combustion stage and the oxyfuel technology (which consists in burning with oxygen instead of air). The generic carbon technologies apply to a series of power plant technologies, including conventional steam turbine plants, supercritical steam turbine plants, fluidized bed combustion plants, integrated gasification combined cycle and gas turbine combined cycle plants. The PRIMES model distinguishes between plants with CCS which are built as CCS plants from the beginning and the possibility of adding auxiliary CCS equipment on plants that when built had not CCS capability. The costs, the performance and the technical possibilities differ in these two cases. Generally, the CCS plants have higher costs and lower thermal net energy efficiency than the corresponding plants without CCS. The model represents transport and storage of CO2 through reduced-form inter-temporal cost-supply curves which are specified per country.

The power agent's profit optimization takes into account non linear cost supply curves of resources used for power generation, as for example for fuels, renewables, sites for nuclear investment, cost of storage of CO2 captured, etc. These cost supply curves incorporate information about the maximum potential of the resources and their decreasing returns of scale associated with their use rate.





The following renewable resources are represented in the power and steam sub-model through non linear cost supply curves:

- Wind Power Low Resource
- Wind Power Medium Resource
- Wind Power High Resource
- Wind Power Very High Resource
- Wind Offshore Power Low Resource
- Wind Offshore Power Medium Resource
- Wind Offshore Power High Resource
- Wind Offshore Power Very High Resource
- Solar PV Low Resource
- Solar PV Medium Resource
- Solar PV High Resource
- Solar Thermal
- Solar PV Very High Resource
- Solar PV very small scale
- Wind very small scale
- Tidal and waves
- Lakes
- Run of River
- Geothermal Medium
- Geothermal High
- Geothermal Small
- Waste Solid
- Landfill Gas
- Biogas produced
- Biomass solid
- Bio-liquid produced or waste.

Non linear cost supply curves are also used for all non renewable fuels, by distinguishing between coal, lignite, diesel, fuel oil, natural gas, coke oven gas (their prices are specified separately for utilities, for CHP and for industrial uses and regarding gas prices vary for base load and peaking units). A cost-supply curve is used for these fuels to represent both market conditions and policy considerations. To quantify such a curve the following are taken into account: maximum fuel availability; possible take or pay conditions; portion of available quantities that may be available at very low prices (example industrial by-products), or take high priority because of policy in place (example indigenous resources, coal mining policies, etc.); upper portions of fuel availability that are considered as risky because of security of supply concerns. A similarly defined cost-supply curve is used for nuclear power considering the possible new plant sites. The cost supply curves change over time reflecting changing market conditions and policy considerations.

The table below shows the list of power and steam technologies represented in the PRIMES power and steam sub-model:

Existing Power Plants (in 2000)
Utility Steam Turbine Fuel Oil
Utility Steam Turbine Fuel Oil CHP
Utility Steam Turbine Refinery Fuels
Utility Steam Turbine Refinery Fuels CHP
Utility Steam Turbine Diesel
Utility Gas Turbine Refinery Fuels
Utility Gas Turbine Refinery Fuels CHP
Utility Steam Turbine Diesel CHP
Utility Gas Turbine Diesel
Utility Gas Turbine Diesel CHP
Utility Internal Combustion Engine Diesel
Utility Internal Combustion Engine Diesel CHP
Utility Steam Turbine Coal
Utility Steam Turbine Coal CHP
Utility Steam Turbine Lignite
Utility Steam Turbine Lignite CHP
Utility Steam Turbine Biomass Solid
Utility Steam Turbine Biomass Solid CHP
Utility Gas Turbine Biogas
Utility Gas Turbine Biogas CHP
Utility Internal Combustion Engine Biogas
Utility Internal Combustion Engine Biogas CHP
Utility Power Plant Coke Oven Gas
Utility Power Plant Coke Oven Gas CHP
Utility Power Plant Blast Furnace Gas
Utility Power Plant Blast Furnace Gas CHP
Utility Steam Turbine Gas
Utility Steam Turbine Gas CHP
Utility Gas Turbine Gas
Utility Gas Turbine Gas CHP
Utility Internal Combustion Engine Gas
Utility Internal Combustion Engine Gas CHP
Utility Gas Turbine Combined Cycle 1st
Utility Gas Turbine Combined Cycle 1st CHP
Utility Gas Turbine Combined Cycle 2d
Utility Gas Turbine Combined Cycle 2d CHP
Industrial Steam Turbine Fuel Oil
Industrial Steam Turbine Fuel Oil CHP
Industrial Steam Turbine Refinery Fuels
Industrial Steam Turbine Refinery Fuels CHP
Industrial Steam Turbine Diesel
Industrial Gas Turbine Refinery Fuels
Industrial Gas Turbine Refinery Fuels CHP
Industrial Steam Turbine Diesel CHP
Industrial Gas Turbine Diesel
Industrial Gas Turbine Diesel CHP
Industrial Internal Combustion Engine Diesel
Industrial Internal Combustion Engine Diesel CHP
Industrial Steam Turbine Coal
Industrial Steam Turbine Coal CHP
Industrial Steam Turbine Lignite
Industrial Steam Turbine Lignite CHP
Industrial Steam Turbine Biomass Solid
Industrial Steam Turbine Biomass Solid CHP
Industrial Gas Turbine Biogas
Industrial Gas Turbine Biogas CHP
Industrial Internal Combustion Engine Biogas
Industrial Internal Combustion Engine Biogas CHP
Industrial Power Plant Coke Oven Gas
Industrial Power Plant Coke Oven Gas CHP
Industrial Power Plant Blast Furnace Gas
Industrial Power Plant Blast Furnace Gas CHP
Industrial Steam Turbine Gas
Industrial Steam Turbine Gas CHP
Industrial Gas Turbine Gas
Industrial Gas Turbine Gas CHP
Industrial Internal Combustion Engine Gas
Industrial Internal Combustion Engine Gas CHP
Industrial Gas Turbine Combined Cycle 1st
Industrial Gas Turbine Combined Cycle 1st CHP
Industrial Gas Turbine Combined Cycle 2d
Industrial Gas Turbine Combined Cycle 2d CHP
Nuclear Plant
Lakes Hydro
Run of River
Wind Power
Solar PV
Geothermal High Enthalpy
Boilers Fuel Oil
Boilers Diesel Oil
Boilers Gas
Boilers Coal
Boilers Lignite
Boilers Biomass
Boilers COG
Boilers BFG
DH Boilers Gas
DH Boilers Fuel Oil
DH Boilers Biomass
DH Boilers Coal
DH Boilers Lignite
DH Boilers Diesel Oil
DH Boilers COG
DH Boilers BFG

Technologies candidate for Investment
Steam Turbine Refinery Fuels
Gas Turbine Refinery Fuels
Steam Turbine Coal Industrial
Steam Turbine Lignite Industrial
Steam Turbine Gas Industrial
Steam Turbine Biomass Industrial
Gas Turbine Diesel Industrial
Gas Turbine Gas Industrial
Gas Combined Cycle Industrial
IG Biomass CC Industrial
Steam Turbine Fuel Oil Conventional
Steam Turbine Coal Conventional
Steam Turbine Lignite Conventional
Steam Turbine Biomass Solid Conventional
Steam Turbine Gas Conventional
Gas Turbine Combined Cycle Gas Conventional
Peak Device Diesel Conventional
Peak Device Gas Conventional
Peak Device Biogas Conventional
Steam Turbine Coal Supercritical
Steam Turbine Lignite Supercritical
Steam Turbine Fuel Oil Supercritical
Fluidized Bed Combustion Coal
Fluidized Bed Combustion Lignite
Integrated Gasification Combined Cycle Coal
Integrated Gasification Combined Cycle Lignite
High Temperature Solid Biomass Power Plant
Integrated Gasification Combined Cycle Biomass
Gas Turbine Combined Cycle Gas Advanced
Pulverised Coal Suprcritical CCS post combustion
Pulverised Lignite Suprcritical CCS post combustion
Fuel Oil Suprcritical CCS post combustion
Integratedl Gasification Fuel Oil CCS pre combustion
Pulverised Coal Suprcritical CCS oxyfuel
Pulverised Lignite Suprcritical CCS oxyfuel
Integrated Gasification Coal CCS post combustion
Integrated Gasification Coal CCS pre combustion
Integrated Gasification Coal CCS oxyfuel
Integrated Gasification Lignite CCS post combustion
Integrated Gasification Lignitel CCS pre combustion
Integrated Gasification Lignite CCS oxyfuel
Gas combined cycle CCS post combustion
Gas combined cycle CCS pre combustion
Gas combined cycle CCS oxyfuel
Nuclear second generation
Nuclear third generation
Nuclear Fourth generation
Nuclear Fusion
Internal Combustion Engine Diesel
Internal Combustion Engine Gas
Internal Combustion Engine Hydrogen
Peak Device Diesel Advanced
Peak Device Gas Advanced
Peak Device Biogas Advanced
Fuel Cell Gas
Fuel Cell Methanol
Fuel Cell Hydrogen
Small Fuel Cell Gas
Small Fuel Cell Methanol
Small Fuel Cell Hydrogen
Small Device Light Oil
Small Device Gas
Small Device Biomass Gas
Wind Power Low
Wind Power Medium
Wind Power High
Wind Power Very High
Wind Offshore Power Low
Wind Offshore Power Medium
Wind Offshore Power High
Wind Offshore Power Very High
Solar PV Low
Solar PV Medium
Solar PV High
Solar Thermal
Solar PV Very High
Solar PV small scale
Wind small scale
Tidal and waves
Lakes
Run of River
Geothermal Medium
Geothermal High
Geothermal Small
Boilers Fuel Oil
Boilers Diesel Oil
Boilers Coal
Boilers Lignite
Boilers Gas
Boilers Biomass
Boilers COG
Boilers BFG
Boilers Hydrogen
DH Boilers Hydrogen
DH Boilers Gas
DH Boilers Fuel Oil
DH Boilers Biomass
DH Boilers Coal
DH Boilers Lignite
DH Boilers Diesel Oil
MBW incinerator CHP
MBW incinerator DH

Tecnhnologies applicable to any thermal plant as an add-on
CHP technologies
Combined cycle with extraction
Combined cycle with Heat Recovery
Backpressure steam turbine
Condensing steam turbine with post firing
Condensing steam turbine of large power plants
Gas Turbine with heat recovery
Internal combustion engine with cogeneration
Others - backpressure steam for district heating
Fuel Cell
Very small scale Gas Turbine with Heat recovery
Emission Reduction technologies as add-on
Desulpurisation
Selective Catalytic Reduction of NOx
Electrostatic precipitator
Post-combustion Carbon capture (add-on)

Information	
Input Data	Overnight Investment Cost
	Fixed O&M Cost
	Variable Non-fuel Cost
	Heatrate
	Self-consumption rate
	Availability Rate
	Lifetime
Output Data	Production per load segment
	Capacity
	Replacement Investment
	Estension Investment
	Premature replacement
	Investment ina New Site
	Consumption of Fuels with multi-fuel capability
	Emissions (CO2, SO2, NOx, VOC, N2O, PM)

THE PRIMES GAS SUPPLY SUB-MODEL

The PRIMES energy system model has recently been expanded to include a gas supply module that provides projections for gas imports by country of origin, by transport mean (LNG, pipeline) and route as well as wholesale gas prices. The gas model studies the relationships between gas resources, gas infrastructure and the degree of competition in gas markets over the Eurasian area and evaluates their impacts on gas prices paid by gas consumers in the EU Member-States.

The gas model is a dynamic market model, which covers the entire Eurasian area and the global LNG market. It presents in detail the gas infrastructure, present and future, as well as the different "agents" that participate in the market. The agents compete for access to gas infrastructure and for gas supply to customers, the latter being responsive to gas prices. The model considers the oligopolistic structure of the gas market, which includes market imperfections [2] and can accommodate different assumptions about the degree of competition and the integration of the EU gas internal market.

The gas supply module uses as input the gas demand projections, available from the end-use sectors for demand (twelve industrial sectors, transport, residential, services and agriculture) and electricity generators of the PRIMES model. The model determines the equilibrium by finding the prices such that the quantity producers find best to supply matches the quantity consumers wish to use. Thus, the flow of gas over the entire gas network, the economic decisions of the agents and the market prices are endogenous and are computed dynamically. The module operates on an inter-temporal basis from 2000 to 2030 and produces results by five year period.

The gas module represents in detail the present and future gas infrastructure of each Member State and of gas producing and consuming countries of the Eurasian area, including Russia, Ukraine, Belarus, the Caspian countries, Middle East, Persian Gulf and North African countries. The model also represents the supply possibilities of LNG worldwide and also the demand for LNG. The infrastructure types include: gas pipelines (represented as a network), gas storage, LNG terminals, gas production and gas liquefaction.

The interregional flow of gas is simulated on the basis of a gas transport network consisting of high pressure gas pipelines and ship routes for LNG. A simplified representation of the physical natural gas pipeline system is

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[2] In technical terms the model solves a Nash-Cournot oligopoly game with conjectural variations to find imperfect market equilibrium.

used to establish the current and possible interregional transfers, allowing moving the gas from the producers (the supply source) to end-users.

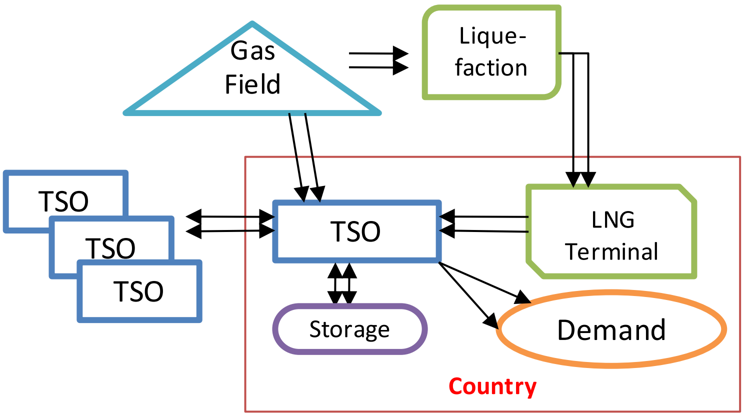
Each country contains a Transmission System Operator (TSO) which manages flows coming into and out of the region. Each TSO represents a transshipment node in the gas supply module. The nodes are connected by arcs, defined to represent the gas flows between TSOs. Each arc provides an aggregation of the pipelines between any two neighbouring countries. In cases where the aggregation incorporate some pipelines flowing one direction and other pipelines flowing in the opposite direction, bidirectional flows are allowed.

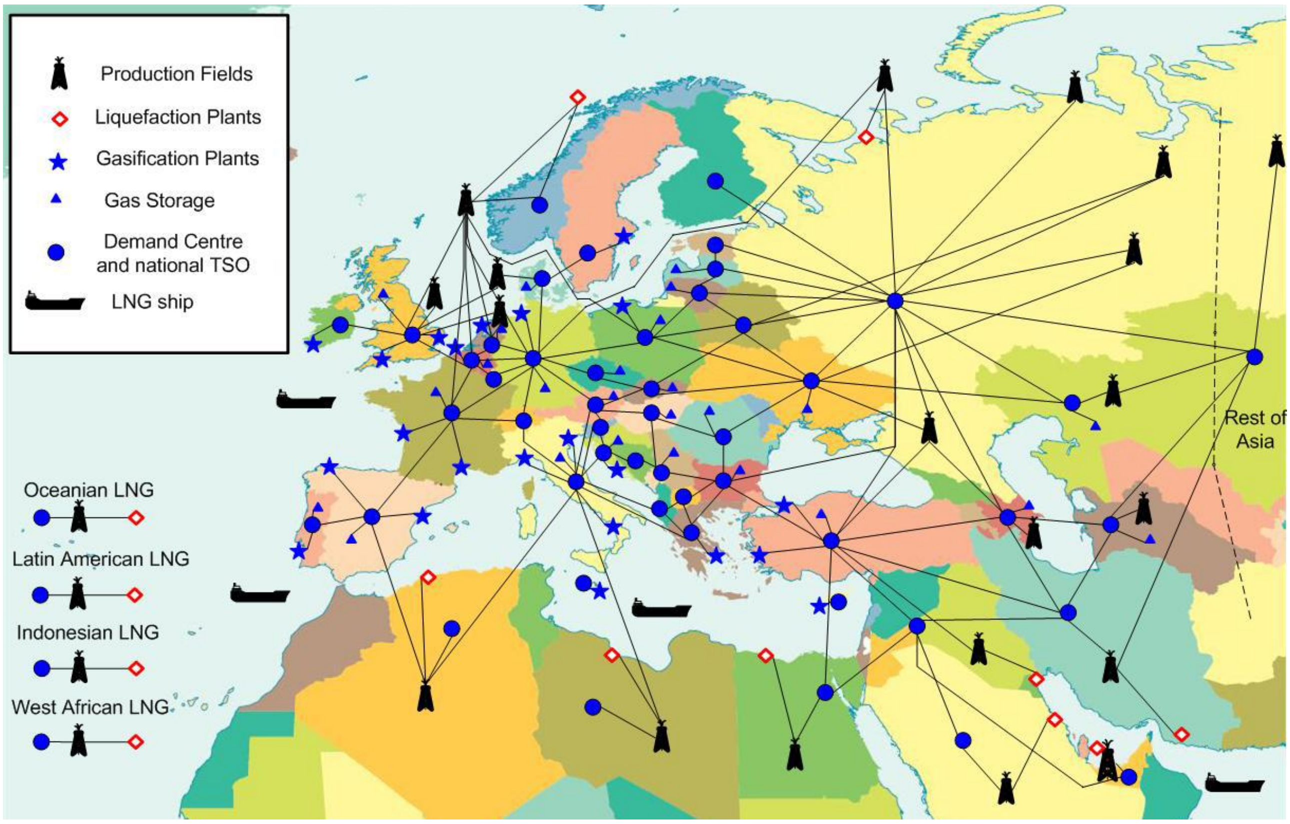
Arcs are also established from gas producers (fields) to transshipment nodes (TSOs) and to gas liquefaction plants. Only one gas producer and one LNG producer, if applicable, are considered by country, whereby the major gas (fields) and/or the liquefaction plants are represented for each country. Also, the gasification plants (one by one) and the storage facilities (aggregated by country) are represented. The supply from each country is directly available to only one transshipment node. If the supply is made available to other countries (at an adjoining transshipment node) it needs first to pass through the transshipment node in the country of origin. Bottom-up cost data (capital and variable operating) associated with each gas infrastructure and gas transportation costs, including LNG ship costs, are function of distances. The final consumer gas prices reflect costs but also market-related and depletion-related rents.

Gas supply and demand are balanced on a daily basis. A few typical days are represented per country and gas demand variability is linked to the gas use patterns by sector. One of the supply sources connected to each transshipment node represents net storage withdrawals in the country during the peak period. During the off-peak period, one of the demand nodes represents net storage injections. The gasification plants are also modelled as storage plants.

Third party access is assumed for most of gas infrastructures and regulated tariffs are applied, which are determined by the model. Exogenous parameters may be used to reflect different regulatory policies for access and use of gas infrastructure. Also long term contracts can be imposed as constraints. Upper and lower variability margins of flows over pipelines, reflecting physical and/or contractual limitations, are represented.

Gas producers and gas suppliers (traders) are considered as separate companies. A gas supplier and/or trader is assumed to have access to a limited number of gas production (or LNG) nodes and to a subset of gas demand nodes. This can vary by scenario to reflect more intensive competition and market integration. The traders are assumed to operate as financial brokers to profit from gas price differences among country-specific demand nodes. It is also assumed that each country-specific TSO operates a gas pool market (a hub) per country which seeks to maximise consumer and producer surplus under imperfect competition among suppliers and price-elastic demand.





The **TSOs** operate as regulated monopolies and seek a regulated maximisation of profits from balancing demand and supply at each node. The TSOs perform a daily balancing of gas demand and supply, only in terms of "mass" of gas. Pipeline capacities and investments are exogenous. Volume dependent curves are specified for computing tariffs for transportation between transshipment nodes (e.g. Member States and neighbouring – transit - countries). The tariff curves extend beyond current pipeline capacity levels and relate incremental capacity to corresponding estimated rates. The TSOs charge tariffs and apply mark-ups for transportation service.

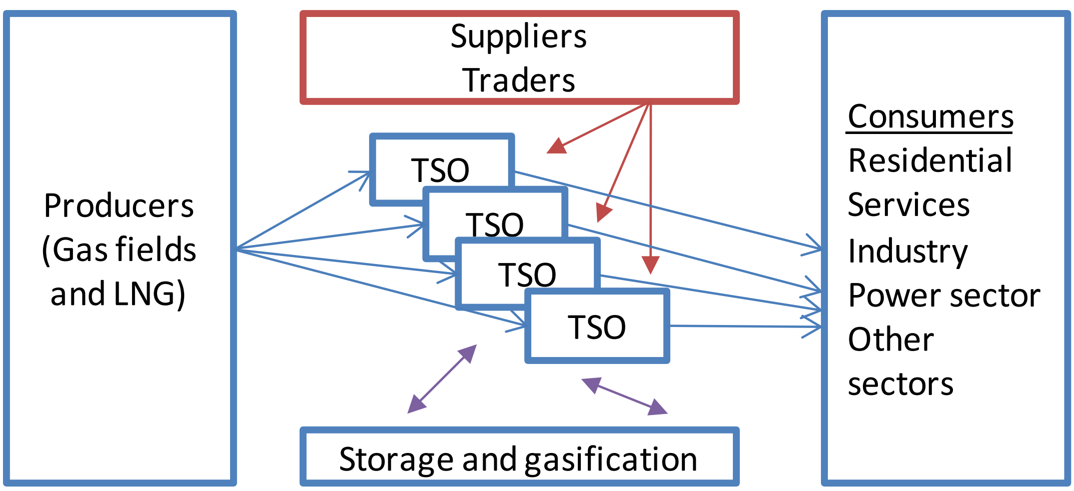
Gas producers (fields) seek the maximization of rents from inter-temporal management of their exhaustible resources, selling to the pool managed by the TSO, while the **LNG producers**, gas storage and LNG storage operators maximize the profits from exploiting the storage facility. Gas production costs and potential rents are represented by cost-supply curves with increasing slope, constrained by resource potential. Use of gas facilities entails variable (non linear) and fixed costs.

Gas field reserves are specified exogenously in the base year but follow a net depletion profile afterwards including further development of reserves. Liquefaction, storage and LNG gasification capacities and investment are exogenous. The dates of commissioning of new infrastructures are exogenous.

The link between the TSOs and the gas consumers (residential sector, services sectors, agriculture sector, transport, industrial sectors and electric generators) is provided by the **gas supplier and/or trader**. Gas suppliers and traders seek to maximize profits by generating revenues with gas sales to consumers, while they incur costs by purchasing gas from pools that are managed by TSOs.

Demand functions for **gas consumers** are price elastic. Demand detailed per load segment is linked with PRIMES demand modules.

The gas supply module, linked with PRIMES, determines oligopolistic market equilibrium and calculates the market prices of gas and LNG per country, year and gas load segment. It also derives the gas flows across the entire Eurasian gas system, classified per gas facility, year and load segment. Congestion for each gas facility (pipeline, LNG terminal, storage, etc.) are reflected by the marginal prices.



THE PRIMES BIOMASS SUPPLY MODEL

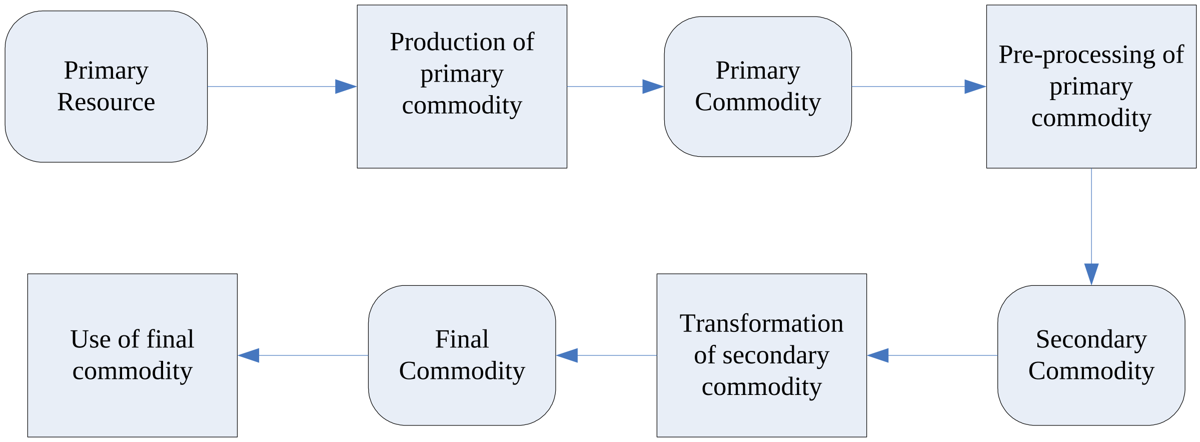
The biomass system model is linked with the PRIMES large scale energy model for Europe and can be either solved as a satellite model through a closed-loop process or as a stand-alone model. The biomass model follows the standards of the PRIMES model: it covers all the EU countries and other associated European countries; it performs dynamic projections to the future from 2000 until 2030 in 5-year time period step; it is calibrated to base years 2000 and 2005 so as to reproduce Eurostat statistics; it computes endogenously the energy and resource balances, the investments, the costs and prices, and the emission of pollutants. The model represents policy instruments, such as taxes, subsidies, technology progress, emission and other policy constraints, and certificate or allowances markets.

It is an economic supply model that computes the optimal use of biomass/waste resources and investment in secondary and final transformation, so as to meet a given demand of final biomass/waste energy products, projected to the future by the rest of the PRIMES model. The biomass supply model determines the consumer prices of the final biomass/waste products used for energy purposes and also the consumption of other energy products in the production, transportation and processing of the biomass/waste products. Prices and energy consumption are conveyed to the rest of the PRIMES model. A closed-loop is therefore established. Upon convergence, a complete energy and biomass scenario can be constructed.

According to the model structure primary commodity (e.g. raw biomass, organic wastes etc) is produced/derived from the primary resource (e.g. biomass energy crops). The primary commodity is, in general, passed through a pre-processing stage (e.g. drying) that produces a secondary/intermediate commodity. The secondary commodity is the input to the transformation process from which the final energy product (e.g. bio-fuel) is derived. Logistics are taken into account as part of the different processes.

The primary production of biomass is classified into four categories, namely energy crops, forestry, aquatic biomass and wastes. Depending on the type of the plants that are cultivated, energy crops are further distinguished into starch, sugar, oil and wood crops. This classification is dictated by the differentiation of the methods that each plant category may be processed with and the final products that derive from them. Starch crops include resources such as maize, wheat, barley etc, sugar crops refer mainly to sugar beet and sweet sorghum and oil crops consist of rapeseed, sunflower seed, olive kernel etc. Regarding wood crops there is a distinction between pure lignocellulosic crops, such as poplar, willow etc, and short rotation herbaceous lignocellulosic crops like miscanthus, switch grass, reed etc.

Agricultural residues were initially treated similarly with biomass energy crops and a categorisation depending on the type of the actual crops was proposed. The common nature of most of the agricultural residues, however, and the difficulty in finding appropriate data, concerning the potential for production of each agricultural residue type, led to the abolishment of this approach and the adoption of one common type consisting of all residues which is included in the waste category.



Energy Crops	
Starch Crops	**Waste**
Sugar Crops	Agricultural Residues
Wood Crops	Industrial Solid
Oil Crops	Industrial Bagasse
	Industrial Pulp
Forestry	Used vegetable oil
Wood Platform	Municipal Solid Sewage
Wood Residues	Sludge Landfill Gas
	Organic Manure
Aquatic Biomass	Animal Platform

Forestry is split into wood platform, i.e. organised and controlled cutting of whole trees for energy use, and wood residues, i.e. the collecting of forestry residues only.

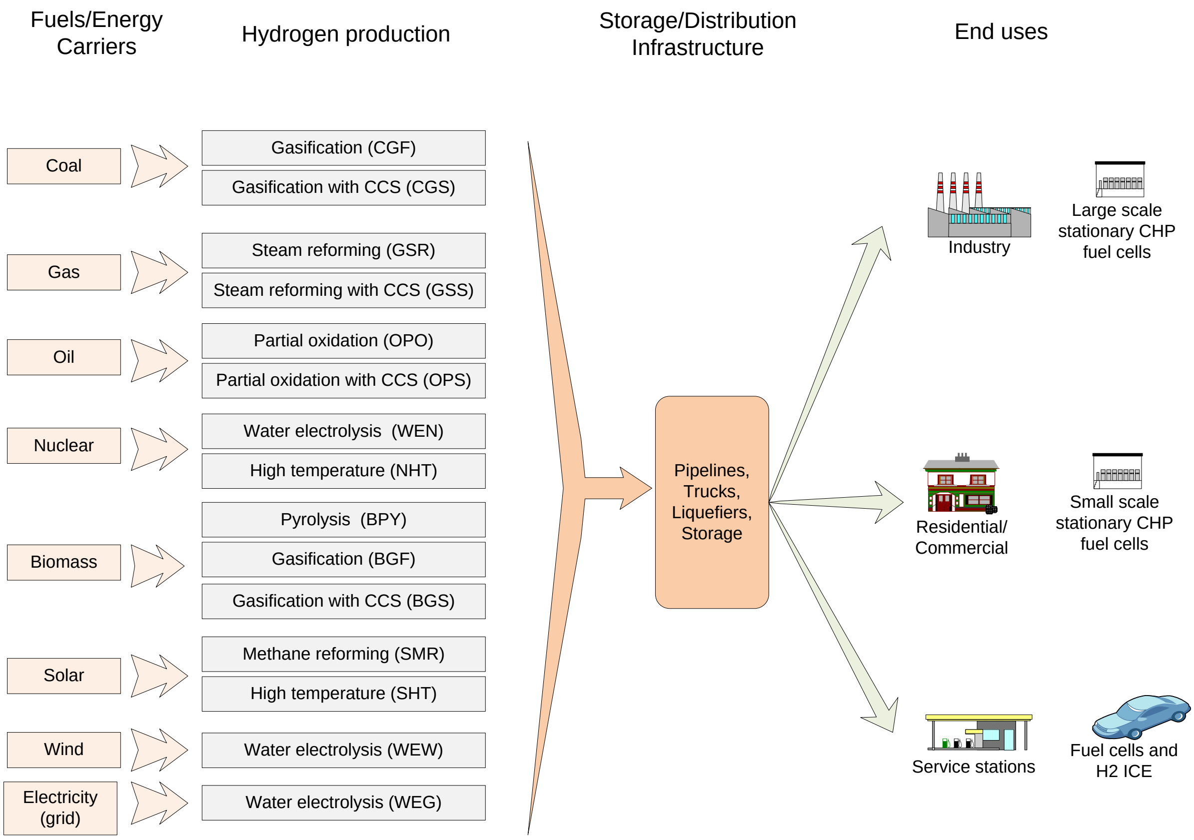
Apart from agriculture residues, several types of wastes have also been identified as potential sources of energy supply. This include industrial solid waste, industrial liquid waste, pulp waste, used vegetable oils, municipal solid waste, sewage sludge, landfill gas, organic manure and animal wastes. This classification was based both on further processing differentiation as well as on data availability.

Based on the general outline of the biomass to energy conversion chain, a complete, to the extent possible, list of the different conversion routes, from primary resource to final commodity, was identified. The biomass conversion chains that were identified during the model specification and data collection process were categorised appropriately to form the biomass system that in total includes sixteen (16) primary resources, seven (7) secondary and ten (10) final transformation processes that produce a total number of thirteen (13) final biomass energy products.

Secondary Transformation	**Final Transformation**
Pellettising	**Solid Biomass**
Wood preparation	*Charcoal*
Sugar pre-treatment	**Biochemical**
Plant Oil pre-treatment	*Fermentation*
Solid waste pre-treatment	*Acid/Enzymatic hydrolysis*
Liquid waste pre-treatment	*Anaerobic digestion*
Gas waste conditioning	*Transesterification*
	Thermo-chemical
	Pyrolysis
	Hydrothermal
	Gasification
	Partial oxidation
	Fluidized bed
	Steam flow

Solids	**Liquid**	**Gaseous**
• *Solid biomass for direct combustion*	• *Pure vegetable oil*	• *Bio-gas*
• *Pellets*	• *Bio-ethanol*	• *Synthetic Gas*
• *Charcoal*	• *Bio-diesel*	• *Bio-hydrogen*
• *Mass burn waste*	• *Heavy Bio-Oil*	
• *Refuse derived fuel*	• *Fischer Tropsch Diesel*	

The hydrogen module of PRIMES model incorporates a large number of technologies for hydrogen production, distribution and end use. In order to describe more accurately some key technologies, such as fuel cells, these technologies are included in the model on component-by-component basis. The characterisation of the technologies and their components was based on the common information base of the CASCADE MINTS project.



The major end uses of hydrogen in PRIMES are for vehicle propulsion and for production of steam or heat and electricity. In this sense, hydrogen is introduced as an energy carrier in the road transport sector, in industry, in the residential/commercial sectors and in power/steam production.

Two kinds of vehicle propulsion engines that use hydrogen are included in PRIMES: fuel cells and internal combustion engines. The fuel cell engine is further differentiated into stack and system components. Moreover, the stacks and systems themselves are varying depending on the fuel used in the fuel cell cars (hydrogen or gasoline). On the other hand, the internal combustion engines technically are not different from the internal combustion engines that are used today in oil-powered vehicles. However, in the common information database they display different economic performance, so it was decided to include them as a different technology in the model.

For automotive on-board hydrogen storage, two options are included in the model: hydrogen in liquid form and hydrogen in gaseous form. These two options compete in the model, since each of them needs its own specific infrastructure to support it.

Onboard gasoline reformers are also included in PRIMES, in order to allow for onboard hydrogen production. These reformers are used in the fuel cell vehicles, bypassing in this way the need for hydrogen distribution infrastructure.

In total, in PRIMES the hydrogen related technologies for mobile applications are two types of fuel cell stacks, two types of fuel cell systems, two types of on board hydrogen storage, one type of onboard reformer and a hydrogen IC engine. All these result in eight different hydrogen related technologies in road transport. These components are combined together to define five new vehicle types in the model:

- Fuel cell cars powered with liquid hydrogen
- Fuel cell cars powered with gaseous hydrogen
- Fuel cell cars with on-board reformer powered with gasoline
- Internal combustion engine cars fuelled with liquid hydrogen
- Internal combustion engine cars fuelled with gaseous hydrogen

The hydrogen powered cars compete with the rest of the car types that are included in the model (Otto, diesel, biodiesel ICE, bio gasoline ICE, hybrid, plug-in hybrid, electric). The decision is based on the cost per vehicle kilometre of each car type. In each year, the increased transport activity generates the need for new vehicle registrations and the different vehicle types are competing to gain share in the new market. The determination of the shares involves the total cost per vehicle kilometre, the relative maturity of the technology and (including acceptability of new technologies in the sector) and saturation effects. The new cars are added to the existing stock. From the car stock, and by applying efficiencies and annual average mileages, the fuel consumption is determined.

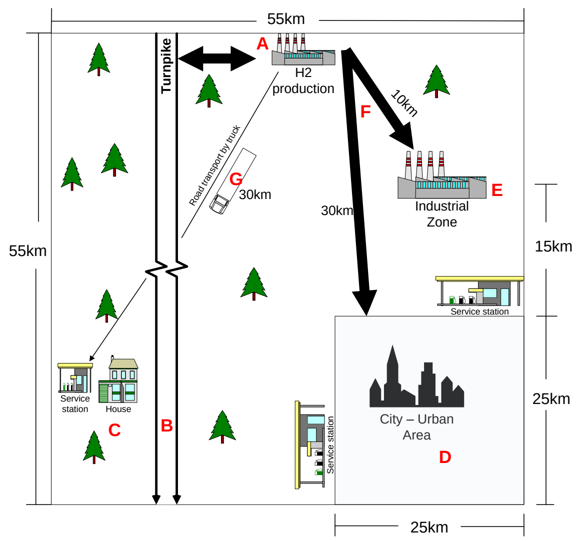
In PRIMES hydrogen is also used for the combined production of heat and electricity. The fuel cell CHP plants are distinguished according to their size and the fuel that they use. Small scale stationary fuel cell CHP plants (1-5Kw) are directly linked with low voltage grid (small scale applications), while fuel cell CHP plants of a size of up to 300Kw are used for the combined production of low enthalpy steam and electricity in the industrial sectors (medium voltage). Regarding the fuel that they use, two types are considered, one which is fuelled directly with hydrogen and one which uses natural gas and onsite steam reforming. For a more accurate characterisation of the fuel cell CHP plants, the fuel cell stacks, the fuel cell systems and the onsite reformers are defined individually. In total, six hydrogen related technologies are considered for stationary applications in the residential/commercial and industrial sectors:

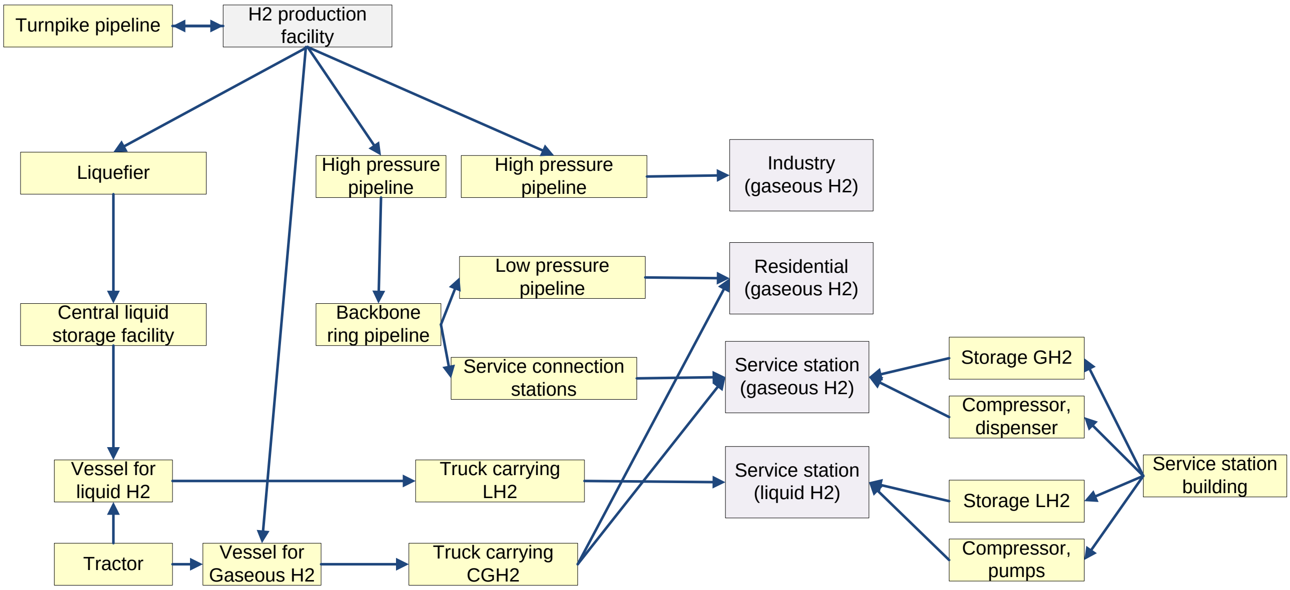
- Fuel cell stacks and fuel cell systems for small scale CHP
- Fuel cell stacks and fuel cell systems for large scale CHP
- Onsite natural gas reformers

PRIMES implement a stylized network of hydrogen transport and distribution, which includes portions of the following technologies:

- Turnpike pipelines of a large scale diameter, which serve as storage medium and load balancing tool. The pipeline is connected with hydrogen production facilities and they actually constitute a large national and international network.
- High pressure transmission pipeline, connecting the turnpike pipelines and the production facilities with the residential/commercial urban areas.
- Medium pressure urban ring pipelines as distribution backbones to ensure higher availability of supply.
- Service stations connection lines, which connect the service stations to the ring.
- Low pressure pipelines, which connect households/stores/offices with the backbone ring.
- High pressure transmission pipeline, connecting the turnpike pipelines and the production facilities with the industrial areas.
- Trucks for delivering gaseous hydrogen to rural and urban areas.
- Trucks for delivering liquid hydrogen to rural and urban areas.
- Liquefiers for hydrogen liquefaction.
- Centralised liquid hydrogen storage facilities.
- Service stations delivering gaseous or liquid hydrogen to vehicles.

Depending on the hydrogen demand scenario, the model determines per country a certain configuration of the transport and distribution infrastructure which is economically consistent with the size and the sectoral structure of the hydrogen market. Costs of the infrastructure are reflected on to different hydrogen prices depending on the consumer type and the kind of connection to the infrastructure.





PRIMES include a detailed portfolio of hydrogen production technologies, as a result of the work performed in the common information base of the CASCADE MINTS project.

Gas	Gas steam reforming Gas steam reforming with CCS
Coal	Coal partial oxidation Coal partial oxidation with CCS Coal gasification Coal gasification with CCS
Oil	Oil partial oxidation Oil partial oxidation with CCS
Biomass	Small scale biomass gasification Large scale biomass gasification Large scale biomass gasification with CCS Biomass pyrolysis
Solar	Solar methane reforming Solar high temperature thermochemical cycle
Nuclear	Water electrolysis from dedicated nuclear plant Nuclear high temperature thermochemical cycle
Wind	Water electrolysis from dedicated wind plant
Electricity (Grid)	Water electrolysis from electricity grid

The above technologies compete in order to satisfy the hydrogen demand. The investment decision is based on the production cost from each technology. In each year the model determines the required new investments, by taking into account scrapping, and then calculates the shares of the production technologies (using a Weibull function) to allocate new investments.

Long term average cost pricing is applied for the production cost of hydrogen. The consumer price also includes overheads for the storage and distribution of hydrogen plus any taxes.

PRIMES-TREMOVE TRANSPORT MODEL

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 new transportation model is much more detailed than the previous version and its mathematical structure is considerably more 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.

MODEL STRUCTURE

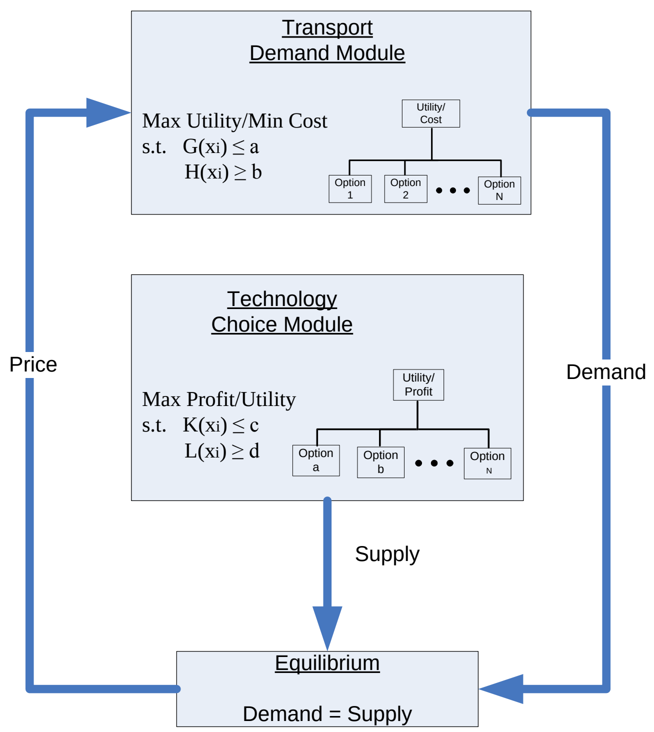
The model consists of two main modules, the transport demand allocation module and the technology choice and equipment operation module. The two modules interact with each other and are solved simultaneously.

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.



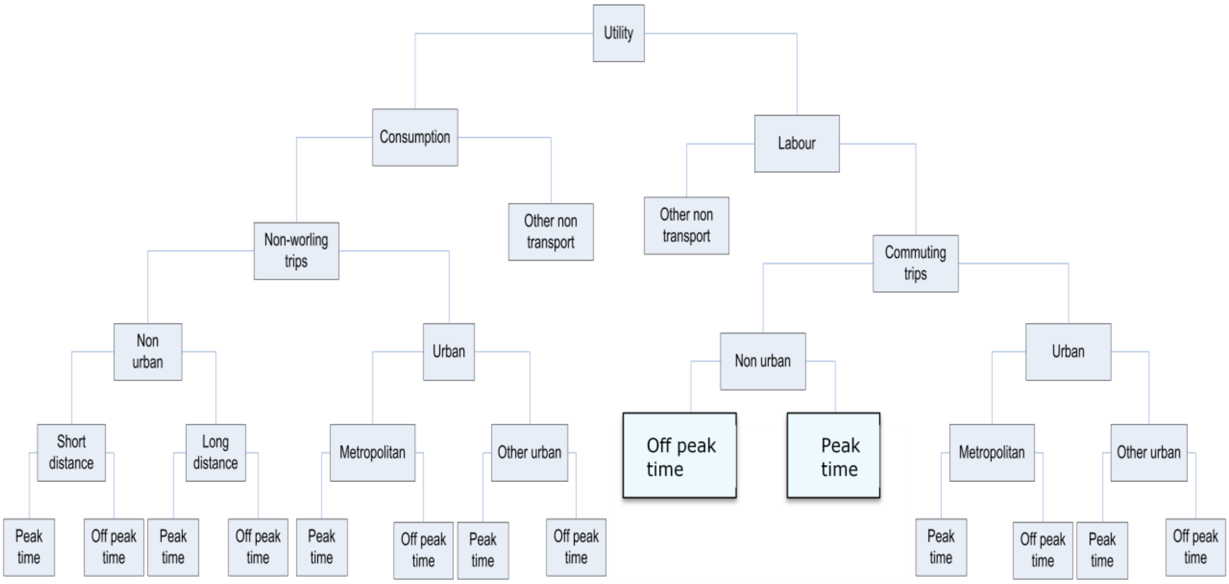
THE TRANSPORT DEMAND MODULE

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.

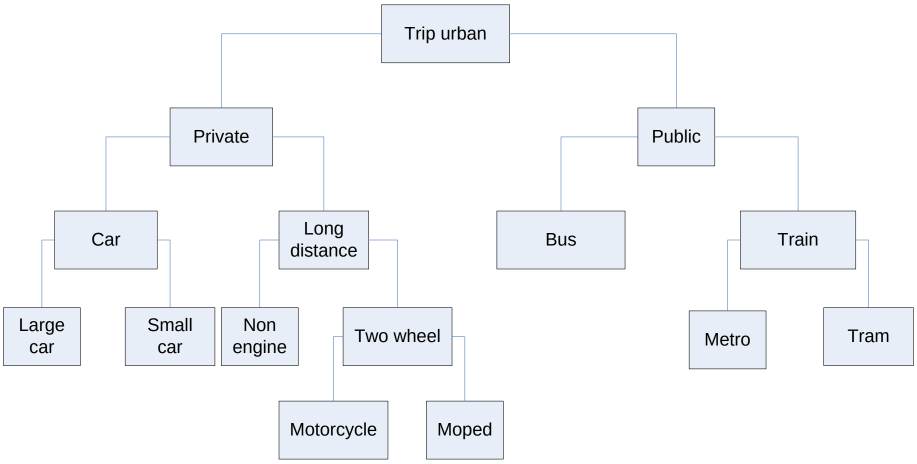
In passenger transport the representative individual, i.e. the passenger, is seeking to maximise a general utility function subject to a budget constraint that represents the total income. The cardinal expression of the individual's utility is assumed to be determined by modal transport cost, an individual's 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.

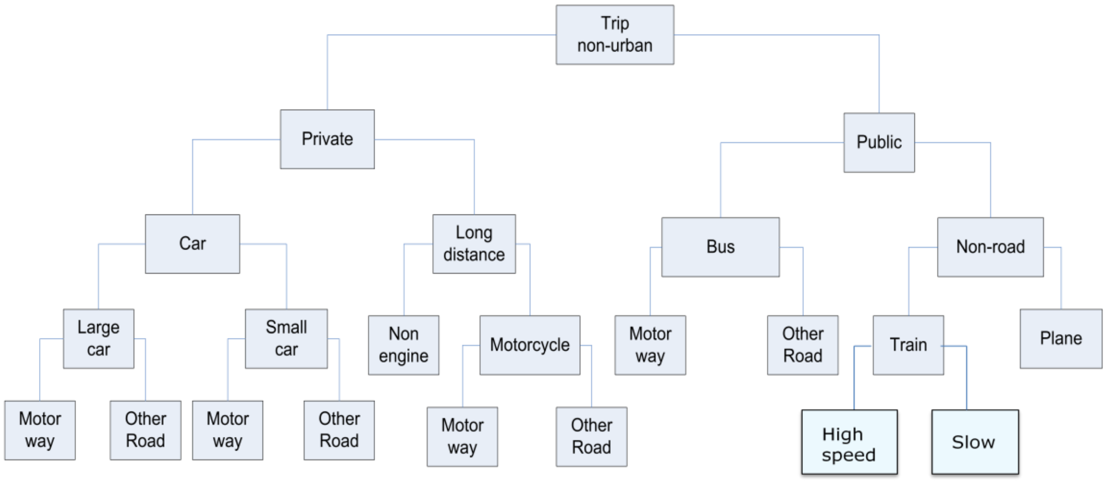
Initially the individual is deciding between the modal transport choices, i.e. whether to make a trip or not, the geographical and temporal identification of the trip etc. Each branch of the initial decision tree is further subdivided into several branches representing various modal choices. Two general 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

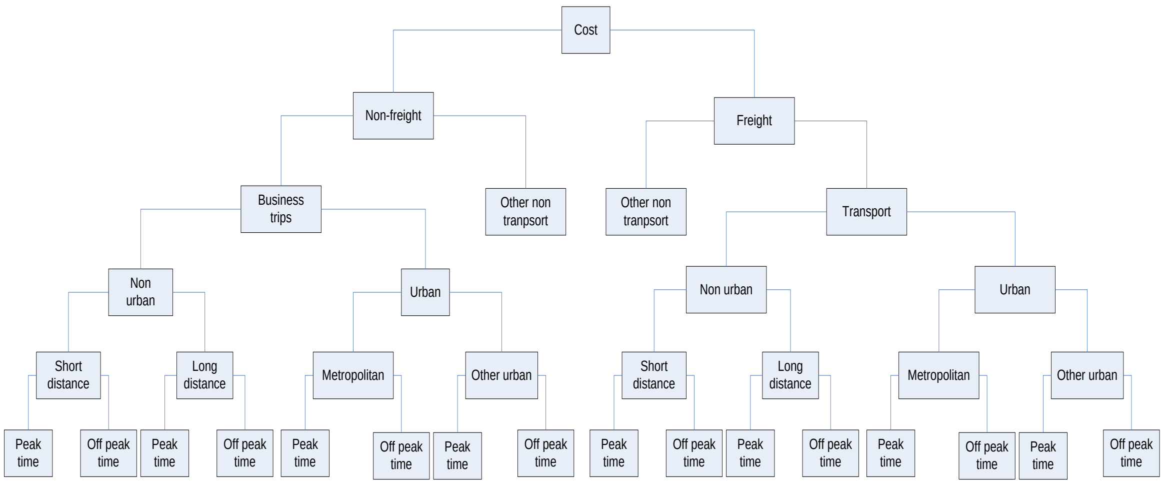


PRIVATE PASSENGER SECONDARY DECISION TREE ON URBAN TRANSPORT

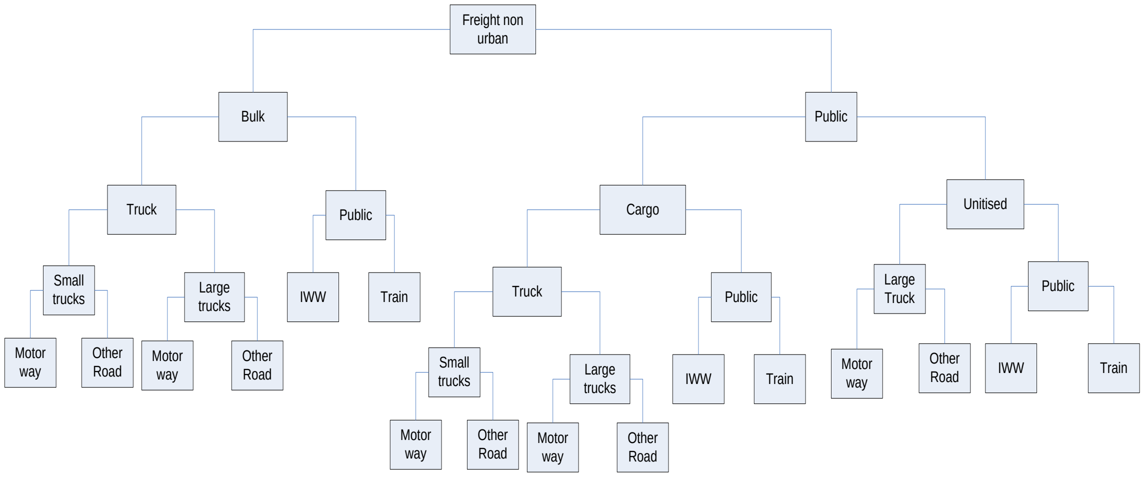


PRIVATE PASSENGER SECONDARY DECISION TREE ON NON-URBAN TRANSPORT

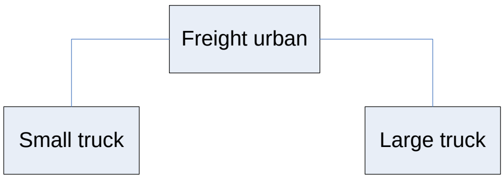
In a similar way the representative firm seeks to minimise total cost of satisfying its transport needs either regarding transportation of goods or business trips. The overall decision process of the firm is modelled as a nested CES cost function. The secondary decision process regarding the modal choice 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

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.

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.

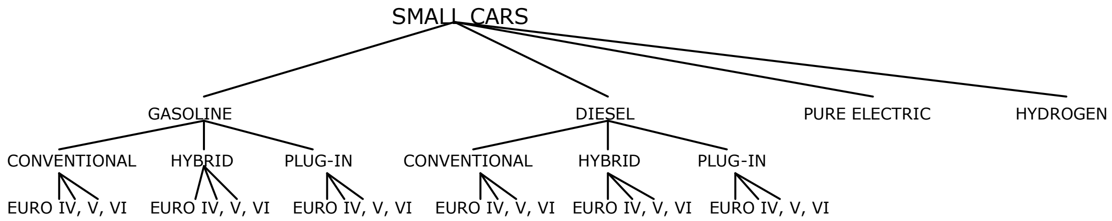
For road transport the actual vehicle stock is split into several vehicle types, and categories including passenger cars, motorcycles and mopeds, busses and coaches, light and heavy duty trucks. Different vehicle technologies and vintages depending on consumption, fuel type and emission standards are 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 passengers 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 (ie 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 behavior is modeled 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 a modified Weibull function.

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.

AIR TRANSPORT

For air transport, there exist three technologies indicating the potential technology progress of the sector. A conventional one bearing 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.

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

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

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 to provide a decent autonomy. 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.

TIME HORIZON

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.

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

<table>
<tr><th>Vehicle Category</th><th>Vehicle Type</th><th colspan="3">Vehicle Technology</th></tr>
<tr><td rowspan="3"></td><td>Capacity 50-250 cc</td><td colspan="3" rowspan="3">4-stroke technology using gasoline/biofuels
or electric motors</td></tr>
<tr><td>Capacity 250-750 cc</td></tr>
<tr><td>Capacity 750cc</td></tr>
<tr><td rowspan="2">Mopeds</td><td>Moped Conventional, Gasoline, biofuels</td><td colspan="3">Conventional, Euro I-V</td></tr>
<tr><td>Electric mopeds</td><td colspan="3">Pure electric technology</td></tr>
<tr><td rowspan="12">Light Duty Vehicles (<3.5 ton)</td><td>Gasoline</td><td colspan="3">Conventional, Euro I-V</td></tr>
<tr><td>Hybrid Gasoline</td><td colspan="3">LDV gasoline hybrid technology</td></tr>
<tr><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>

Table 1:Vehicle technologies classification

Assumptions:

- 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.
- Plug-in hybrid passenger cars are supposed to have an all electric range of either 20 or 40 or 80 km where the pure electric vehicles of either 150 or 250 or 400 km depending on their size.

- 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 non urban.
- In the technology choice model there is the option of hybrid diesel powered busses and coaches.

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

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

CLOSED-LOOP INTERACTIONS BETWEEN TRANSPORT SECTOR AND THE REST OF THE ENERGY SYSTEM

A transport sector scenario is part of energy demand projection to the future. The fuel mix in this demand projection is endogenous in the transport model. Hence: demand for oil products are conveyed to the refinery model, which determines requirements for crude oil and other energy forms and evaluates costs and prices of petroleum products; demand for electricity used in transportation, specified by load segment depending on the time pattern of the load in transportation (e.g. time of charging of batteries, load pattern of electric rail), add to demand for electricity by other sectors and the electricity supply model determines fuel mix, investment, costs and electricity prices; demand for biofuels used in transportation is conveyed to the biomass supply sub-model which determines the use of biomass/waste feedstock, the possible development of energy crops, the costs and prices of biofuels; possible demand for hydrogen for transportation is used by the hydrogen supply model which determines the hydrogen production fuel mix, investments, costs and prices of hydrogen; similarly gas demand for transportation is considered by the gas supply model. All the supply model generate projections of the end-use prices of the various energy forms and fuels, which are further used by the transportation sector model influencing demand and the fuel mix in this sector. A closed-loop is then established which lead to simultaneous markets equilibrium, dynamically until the end of the time horizon of the model-based projection. All demand and supply models estimate emissions of greenhouse gases, acid rain pollutants and urban air quality pollutants. These emissions interfere with policy objectives and targets which may be represented in a scenario, for example involving pollution or carbon taxes, ETS market, non ETS carbon shadow prices (dual cost associated with an emission constraint), shadow renewable subsidy (dual value associated with a possible renewable obligation or target), etc. So pollution, carbon or RES marginal costs or values are revised, following the market equilibrium, thus influencing end-use prices for the energy forms and fuels, which in their turn further influence energy demand and the fuel mix in all sectors, including transportation. Thus, a closed loop is again established between demand-supply-prices and policy targets or instruments for the emissions and the renewables.

Summing-up, the tool provides impact assessment information of transport policies and changes on costs, prices, investment, emissions, primary energy supply, energy balances and security of supply for the entire energy system.

PETROLEUM PRODUCTS SUPPLY MODULE

The refinery sub-model is used to project petroleum product prices, refining activities and refinery capacity expansion, including where appropriate technological change. The whole petroleum market is modelled as one typical refinery involving few generic distillations and cracking processes. The generic processing units are atmospheric distillation, vacuum distillation, coking, catalytic cracking, hydrocracking, and visbreaking.

The model chooses a set of petroleum industry activities (e.g. crude oils, processing units, etc.) to produce an inter-temporal least cost product mix that satisfies the exogenous demand given from the energy demand and supply modules. Imports and exports of petroleum products are exogenous. The activities are constrained by specific blending requirements on the crude oil and intermediate streams, product specifications, processing and transportation capacities.

The selection of crude oils, refinery process utilization, and logistics adjust to minimize the overall cost of supplying the market with petroleum products. The model uses the best available information concerning future prices, demands, market conditions and future technology.

Capacity is allowed to expand, with some technical limitations. Investment criteria are developed exogenously, although the decision to invest by process is endogenous.

The regulatory framework concerning product types are incorporated as simple additive factors that increase cost of production.

End-use petroleum product prices are formed as function of marginal costs of production, plus transportation costs, distribution costs and taxes. Marginal cost pricing is assumed to adjust to reflect total average costs and mark-ups.

REST OF ENERGY SYSTEM

ENERGY CONSUMPTION BY ENERGY BRANCH

The PRIMES model computes in detail energy consumption by fuel type and electricity that are used sectors producing or converting energy. Energy is used for Motor drives and engines, Steam and for Specific electricity uses (including self consumption of electricity by power plants and electricity loses for pumping). The list of sub-sector of the energy branch is the following: Coal, Lignite extraction; Gas, Oil extraction; Briquetting; Coke production; Gas works; Pipelines and compressors; LNG terminals; Nuclear fuel and waste; Refineries; Bioenergy and biofuels; Self consumption by power and pumping plants.

TRANSMISSION AND DITRIBUTION LOSSES

Losses in transmission/distribution of electricity are calculated according to fixed loss ratios (by country) by distinguishing between types of voltage. The loss ratios are assumed to change over time reflecting technical improvement. Losses in steam/ heat distribution are calculated in a similar manner.

Losses in gas transportation and gas infrastructure are calculated by using fixed loss ratios. The calculation is integrated in the gas supply sub-model and distinguishes between different types of gas infrastructures.

SOLID FUEL CONVERSION PLANTS

The model calculates in a simple way inputs and outputs of plants that convert solid energy forms. The following are included: briquetting of coal and lignite; coke production from coal; coke oven gas production; blast furnace gas production. The coke and derived gas activities are related to the existence and operation of blast furnaces in a country.

NON ENERGY CONSUMPTION OF ENERGY

The model treats petrochemical consumption of fuels for energy and non energy purposes (raw material) within the sub-model treating the chemicals sector and its sub-sector. Other fuels used for non energy purposes are linked to activity of the Construction sector.

CO_2 emissions from energy are computed by multiplying quantities of fossil fuel combusted (measures in energy terms) by emission factors which are specific to fuels and countries. Abatement of energy-related CO_2 emissions is an endogenous result of the model and depends on fuel mix, technology and process mix within the energy system. The model projects a configuration of the energy system to the future and computes energy-related CO_2 emissions. The model does not include any explicit marginal abatement cost curve (MAC) for energy-related CO_2 emissions. Abatement and its relation with costs result from energy system simulation. MACs can be quantified using the results of the model for a variety of imposed abatement levels.

When in a scenario CO_2 pricing, taxation or quantity limitations apply, a feedback effect is simulated by the model acting from emissions to the energy system. A quantity limitation on emissions may be treated at the level of each sector or for a country's energy system or for the EU as a whole. In such cases the model also considers the shadow value of the carbon constraint, which is termed carbon value and influences demand and supply decisions of agents. A carbon value differs from carbon taxes as it does not entail direct payments, although may inducing higher indirect costs. When policy instruments involving CO_2 emission allowances apply, the quantity of available emission allowances are represented as a carbon constraint and the shadow value, which is computed by the model, acts as a carbon value. When in addition allowances are purchased on auctions, then direct payments are induced and the model takes them into account in the simulation of agents' choices.

CO_2 from process emissions are computed through simple relationships which involve physical production of the relevant industrial commodities (e.g. cement). Simple techniques that may reduce such emissions are represented through marginal abatement cost curves. Higher emission reductions are represented by assuming Carbon Capture and Storage techniques, which apply on the processing of industrial commodities. The representation includes capital and variable costs of CCS, as well as electricity consumption associated with capture, which adds up to total demand for electricity.

Emissions of non CO2 Greenhouse Gases are included in the PRIMES report based on calculations using marginal abatement cost curves and projections quantified by the GAINS model of IIASA.

When in a scenario GHG emission constraints apply, the PRIMES model computes allocation of reduction efforts to the various emission components (energy CO_2, process CO_2 and the various non CO2 GHGs) by considering equalisation of carbon values (i.e. equal marginal abatement costs). Sector specific emission reduction constraints can also be treated.