



The E3MLab Models



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1. The PRIMES Energy Model

General Overview

PRIMES ENERGY SYSTEM MODEL

1. Partial equilibrium model simulating the entire energy system, both in demand and supply
2. Mixed representations:
 - ▶ Bottom-up (engineering, explicit technology choices) and
 - ▶ Top-down (microeconomic behaviors, consistent economic decisions by agent)
3. Modular, with separate modules for each demand and supply sector and separate decision making
4. Decentralized decisions for demand and supply of energy commodity interacting via commodity prices
5. Market-oriented: market equilibrium prices drive energy balancing of demand and supply per energy commodity
6. Electricity and/or Gas trade within the EU Internal Market and beyond is simulated
7. Extensive set of policies represented
 - ▶ Taxes, subsidies, Tradable Permits or certificates
 - ▶ Technology supporting policies
 - ▶ Environmental policy instruments

PRIMES Coverage

- Geographical coverage
 - ▶ Each EU-27 member-state taken individually
 - ▶ Also, candidate MS and neighbors, such as Norway, Switzerland, Turkey, South East Europe
- Network coverage
 - ▶ Electricity and gas interconnections over Eurasian area
 - ▶ For electricity and gas markets, the European countries can be simulated as an interlinked system
- Core of the model: market linked sub-models for demand sectors, power/steam generation, fuel supply
- Satellite models: Biomass supply, refineries, detailed transport sector model, gas supply (Eurasian), H2 supply
- Time frame : 2000 to 2050 by five-years periods
- Model results fully calibrated to Eurostat data for the period 1990 to 2005. Projections start from 2010

Comparison with other energy models

- ▶ Similarities with NEMS used by US-EIA/DOE (economy-engineering, modularity, price-driven market equilibrium)
- ▶ Fundamentally different from optimisation models, such as Markal, TIMES or MESSAGE
- ▶ Different in scope from Excel-type calculation models, such GREEN-X or other similar models that simulate technology penetration
- ▶ IEA World energy model uses reduced-form equations (like econometric equations) for estimating energy demand and a simple allocation model for power generation; the POLES and the Prometheus world energy models use the same technique as IEA; PRIMES and NEMS use more detailed formulations based on a micro-economic foundation (e.g. demanders maximize utilities, suppliers maximize profits, and markets are cleared through prices) and are also richer than IEA's model regarding engineering-type information and constraints
- ▶ PRIMES is a partial (energy only) market equilibrium model and to that respect differs from general equilibrium models

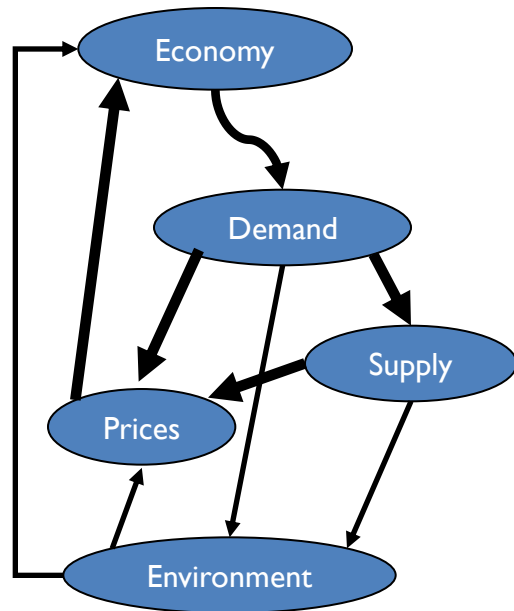
PRIMES: PRICE-DRIVEN AND AGENT-BASED SIMULATION OF MARKETS

- ▶ **Fundamental feature of PRIMES model:**
 - ▶ Agents (e.g. households, steel industry, trade sector, power generation, etc.) act individually optimizing their profit or welfare, influenced by habits, comfort, risk and inertia
 - ▶ Accordingly they determine energy flows, investment and choice of explicit technologies in vintages
 - ▶ Demand and supply of energy commodities interact according to an assumed market regime
 - ▶ Simultaneous energy markets are cleared to determine prices that balance demand and supply
 - ▶ Ramsey-Boiteux pricing (adaptable to both regulated monopoly and competitive markets) plus mark-up reflecting market power determines commodity prices
 - ▶ Market equilibrium evolves over time with investment being endogenous
- ▶ **Policies and measures, the world energy markets, technology and the economy are exogenous and influence behaviors and market equilibrium**

PRIMES MODEL FEATURES

- ▶ Explicit technologies in all demand and supply sectors
 - ▶ Technology dynamics
 - ▶ vintages
 - ▶ penetration of new technologies
 - ▶ inertia from past structures and
 - ▶ pace of capital turnover
- ▶ Time-of-use varying load of network-supplied energy carriers to synchronize electricity and steam in both demand and supply
- ▶ Non-linear relations:
 - ▶ Economies of scale and Learning by doing for technologies
 - ▶ Consumer choices and saturation effects
 - ▶ Supply cost-curves for potential of resources, new technologies and the use of new sites for energy plants
 - ▶ Perceived costs of technology and risk premium

ENERGY-ECONOMY-ENVIRONMENT SYSTEM COVERAGE



Economy system (exogenous, links with GEM-E3)

- ▶ GDP, demographics, exchange and interest rates
- ▶ Activity by sector (18 sectors), income of households
- ▶ Transport activity flows

Energy demand system

- ▶ Consumption habits, durable goods and comfort
- ▶ Manufacturing technology, industrial processes and energy needs
- ▶ Transportation modes/means and technologies as drivers of energy needs

Energy supply system

- ▶ Primary energy supply (depletable and renewable sources)
- ▶ Secondary energy supply (power generation, refineries, etc.)
- ▶ Energy System Balances

Energy Markets

- ▶ Competition, price formation and regulation, import/export

Environment Impacts

- ▶ Energy-related emissions
- ▶ Environmental impacts and pressures, damages
- ▶ Preventive and corrective measures

POLICY INSTRUMENTS

- ▶ Technology promoting policy both in demand and in supply sectors
- ▶ Standards on appliances, processes and plants and other energy efficiency regulation
- ▶ Investment policy (whenever exogenous, e.g. networks)
- ▶ Taxes and subsidies
- ▶ Emission constraints and environment-related directives (LCP, BAT, ...)
- ▶ Emission Trading Schemes
- ▶ Green, White Certificates or other obligations and support schemes (e.g. RES)
- ▶ Security of Supply constraints
- ▶ Price and competition regulation

INPUTS FOR A SCENARIO

- ▶ GDP and economic growth per sector (many sectors)
- ▶ World energy supply outlook – world prices of fossil fuels
- ▶ Tax and subsidy policies
- ▶ Interest rates, risk premiums, etc.
- ▶ Environmental policies and constraints
- ▶ Technical and economic characteristics of future energy technologies
- ▶ Energy consumption habits, parameters affecting supply curves for primary energy, potential of sites for new plants, parameters about comfort, rational use of energy and savings
- ▶ Parameters of supply curves for primary energy, energy efficiency potential, power generation sites, renewables potential per source type, etc.

OUTPUTS OF A SCENARIO

- ▶ Per country and time period
 - ▶ Detailed energy balance (EUROSTAT format), including
 - ▶ 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 supply per subsystem and primary energy
 - ▶ Energy system costs, prices and investment expenditure
 - ▶ Emissions from energy
- ▶ Policy Assessment Indicators
- ▶ Additional material
 - ▶ GDP and economic outlook
 - ▶ World energy supply outlook

BASELINE AND SCENARIOS

- ▶ Baseline is a reference scenario needed for the assessment of policies included in alternative scenarios
- ▶ Alternative scenarios reflect new policies and contrasted evolutions
- ▶ Baseline is not a forecast, nor the most likely future
- ▶ Baseline should correctly estimate effects of current trends and policies
- ▶ Examples:
 - ▶ DG TREN: periodic energy outlook – Baseline
 - ▶ DG TREN: policy scenarios (renewables, efficiency, nuclear, high prices, key drivers, etc.)
 - ▶ DG ENV: policy scenarios on climate change, on emission ceilings, on ETS, etc.

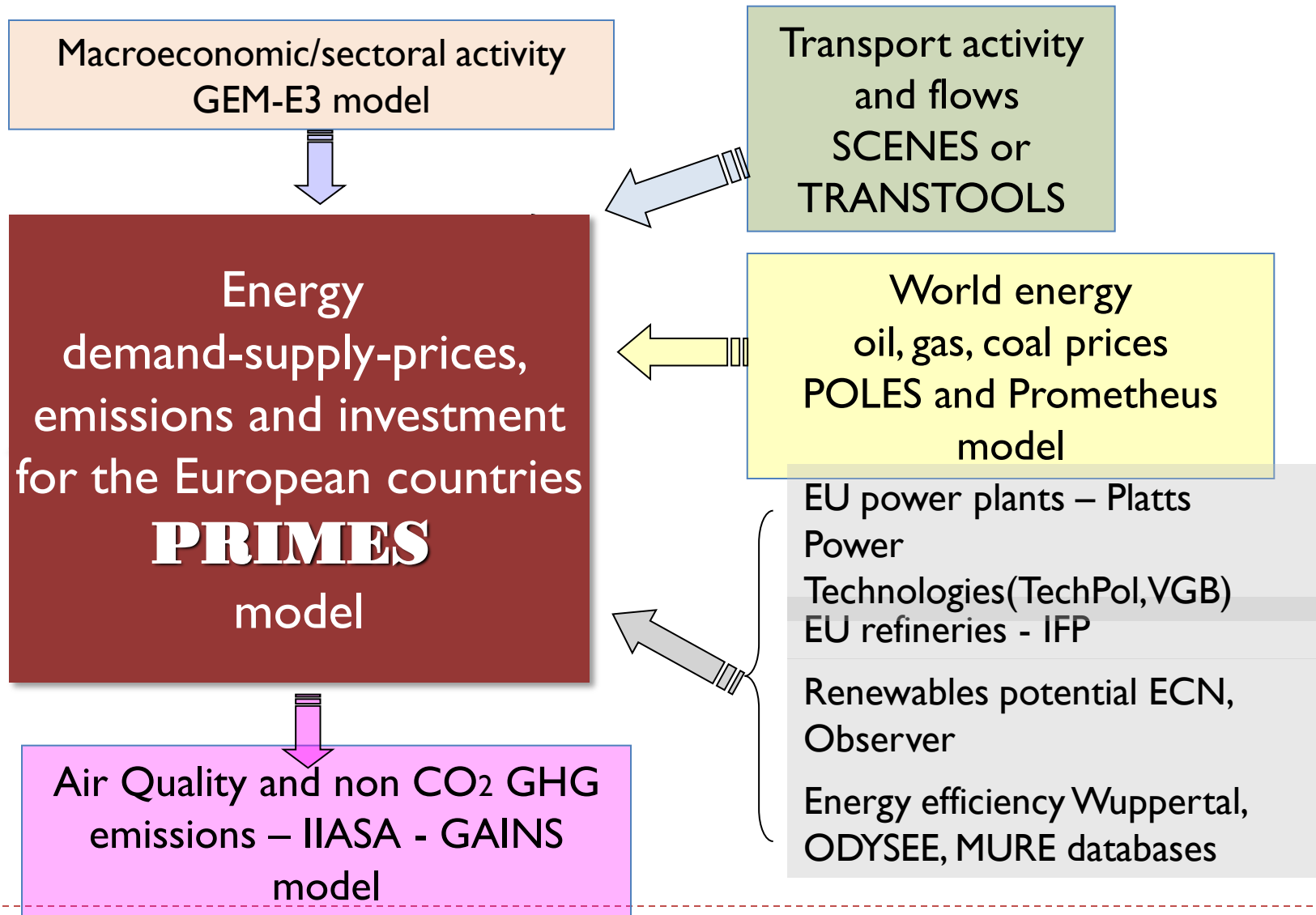
SYSTEM COVERAGE

- 12 industrial sectors, subdivided into 26 sub-sectors using energy in 12 generic processes (e.g. air compression, furnaces)
- 5 tertiary sectors, using energy in 6 processes (e.g. air conditioning, office equipment)
- 4 dwelling types using energy in 5 processes and 12 types of electrical durable goods (e.g. refrigerator, washing machine, television)
- 4 transport modes, 10 transport means and 10 vehicle technologies
- 14 fossil fuel types, new fuel carriers (hydrogen, biofuels) 10 renewable energy types
- Main Supply System: power and steam generation with 150 power and steam technologies and grid interconnections
- Other sub-systems: refineries, gas supply, biomass supply, hydrogen supply, primary energy production
- 7 types of emissions from energy processes

DATA INPUT SOURCES

- ▶ **NEW CRONOS - EUROSTAT**
 - ▶ Energy Balance sheets
 - ▶ Energy prices (complemented by other sources)
 - ▶ Macroeconomic and sectoral activity data
 - ▶ Population data and projection
- ▶ **Technology databases developed under EC programs**
 - ▶ MURE, ICARUS, ODYSEE – demand sectors
 - ▶ VGB, SAPIENTIA, TECHPOL – supply sector technologies
 - ▶ NEMS model database, US DOE
- ▶ **Activity data from Industry associations**
- ▶ **Various surveys (e.g. CHP)**
- ▶ **Specifically commissioned studies**
 - ▶ ECN's and Observer's databases on RES potential
 - ▶ TNO study on CO2 storage potential
 - ▶ Specific database on biomass resources and possibilities

ENERGY-ECONOMY-ENVIRONMENT PRIMES MODEL AND LINKS WITH OTHER MODELS



DATABASE UPDATE AND MODEL DEVELOPMENT

- ▶ The PRIMES model database is updated:
 - ▶ EUROSTAT statistics up to 2005 and available information up to 2007 (partially up to 2008)
 - ▶ Revision of the power plant database, including information on new constructions and projects as well as techno-economic data on CCS
 - ▶ Updated information on prices, taxes and tariffs
 - ▶ Updated information about renewables: potential, non linear cost curves, learning by doing, etc.
- ▶ Satellite models of PRIMES
 - ▶ Prometheus world energy markets and system model
 - ▶ Biomass supply - biorefineries
 - ▶ Hydrogen economy
 - ▶ Detailed PRIMES-TREMOVE Transport model

Methodology for Demand Sectors

- ▶ For each sector a representative decision making agent is assumed to operate
- ▶ The agent 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
- ▶ 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
 - ▶ Endogenous choice of equipment (vintages, technologies and learning)
 - ▶ Endogenous investment in energy efficiency (savings)
 - ▶ 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

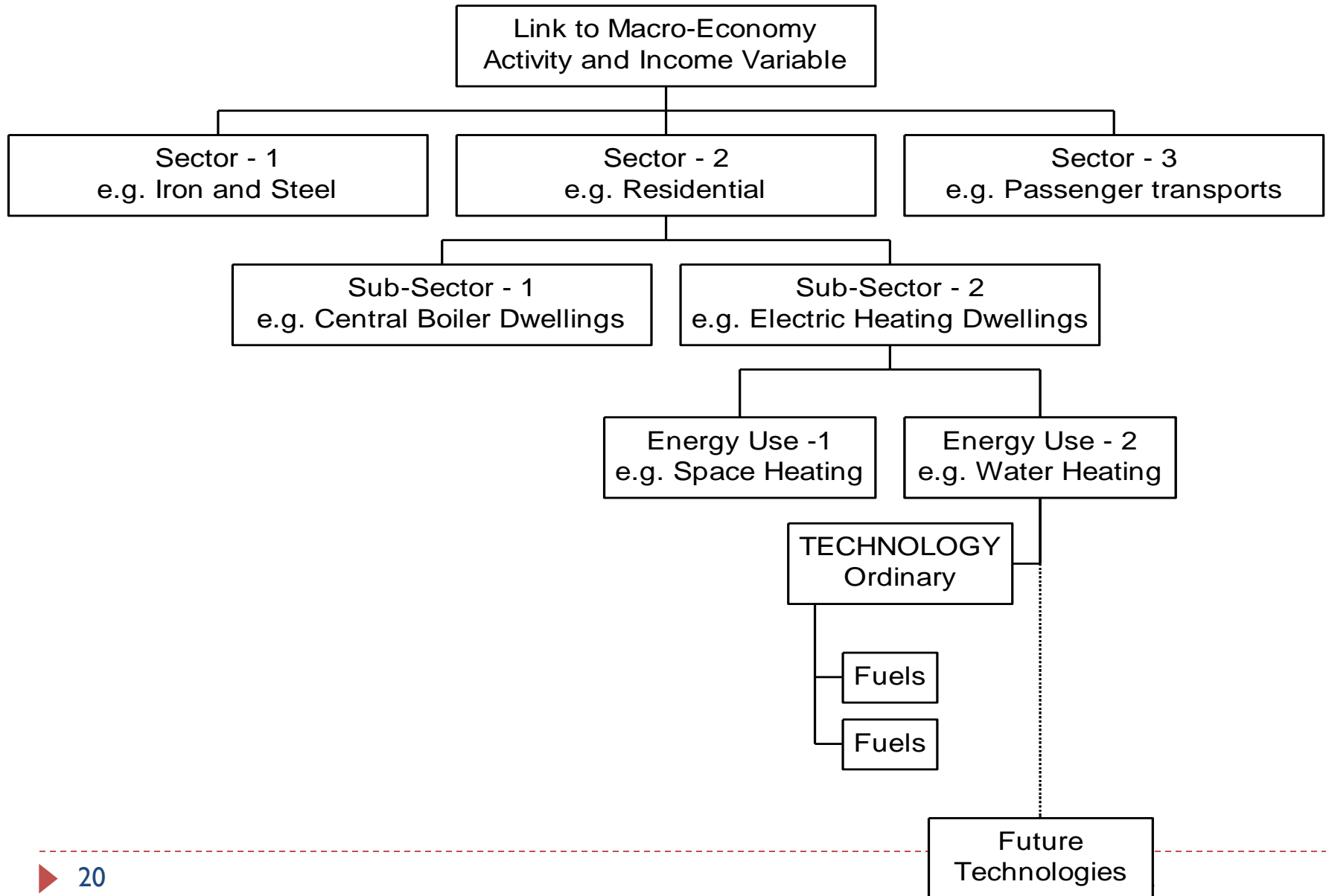
Industrial Energy Demand

- ▶ **Mechanisms represented**
 - ▶ Integration in macroeconomic decisions (production function)
 - ▶ mix of industrial processes (e.g. different energy intensity for scrap or recycling processes and for basic processing);
 - ▶ mix of technologies and fuels, including the use of self-produced by-products
 - ▶ engineering-oriented representation of energy saving possibilities
 - ▶ Influence from standards, emission constraints, pollution permits and
 - ▶ Technology vintages and dynamics
- ▶ **Substitutions are possible between processes, energy forms, technologies and energy savings**

Energy Demand in Buildings

- ▶ **Mechanisms represented**
 - ▶ Useful energy demand, final energy demand, equipment choice, energy efficiency investment and fuel mix solved from with utility maximization under budget constraint
 - ▶ Useful energy demand depends on behavioural characteristics partly influenced by costs and prices
 - ▶ Distinction of households types according to energy consumption patterns and for tertiary consideration of services sectors
 - ▶ Separate treatment of electric appliances
 - ▶ Final energy demand linked with thermal integrity of building, with consideration of renovation investment and vintages
 - ▶ Heat pumps and direct use of Renewables included
 - ▶ Influence from standards, emission constraints, pollution permits and
 - ▶ Technology vintages and dynamics
- ▶ **Substitutions are possible between processes, energy forms, technologies and energy savings**

MODEL STRUCTURE IN DEMAND SIDE



Examples of Industry Decomposition

SECTOR

Iron and Steel

SUB-SECTORS

Electric arc

Iron and Steel integrated

ENERGY USES

Air compressors

Blast furnace

Electric arc

Electric process

Foundries

Lighting

Low enthalpy heat

Motor drives

Process furnaces

Rolled steel

Sinter making

Steam and high enthalpy heat

Examples of Industry Decomposition

<u>SECTOR</u>	<u>SUB-SECTORS</u>	<u>ENERGY USES</u>
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		

Decomposition in the Residential sector

SECTOR	HOUSEHOLD TYPES	ENERGY USES
Dwellings	<ul style="list-style-type: none">• 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

Decomposition in Tertiary sector

SECTOR	ENERGY USES	ENERGY TECHNOLOGIES
Agriculture	Lighting Space heating Greenhouses Electrical uses Pumping Motor energy	Lighting Heating/Cooling Pumping Motor drives Electrical equipment Greenhouse types
Services		
Market Services	Lighting Space heating Air conditioning Steam uses Electrical uses Water heating	Lighting Electric heating/cooling Gas heating/cooling Boiler heating/cooling District heating Electrical equipment
Trade	Lighting Space heating Air conditioning Steam uses Electrical uses Water heating	Lighting Electric heating/cooling Gas heating/cooling Boiler heating/cooling District heating Electrical equipment
Public services	Lighting Space heating Air conditioning Steam uses Electrical uses Water heating	Lighting Electric heating/cooling Gas heating/cooling Boiler heating/cooling District heating Electrical equipment

Decomposition in the Transport sector

(core model less detailed than PRIMES-Tremove transport model)

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	

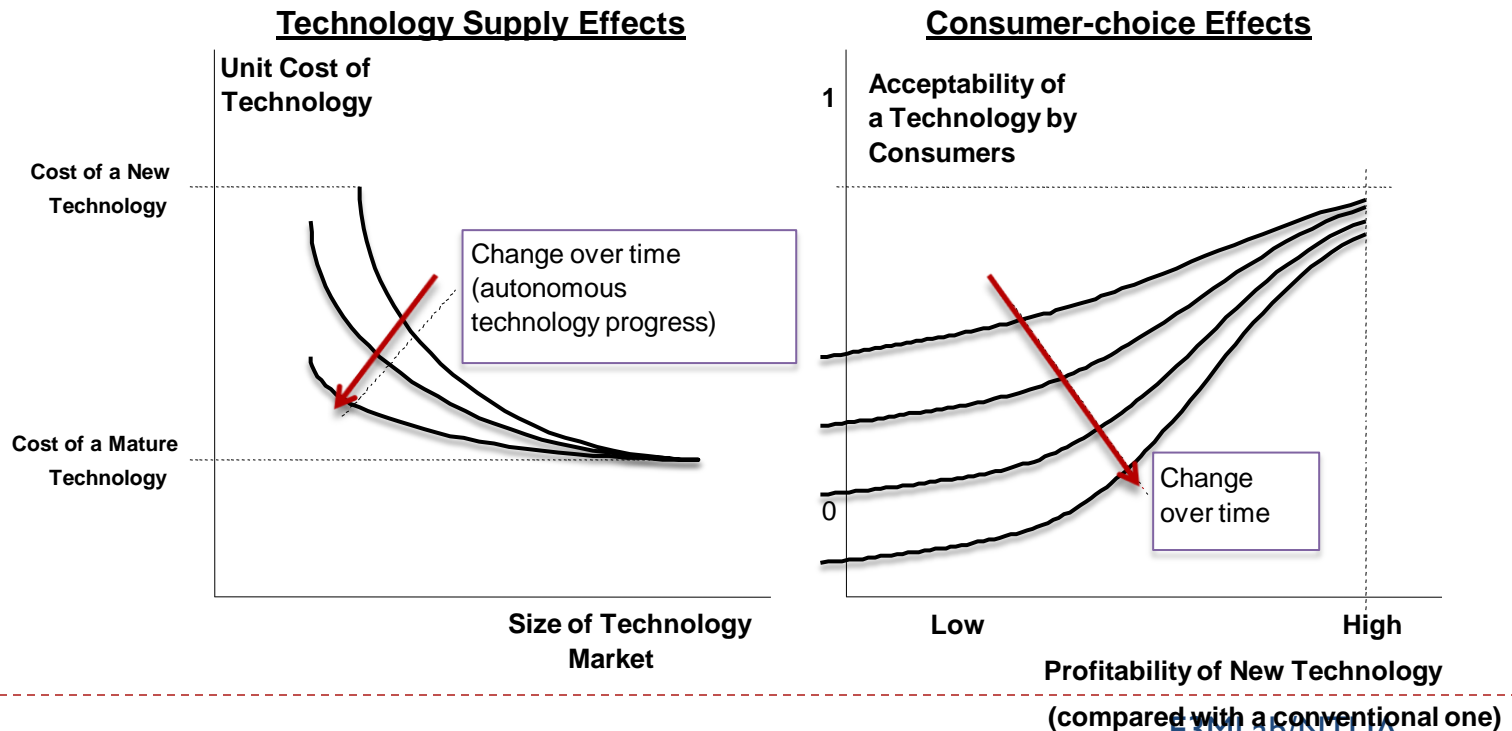
SECTOR	SUB-SECTORS	ENERGY TECHNOLOGIES
Goods transport	Trucks	Internal combustion engines
	Trains	Electric motors and hybrid
	Navigation	Fuel cell
		Gas turbine and CNG



TECHNOLOGY DYNAMICS IN PRIMES

Technology Dynamics in the Demand-Side of the PRIMES model

- **Autonomous Changes:** Technology availability and acceptability increases over time
- **Induced Changes:** Higher profitability of a new technology implies more acceptance at consumer level further inducing lower technology supply costs

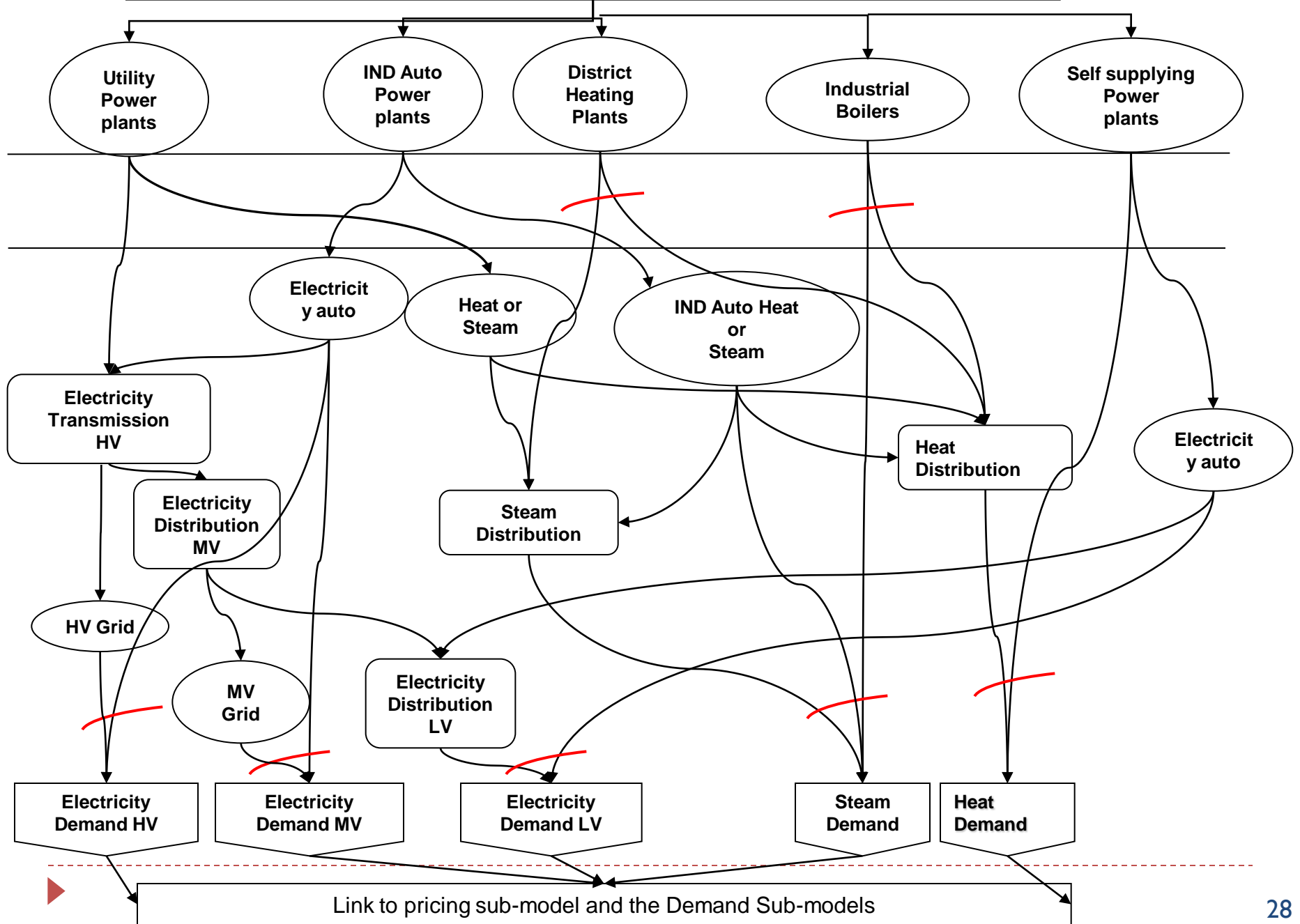


PRIMES: Details for Power Sector

- ▶ Commodities (simultaneously determined):
 - ▶ Electricity - High, Medium, Low Voltage for Grid Power and in situ for own use (non grid)
 - ▶ CHP Steam/Heat
 - ▶ in situ for own use and
 - ▶ CHP with steam/heat distribution)
 - ▶ Steam/Heat from Industrial Boilers
 - ▶ District Heating
- ▶ Stylised Companies: Utilities, Industrial small producers, Regulated Networks
- ▶ Elastic Demand – fairly disaggregated
- ▶ Fuel Supply Non linear curves
- ▶ Plant site-related costs Non linear curves

Skip

Input fuels – link to fuel supply non linear curves



PRIMES DETAILS FOR POWER SECTOR

- ▶ Very detailed electricity and steam sub-model
 - ▶ Optimal unit commitment with endogenous investment
 - ▶ More than 150 explicit technologies
 - ▶ DC linear optimal power flow with single load node per country (34 nodes) and present and future interconnectors → endogenous flows and trade of electricity
- ▶ Calibration Data
 - ▶ Inventory of existing and planned power plants
 - ▶ Technical and Economic data for old and new plants, with and without cogeneration and CO₂ capture
- ▶ Economics of investment and pricing related to liberalized market conditions
- ▶ Environmental policies and technologies including ETS

PRIMES: DETAILS FOR POWER SECTOR

- ▶ Endogenous Investment decisions:
 - ▶ Lifetime extension of old plants
 - ▶ Premature scrapping and replacement on the same site
 - ▶ New plant on an existing site (depending on site availability)
 - ▶ Development of new plant on a new site
 - ▶ Auxiliary equipment on a new or old plant:
 - ▶ DeSox, DeNox, ESP, ...
 - ▶ CCS (12 types)
- ▶ Hydro lakes and Pumping represented endogenously
- ▶ Intermittent RES as deterministic equivalent
- ▶ Reliability constraints per country
- ▶ Interconnection DC power flows constraints

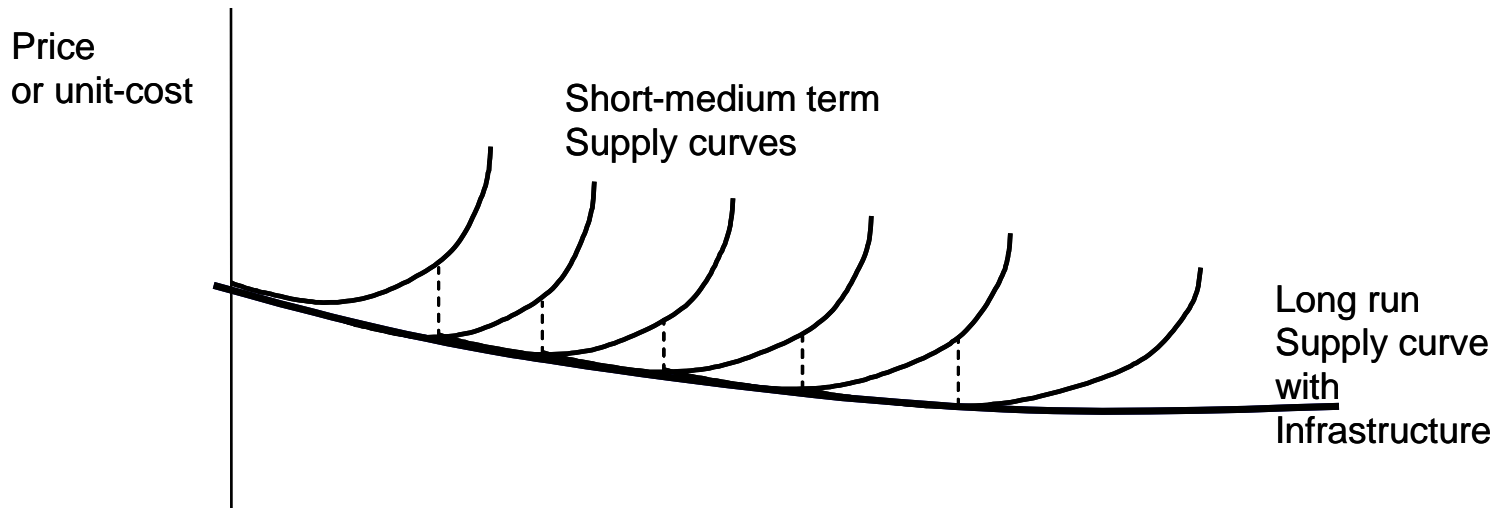
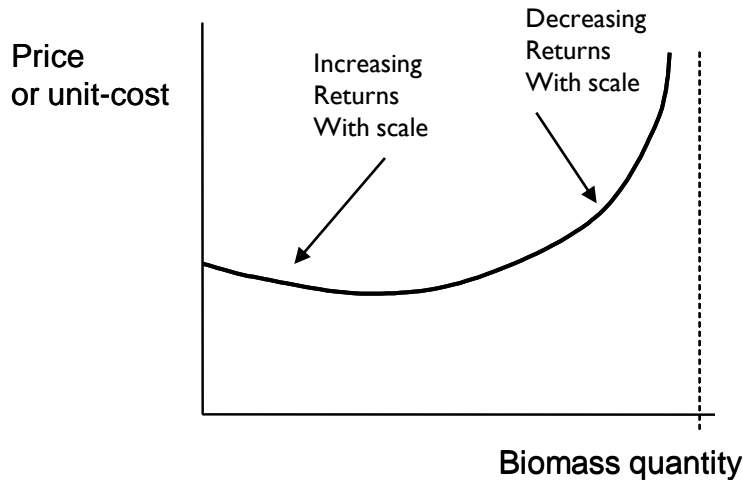
Technical-Economic Parameters of Plants

1. Capital cost (Euro'00/kW) and financial charges during construction
 1. Retrofitting costs and possibilities
 2. Capital costs related to the plant site
2. Risk premium and learning rates per technology
3. Variable cost (per kWh produced) and annual fixed costs (per kW) and rate of increase with age
4. Thermal efficiency rate and multiple fuel capability (blending constraints)
5. Self consumption rates (important for CCS plants and others)
6. Plant availability rate and rate of utilization for intermittent plants.
7. Technical lifetime and economic lifetime and constraints about extension
8. Technical parameters for the feasible combinations of electricity and steam output
9. Renewable resource availability data
10. Availability of future technologies

THE CONCEPT OF “SUPPLY CURVE”

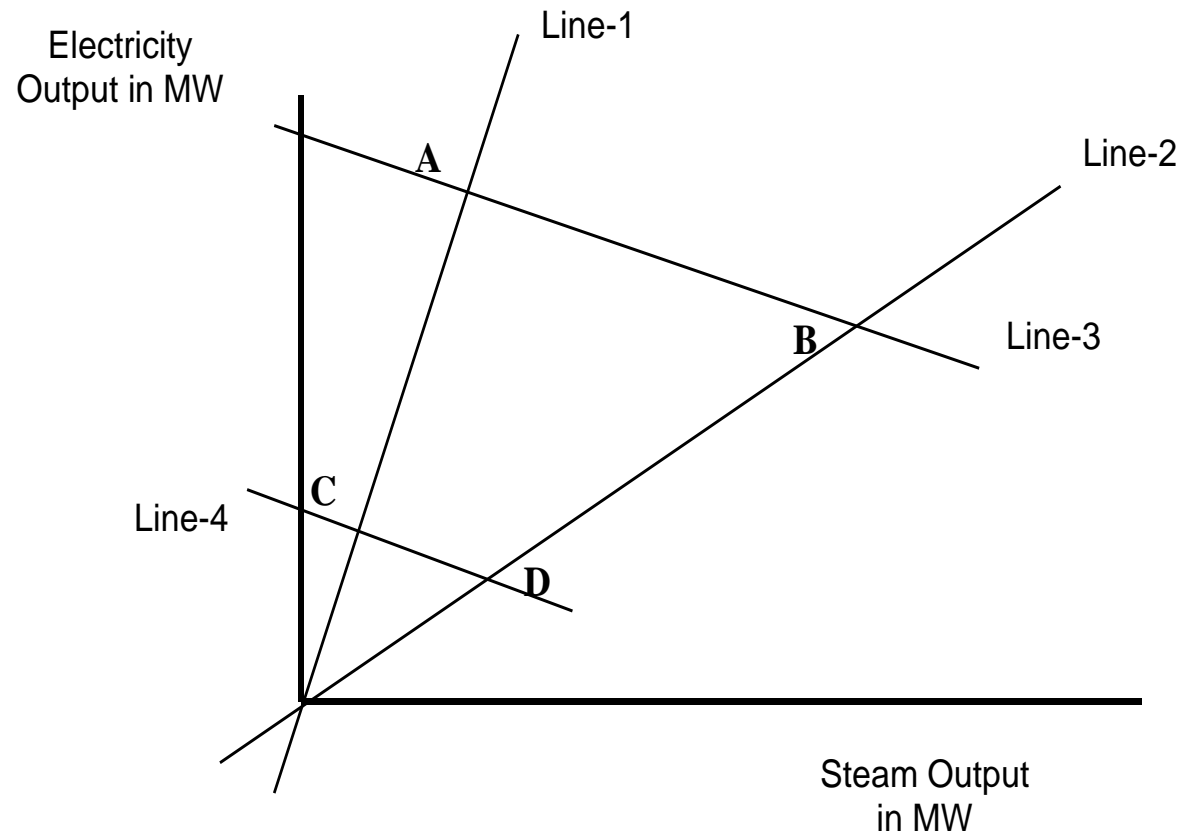
Supply curves are used in many places in PRIMES:

- ▶ Renewable sources
- ▶ Sites for Wind
- ▶ Nat. Gas supply
- ▶ Biomass and Waste etc.



CHP technology and endogenous choice

1. Combined cycle with extraction
2. Combined cycle with Heat Recovery
3. Backpressure steam turbine
4. Condensing steam turbine with post firing
5. Condensing steam turbine of large power plants
6. Gas Turbine with heat recovery
7. Internal combustion engine with cogeneration
8. Others - backpressure steam for district heating
9. Fuel Cell
10. Very small scale Gas Turbine with Heat recovery

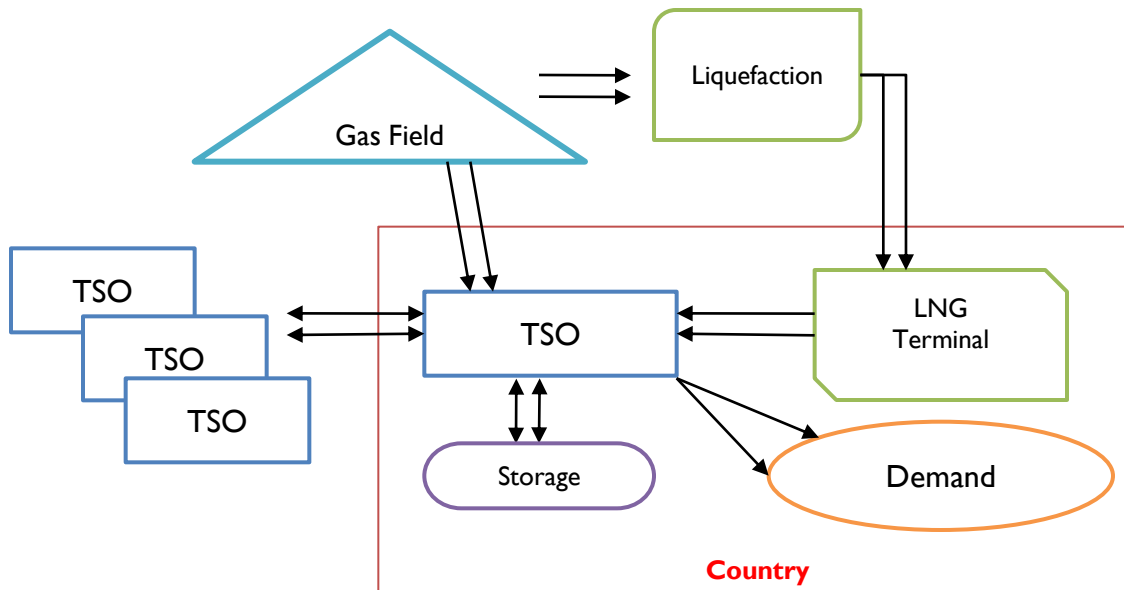
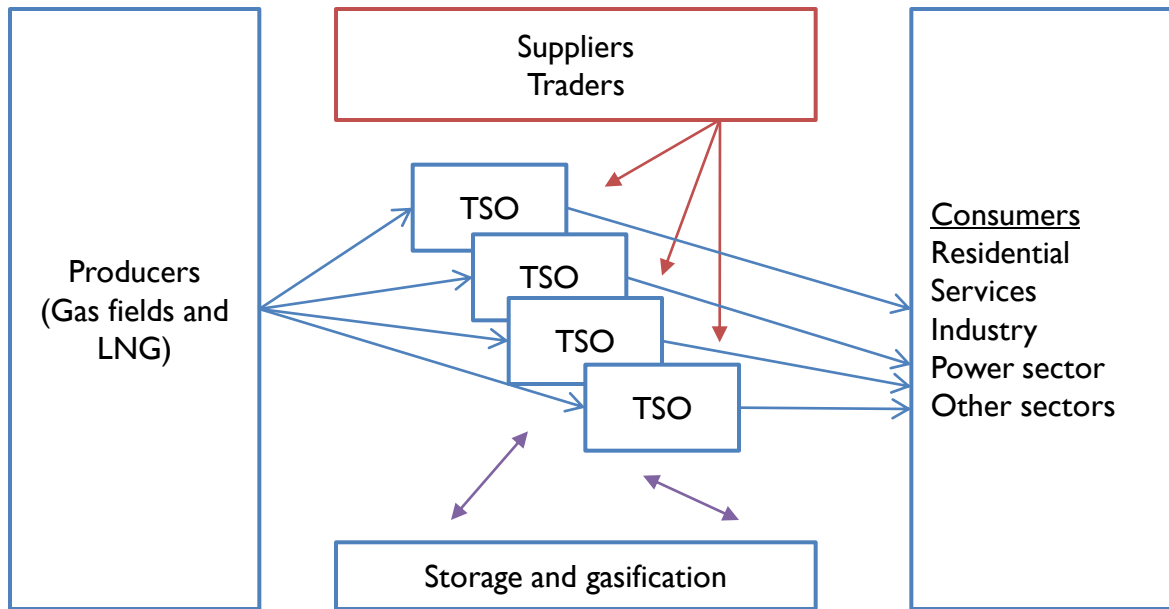


List of Renewable energy technologies in the power sector

1. Wind Power Low Resource
2. Wind Power Medium Resource
3. Wind Power High Resource
4. Wind Power Very High Resource
5. Wind Offshore Power Low Resource
6. Wind Offshore Power Medium Resource
7. Wind Offshore Power High Resource
8. Wind Offshore Power Very High Resource
9. Solar PV Low Resource
10. Solar PV Medium Resource
11. Solar PV High Resource
12. Solar Thermal
13. Solar PV Very High Resource
14. Solar PV very small scale
15. Wind very small scale
16. Tidal and waves
17. Lakes
18. Run of River
19. Geothermal Medium
20. Geothermal High
21. Geothermal Small
22. Waste Solid
23. Landfill Gas
24. Biogas produced
25. Biomass solid
26. Bio-liquid produced or waste.

New Gas Supply Model

- ▶ Geographic coverage (55 countries in total)
 - ▶ Europe, former Soviet Union, Middle East, Gulf area, North Africa, China-India fully represented
 - ▶ In addition Japan-Korea and North America for LNG
- ▶ All types of gas infrastructure in detail: pipelines, gas storage, LNG terminals, Liquefaction trains, Fields
 - ▶ Investment in new gas infrastructures is exogenous
- ▶ Time period: 2000 – 2030 (5-years time steps)
- ▶ Market competition and oligopoly rents are modelled
 - ▶ Distinct gas companies
 - ▶ Price elastic demand
 - ▶ Oligopoly competition combined with regulated markets (where applicable)
- ▶ Commercial gas exchanges and prices are endogenous, as also the physical gas flows
- ▶ Demand for gas calibrated to PRIMES projections

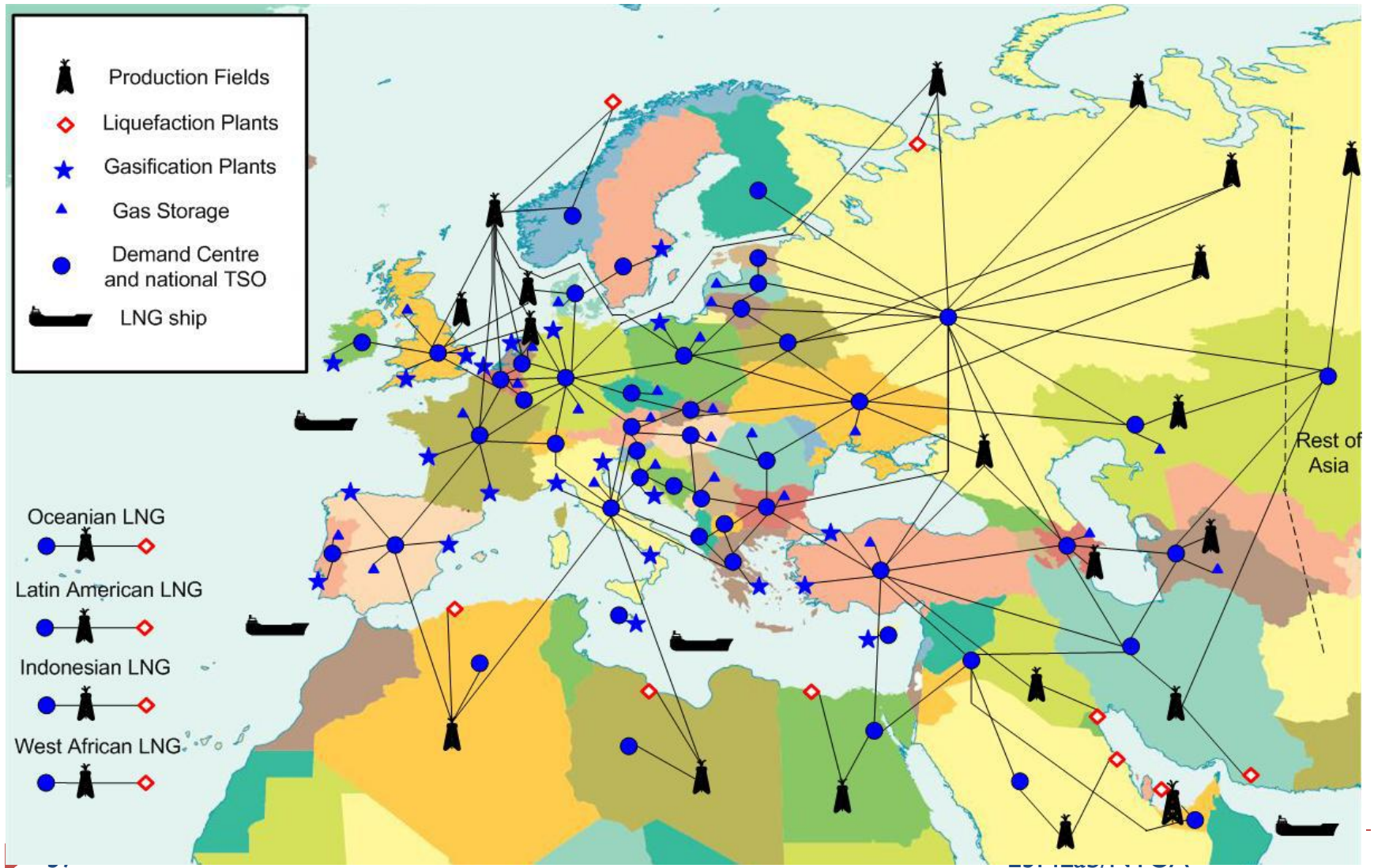


Gas model structure

- Every gas agent (producer, consumer, TSO, trader) is represented as a distinct decision maker
- Pipeline gas and LNG are treated as distinct commodities competing against each other
- Physical flows across the gas network and engineering-type constraints are modelled
- Gas demand seasonal variability is included (typical days)

Geographical form of the Gas Model

Includes also the global LNG market (not shown)



PRIMES-Biomass Supply Model

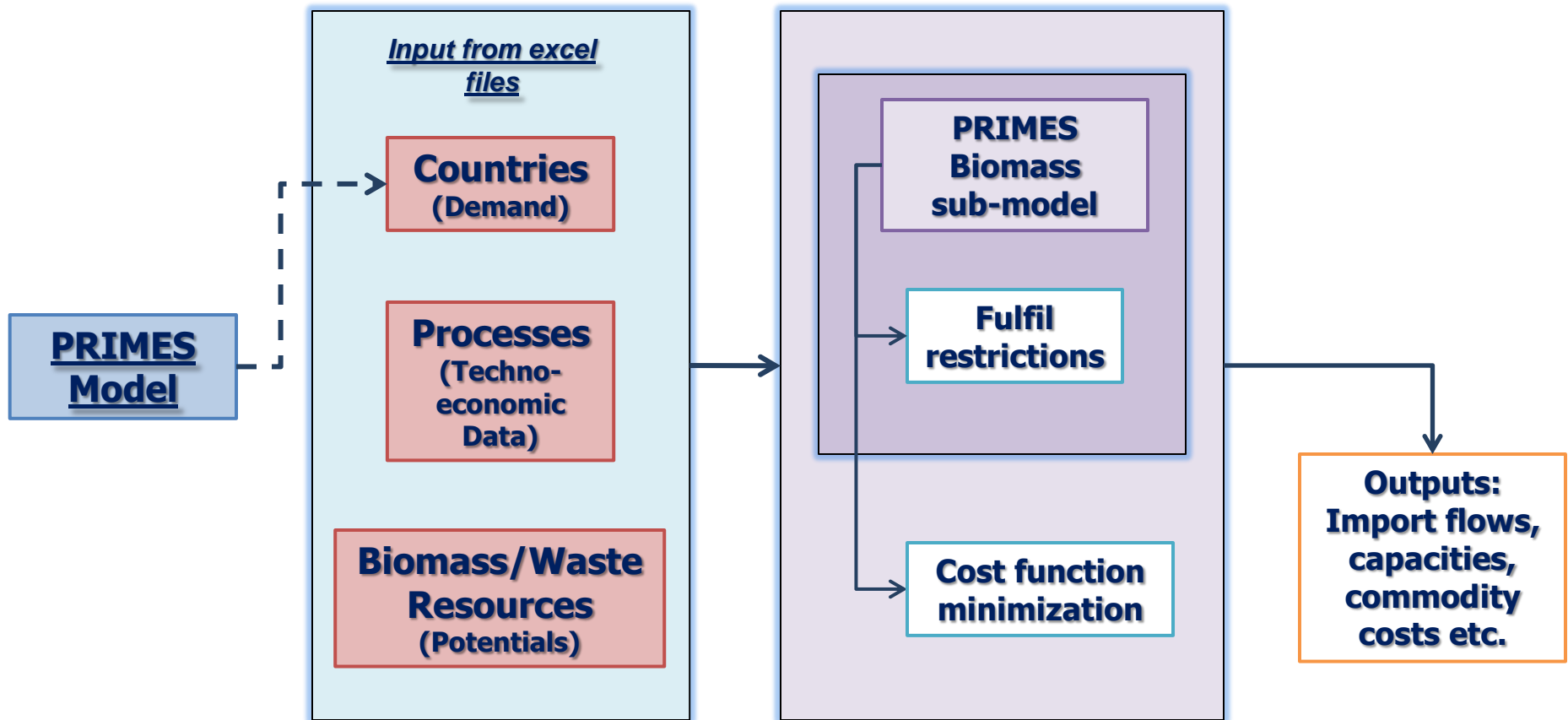
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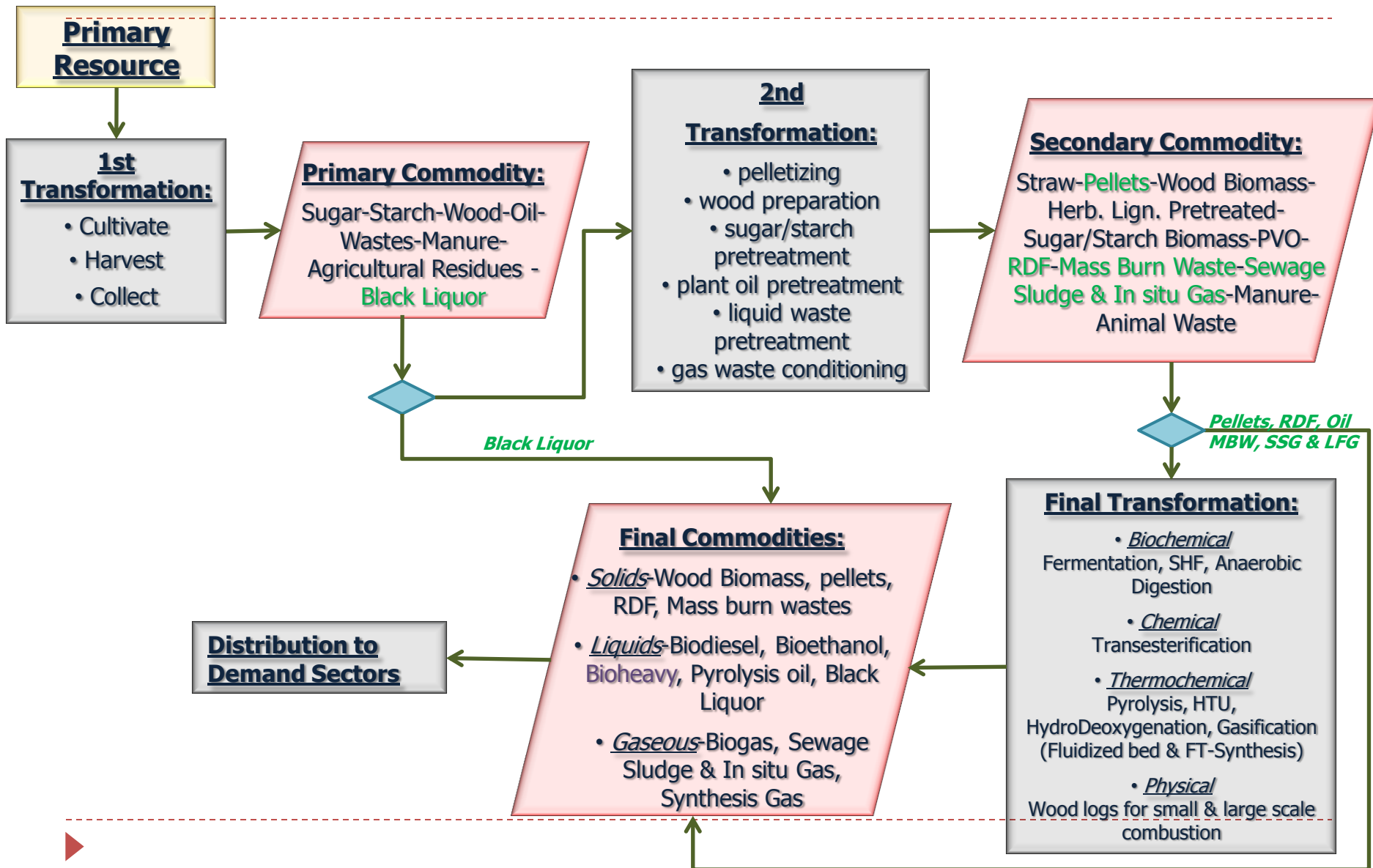
Biomass Supply model

- ▶ Projects 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.
- ▶ Projects land, agricultural, forest and waste resources used in production of bio-energy products.
- ▶ Determines endogenously imports-exports of bio-energy products and feedstock
- ▶ Evaluates energy demand and emissions in bio-energy production
- ▶ Determines the consumer prices of the final bio-energy products.

Biomass Supply model



Processing flows scheme



Bio-energy resources

Energy Crops

Starch Crops

Sugar Crops

Wood Crops

Oil Crops

Forestry

Wood Platform

Wood Residues

Aquatic Biomass

Waste

Agricultural Residues

Industrial Solid

Industrial Bagasse

Industrial Pulp

Used vegetable oil

Municipal Solid Sewage Sludge Landfill

Gas

Organic Manure

Animal Platform

Overview of biomass processing technologies

Secondary Transformation

Pellettising

Wood preparation

Sugar pre-treatment

Plant Oil pre-treatment

Solid waste pre-treatment

Liquid waste pre-treatment

Gas waste conditioning

Final Transformation

Solid Biomass

Charcoal

Biochemical

Fermentation

Acid/Enzymatic hydrolysis

Anaerobic digestion

Transesterification

Thermo-chemical

Pyrolysis

Hydrothermal

Gasification

Partial oxidation

Fluidized bed

Steam flow

Bio-energy products

Solids

- *Solid biomass for direct combustion*
- *Pellets*
- *Charcoal*
- *Mass burn waste*
- *Refuse derived fuel*

Liquid

- *Pure vegetable oil*
- *Bio-ethanol*
- *Bio-diesel*
- *Heavy Bio-Oil*
- *Fischer Tropsch Diesel*

Gaseous

- *Bio-gas*
 - *Synthetic Gas*
 - *Bio-hydrogen*
-

World Energy Markets Outlook by using the PROMETHEUS world energy stochastic model

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May, 2009

Overview of current work with PROMETHEUS world energy model

- ▶ Study about the fossil fuel market and prices until 2050 and the uncertainty related to resources, production and demand worldwide
- ▶ Sensitivity Analysis about fossil fuel market and prices trends to 2050
 - ▶ Impact of low versus high oil and gas resources
 - ▶ Impact of world energy demand uncertainty
 - ▶ Impact of undertaking more active Climate Change mitigation policies worldwide
- ▶ Forthcoming analysis at a Global level:
 - ▶ Impact of Energy Efficiency and Renewables Policies
 - ▶ Impact of Nuclear Policies, combined with RES and Efficiency
 - ▶ Impact of Carbon pricing and promotion of Carbon Capture and Storage
 - ▶ Policy Analysis with distinction between unilateral actions by Europe and Global actions

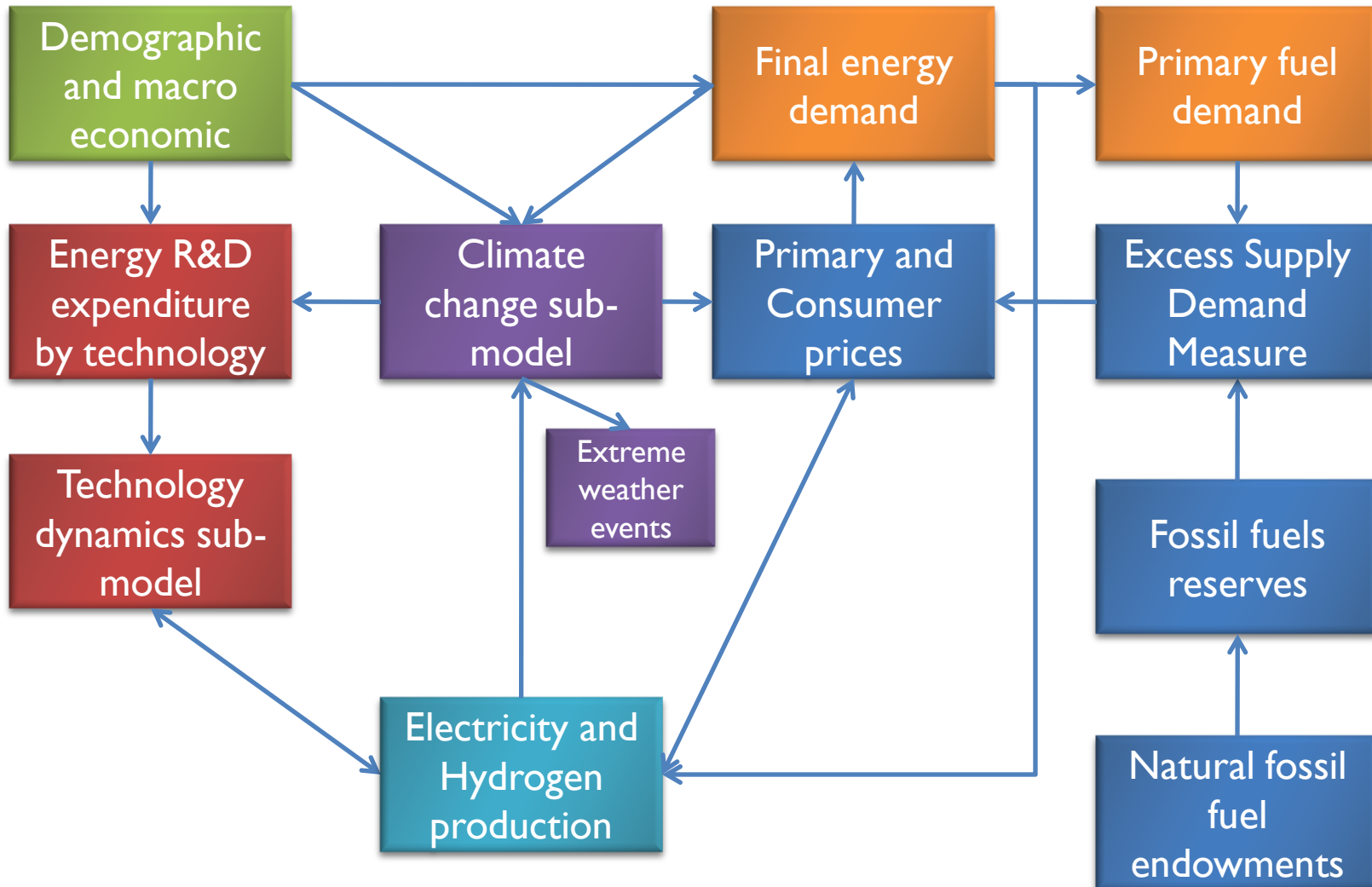
Why stochastic models?

- ▶ The World and its future are obviously subject to variability that can not be fully and explicitly modelled
- ▶ Scenarios using deterministic models may explore possibilities but give no indication of their likelihood
 - ▶ The output of a stochastic model are probability distributions and not single numbers as the deterministic models do
 - ▶ Probability distributions are useful to measure risk, which is strategically important in itself
- ▶ **Prometheus world energy stochastic model is the first of its kind operational model in the EU**

The PROMETHEUS model

- ▶ PROMETHEUS is a full scale simulation model of energy supply, energy demand and energy prices at world and regional level, including
 - ▶ Projection of demographic and economic activity growth
 - ▶ Energy system balances
 - ▶ Energy demand sectors, including transport sector
 - ▶ Power generation
 - ▶ Hydrogen production and use technologies
 - ▶ Production and market equilibrium of primary resources (oil, gas, coal, nuclear, RES)
 - ▶ Technologies and their dynamic learning-by-doing
- ▶ All exogenous parameters are stochastic (known as probability distributions)
- ▶ PROMETHEUS generates stochastic information (probability distributions) for all energy, environment and technology results, yearly up to 2050
 - ▶ Results Include demographic and economic activity indicators, energy consumption by fuel, fuel resources and prices, CO₂ emissions, greenhouse gases concentration, temperature change, technology uptake and dynamic technology improvement

Sub-models in PROMETHEUS



Macroeconomic and multi-sectoral multi-country modelling

Leonidas Parousos, P. Capros et al.
E3MLab
National Technical University of Athens

May, 2009

GEM-E3 – applied general equilibrium model for economy-energy-environment analysis

- ▶ Detailed computable general equilibrium model with integration of energy and environment for all EU MS and for world regions
- ▶ Model data for the EU based entirely on EUROSTAT
- ▶ Multiple sectors and endogenous trade
- ▶ Long experience of policy analysis with GEM-E3 for the European Commission:
 - ▶ Analysis for the EU Single Market Act
 - ▶ Climate change policies
 - ▶ Energy policies
 - ▶ Taxation, Social Security, Double Dividend
 - ▶ Research and Development Policies

PRIMES-TREMOVE Transport Model

E3MLab/ICCS-NTUA
Prof. P. Capros

Tools for scenario building and analysis – Well to Wheel

- ▶ PRIMES-TREMOVE Transport model
 - ▶ Simulator of the transport sector pathways incl. the effects of policy measures
- ▶ PRIMES Energy System model
 - ▶ Evaluation of impacts on primary/secondary energy, lifecycle emissions, system costs, energy dependency, ...
- ▶ PRIMES Biomass Supply sub-model
 - ▶ Biomass energy and biofuels production simulation



Coverage of the Analysis

- ▶ Results for each EU27 Member-State and for the EU as a whole
- ▶ Dynamic analysis until 2050 by 5-year time periods. Calibration to statistics for years 2000 and 2005 and partially for 2010.
- ▶ Detailed transport sector results per transport mode-mean-technology-fuel (separately urban and non urban)
- ▶ Energy system and lifecycle analysis: Eurostat balance sheet detail



Tentative List of Policy Measures

▶ Transport Means

- ▶ Regulations on vehicle-vessel-aircraft-train performance
- ▶ RTD and market facilitation measures

▶ Taxation-Subsidies and Pricing

- ▶ Fuel taxation
- ▶ Emission taxation
- ▶ Externalities, Congestion
- ▶ Transport mean price signals
- ▶ ETS driven signals

▶ Infrastructure

- ▶ Fuel distribution
- ▶ Infrastructure facilitating modal shifts
- ▶ ICT

▶ Fuel Policy

- ▶ Biofuels
- ▶ Decarbonised transport energy carriers

▶ Behavioral

- ▶ Eco-driving
- ▶ Soft transport means



Projections by PRIMES-TREMOVE Transport Model

- ▶ Transport activity for passengers and freight and per transport mode
 - ▶ Energy Consumption by fuel type and by transport mode and transport mean.
 - ▶ Report on technology choice per transport mode and mean. Fast train is separately treated within rail transportation
 - ▶ Full distinction between urban and inter-urban transportation for all model results.
 - ▶ Vehicle, aircraft, vessel and train stock accounting (dynamically) according to technology vintages, with separate reporting on the choice of new transport means (incl. possible choice of used cars); reporting of activity and fuel consumption per transport mean technology, fuel type and age.
 - ▶ Calculation of emissions for a series of greenhouse gases and for other atmospheric emissions, including SO₂, NO_x, PM, CO and VOC.
 - ▶ External costs (associated with emissions, noise and others) using the unit values from the “Handbook on estimation of external costs in the transport”.
 - ▶ Detailed cost, tariff (public transportation) and investment reporting.
 - ▶ Evaluation of emissions tank to wheel and well to wheel for all fuels and energy carriers, through the linkage of the PRIMES-TREMOVE Transport model with the core PRIMES model and the PRIMES-Biomass model.
 - ▶ Reporting on Biofuels, on the share of Renewables in gross final energy consumption and in the blending of gasoline and diesel.
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Objective of the PRIMES-TREMOVE Transport Model

- ▶ 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.
 - ▶ 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.
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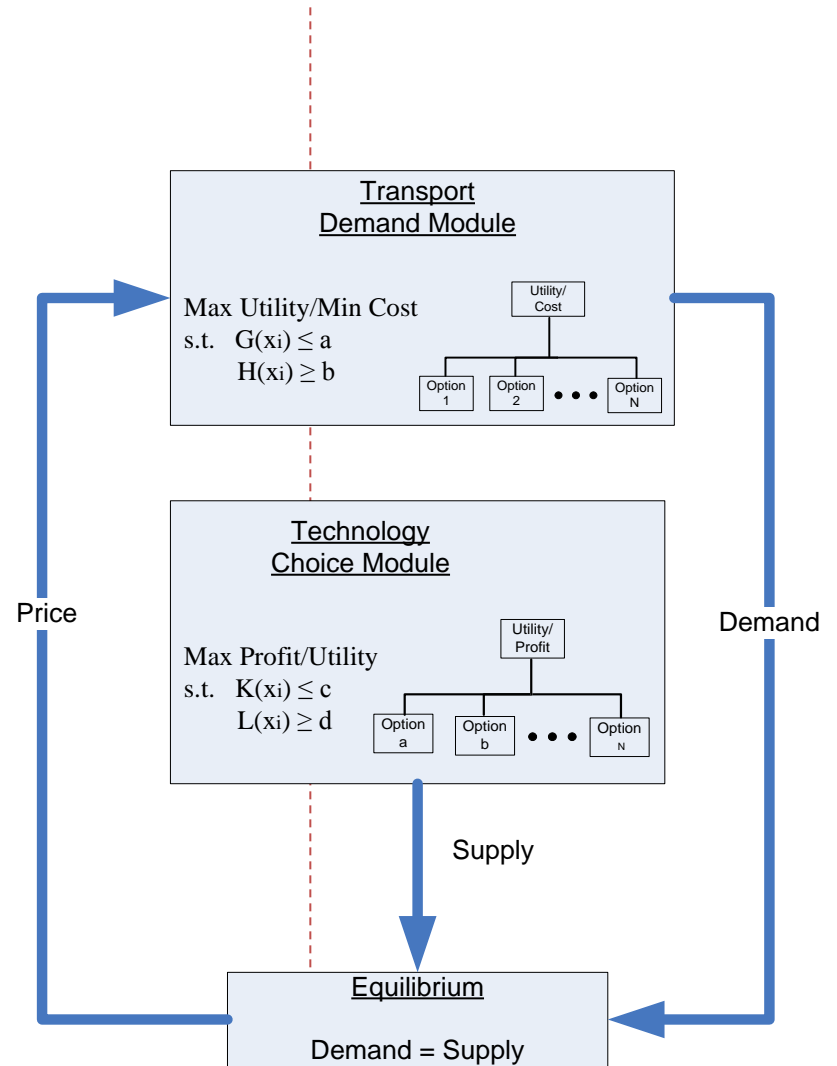


Mathematical Structure of the Model

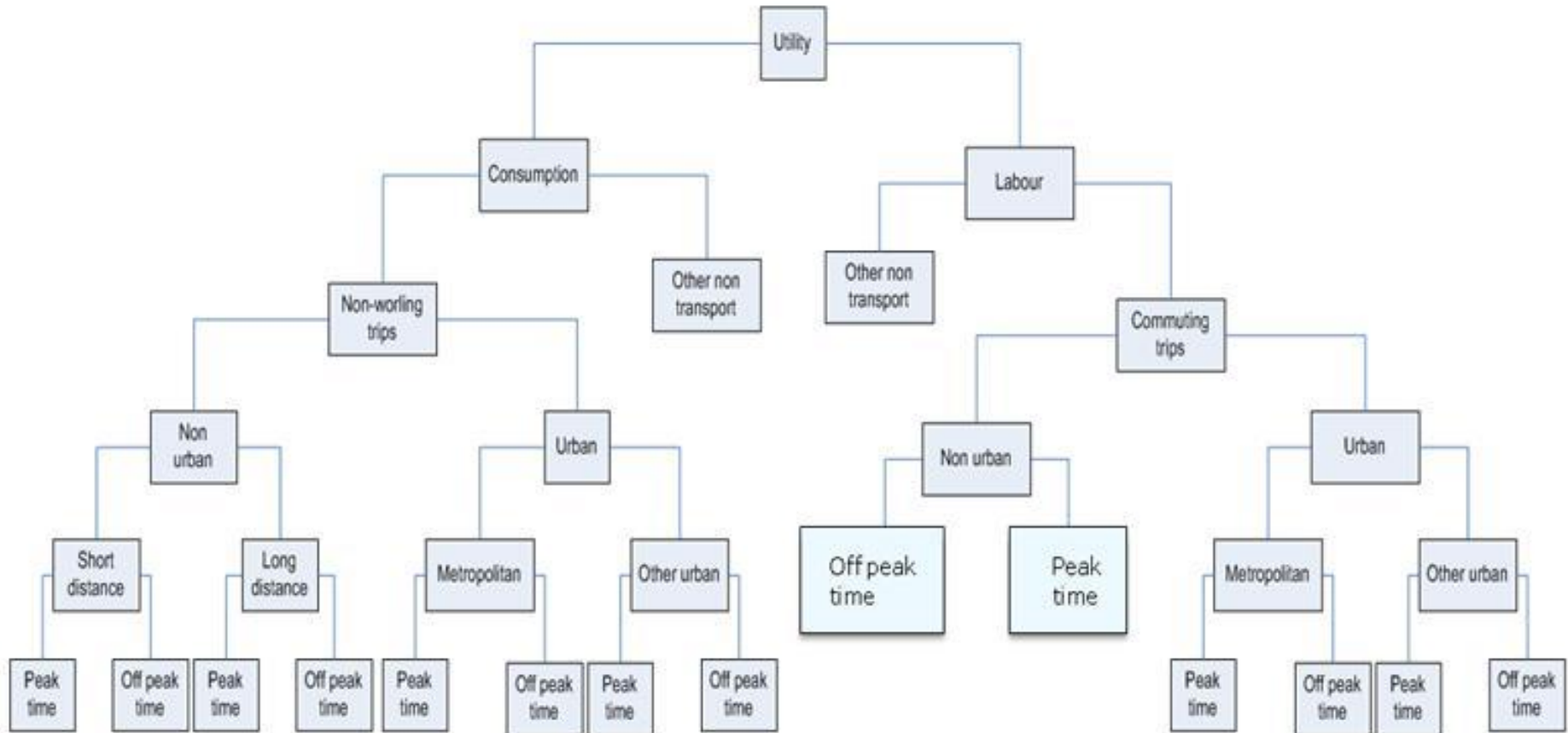
The transport demand module simulates decisions regarding allocation of transport activity to the various modes, identifying transport service by mode of transport for both individuals and firms

The 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.

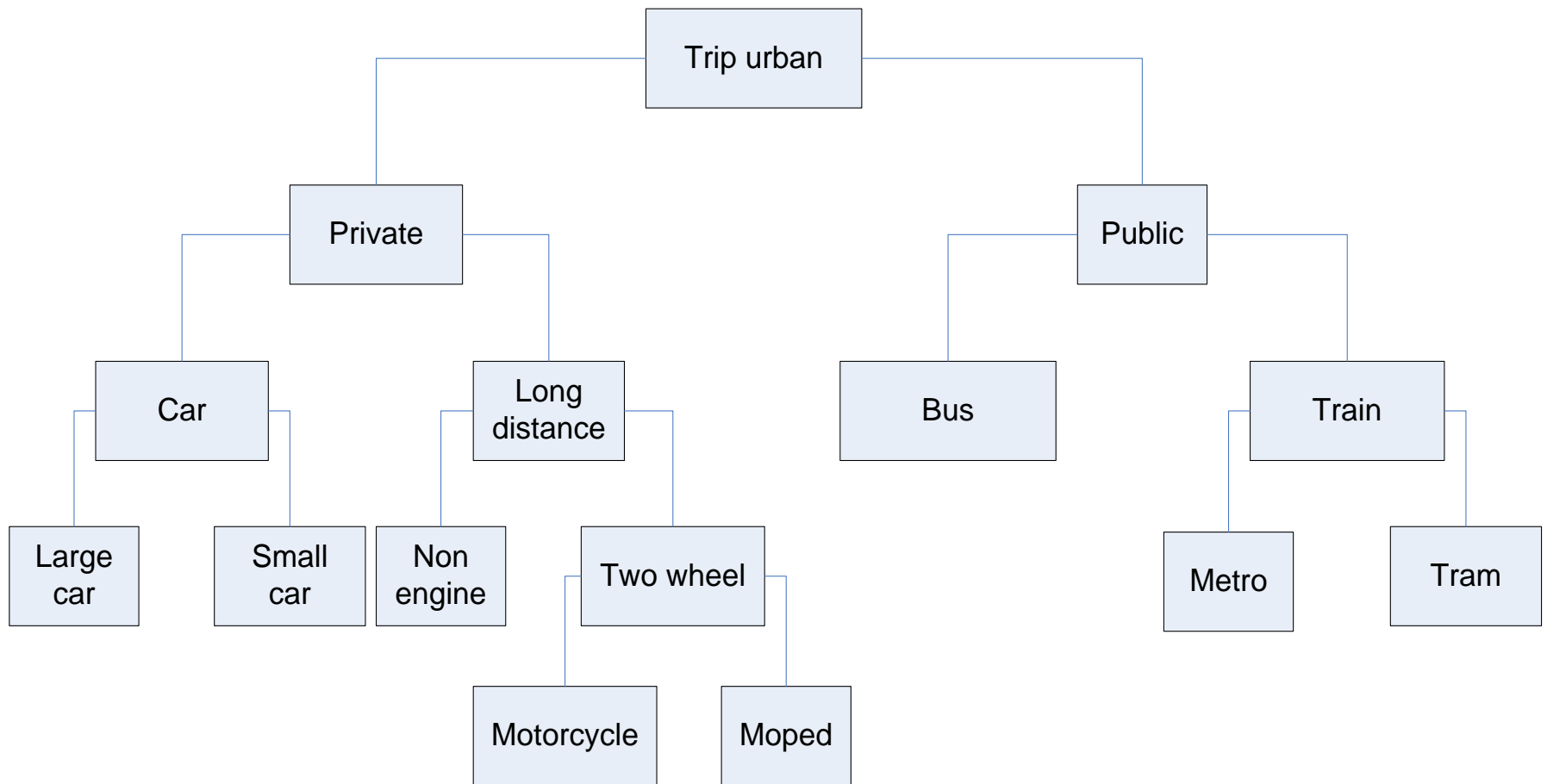
The transport demand module and the technology choice module are solved simultaneously in one single mathematical model, using the MCP algorithm PATH in GAMS



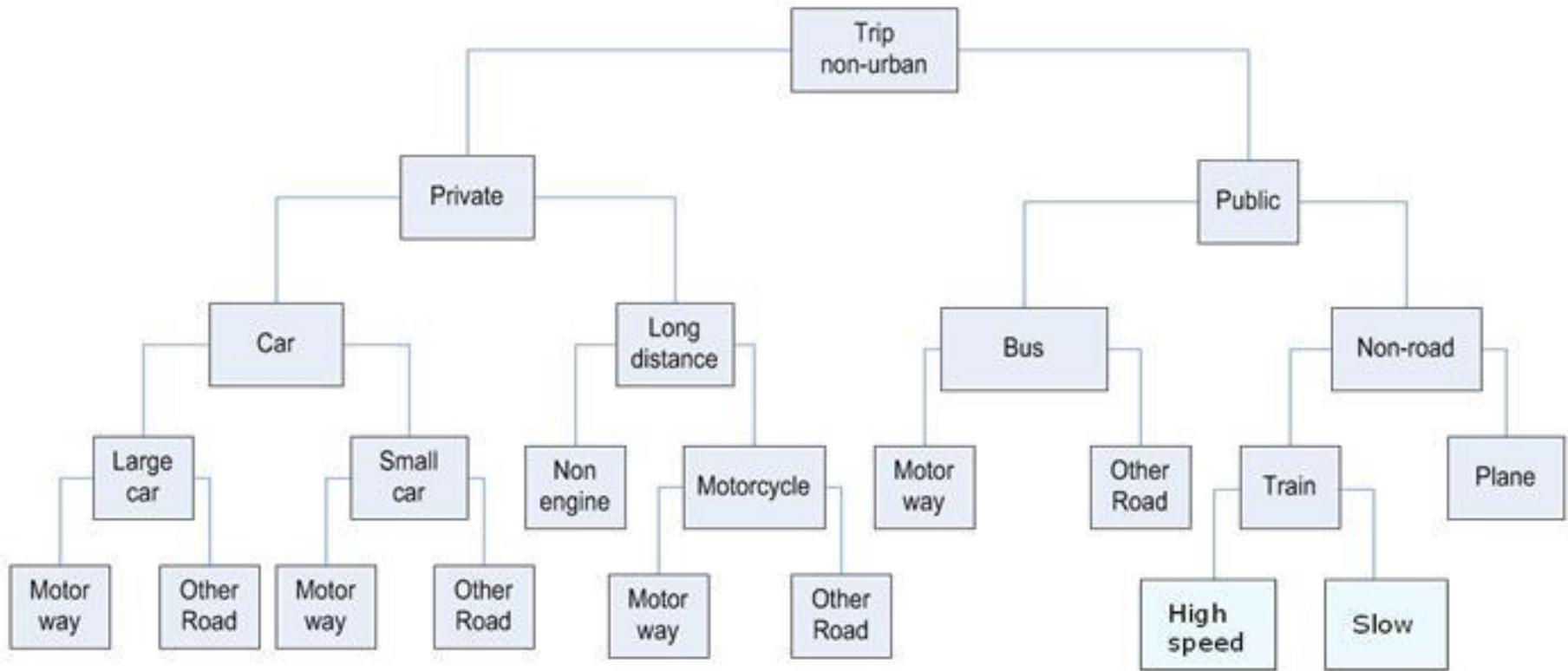
Private passenger primary decision tree



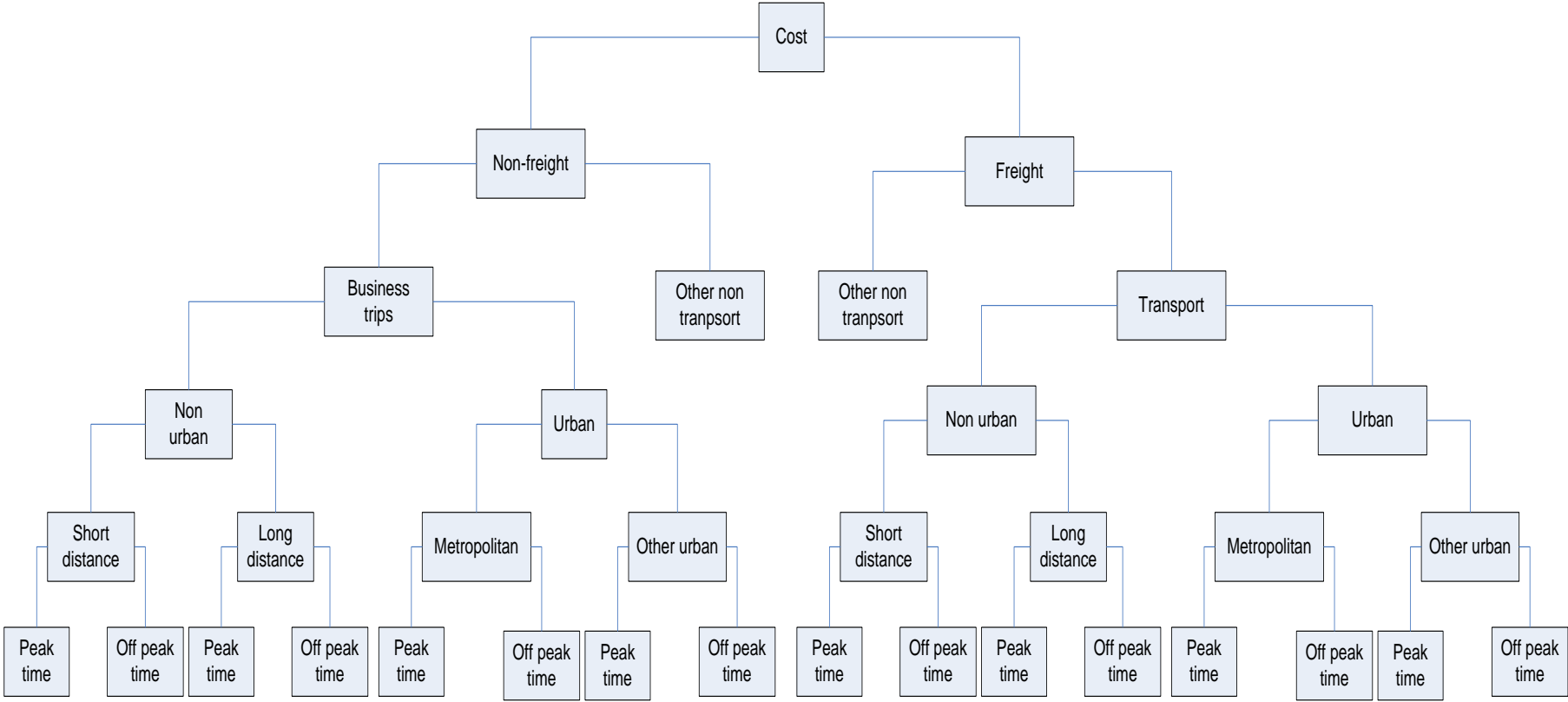
Private passenger secondary decision tree on urban transport



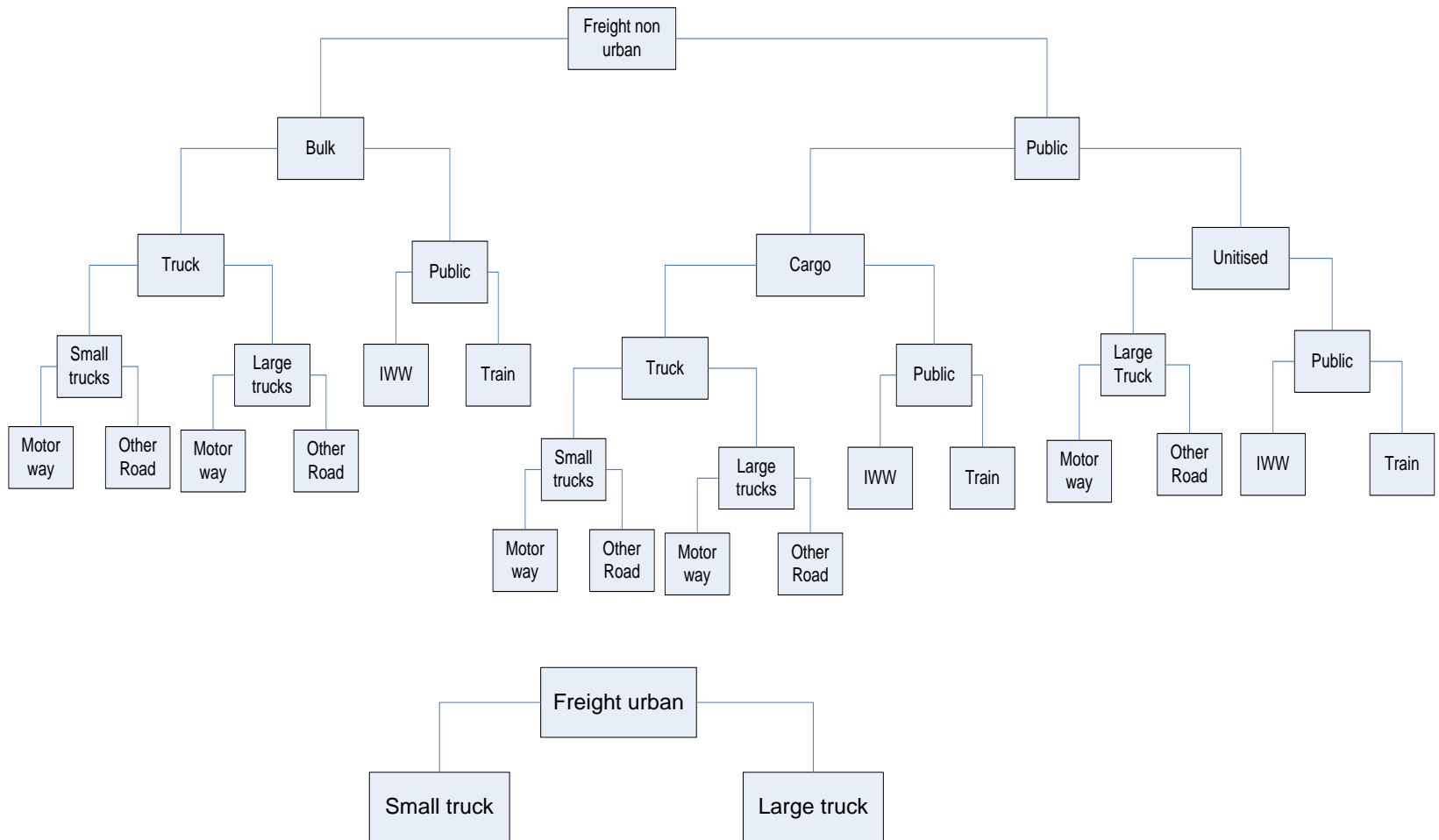
Private passenger secondary decision tree on non-urban transport



Firm's primary decision tree



Firm's secondary decision trees on 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.
- ▶ Private transportation 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
- ▶ 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



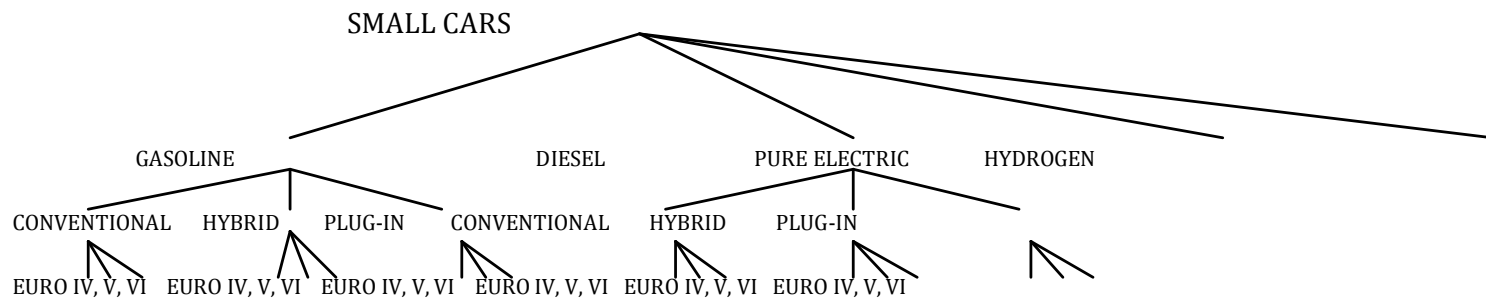
The technology choice module

- ▶ 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.



Discrete choice model

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:



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



Energy consumption and emissions

- ▶ For road transport, fuel consumption and emissions of non-CO₂ pollutants are calculated by using the COPERT methodology. The computation covers a wide range of pollutants including NO_x, CO, PM, CH₄, Non-Methane VOCs, N₂O, NH₃ 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 calculation of fuel consumption for hybrid and electric vehicles has been modelled in such a way that takes into account the region in which the vehicle is moving.



Lifecycle emissions and energy system impacts

- ▶ Demand for fuels and energy carriers as estimated by the transport model are conveyed to the core PRIMES model, which evaluates energy markets and system equilibrium, prices, investment, primary energy demand and supply and emissions
 - ▶ Sub-models of PRIMES affected by transport demand for energy: electricity supply, hydrogen supply, refineries, biomass supply, gas supply
 - ▶ The PRIMES model performs a full scale dynamic simulation of demand and supply and computes all standard policy assessment indicators: energy dependence, GHG, Renewable shares, Efficiency indicators, etc.
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